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Practical Learning to Build an IoT-Based Oyster Mushroom Control and Cultivation System and Its Learning Effects for Students

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Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means the learning media and research of IoT in student education are still challenging for researchers. In the meantime, mushroom cultivators do not understand what actions must be considered when cultivating mushrooms. Besides that, oyster mushroom cultivation also often fails due to Baglog's environmental conditions, which do not support the cultivation of oyster mushrooms. Also, by remembering, the development of educational technology has demanded efforts to use technology as a learning medium in learning. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The stages of developing a control system and cultivating oyster mushrooms in this study use the Waterfall model. This research method combines experimental, surveys, and observation procedures. This research succeeded in carrying out educational activities with results that satisfied students and made most students able to build an IoT-based control system and cultivate oyster mushrooms. This study found that the growth of oyster mushrooms whose Baglog environment was managed by an IoT-based system automatically grew faster, and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. This study's findings also remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.

KEYWORDS

practical learning, control system, cultivating oyster mushrooms, internet of things, education technology

1. Introduction

Education is increasingly moving toward the digital age (Rohles, Backes, Fischbach, Amadieu, & Koenig, 2022; van Laar, van Deursen, van Dijk, & de Haan, 2017). Currently, digital technology plays a dominant role in facilitating the learning process (Srivastava & Dey, 2018). Previous research has also shown that students react positively to digital technology-based learning processes (Jones & Shao, 2011). Meanwhile, IoT, one of the digital technology innovations, has become a research concern in the field of education and the application of the latest technology (Madni et al., 2022). IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real-time (Malik, Dedeoglu, Kanhere, & Jurdak, 2019; Powell, Foth, Cao, & Natanelov, 2022).

IoT technology utilization allows control to be done automatically and monitored from anywhere (Kumar et al., 2022) and supports heterogeneous automation models (Li, Zhang, Fei, Shakeel, & Samuel, 2020). But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited (Madni et al., 2022). In other words, the application of IoT in education is still a challenge for researchers. Or in other words, the application of IoT in education is still a challenge for researchers. Moreover, the learning, whether producing satisfactory competencies, are essential (Xue, Xu, Wu, & Hu, 2023).

In the meantime, cultivating mushrooms often faces problems/difficulties for beginners, how to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful (Anamosa, 2021). Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms (Suada, Sudarma, Kim, Cha, & Ohga, 2015). It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production (Okuda, 2022). In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning process (Ediyani et al., 2020). Besides that, in teaching students how to achieve these skills is a teaching practice challenge (Adıgüzel, Aşık, Bulut, Kaya, & Özel, 2023). Therefore, this study aims to build a learning media device for students based on IoT digital technology to cultivate oyster mushrooms and its learning effects for students.

IoT is the future communication technology equipped with a microcontroller (Atzori, Iera, & Morabito, 2010). IoT technology has replaced the traditional method (Puliafito, Mingozzi, Longo, Puliafito, & Rana, 2019). IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment (Arasteh et al., 2016; Pardini, Rodrigues, Kozlov, Kumar, & Furtado, 2019; Raaijen & Daneva, 2017; Sumi & Ranga, 2016). Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models (Ou & Xie, 2012). As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary (Jiang, Yang, Xu, Song, & Zheng, 2019). Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices (Sun, 2022). As a result, teaching media devices has become a significant concern for colleges today (Liu, Wang, & Xiao, 2021).

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments (Babiuch, Foltynek, & Smutny, 2019). Microcontrollers are primarily for control, wireless, and automation systems (Salah & Zneid, 2020). The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The microcontroller used is NodeMCU ESP32. The ESP32 microcontroller supports web servers and real-time work (Allafi & Iqbal, 2018). In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost (Fabregat, Belloch, Badia, & Cobos, 2020; Tueche et al., 2021). Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces (Babiuch et al., 2019). Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance (Fezari & Zakaria, 2019). The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system.

In the meantime, Oyster mushrooms are widely cultivated worldwide (Royse, 2012) and as edible mushrooms (Melanouri, Dedousi, & Diamantopoulou, 2022; Törős, El-Ramady, & Prokisch, 2022). Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk (Pathmashini, Arulnandhy, & Wijeratnam, 2009). Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug (El-Ramady et al., 2022; Raman et al., 2021), its taste (Jongman, Khare, Loeto, & Behari Khare, 2018; Raman et al., 2021) and contains lots of fiber, minerals, vitamins (Feeney et al., 2014; Raman et al., 2021), carbohydrate, and essential amino acids (Raman et al., 2021). In addition, oyster leaves are an important source for the human diet, antiinflammatory, antidiabetic, antifungal, antiviral, and antibacterial (Törős et al., 2022; Zawadzka et al., 2022). It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries (Jongman et al., 2018). However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary (Girmay, Gorems, Birhanu, & Zewdie, 2016).

Oyster mushrooms can grow at temperatures between 18 to 30°C as well as the rapid growth of mycelium and substrate colonization (Girmay et al., 2016; K. Dhanalakshmi & V. Ambethgar, 2021; Sulistyanto et al., 2018), and the environment moist or not dry and not wet (Sulistyanto et al., 2018). Other researchers have also confirmed that humid environments positively affect fungal growth and colonization (Jongman et al., 2018; Nongthombam et al., 2021). Generally, suitable temperatures range from 25-30 °C (Jongman et al., 2018) and 20-30 °C (Nongthombam et al., 2021). The pH concentration of the fungus is slightly acidic to slightly alkaline (Chang, 2007). The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 (Sultana, Hossain, Saifullah, Amin, & Chakraborty, 2018). Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water three times daily and lighting around 300-500 lux (Sultana et al., 2018).

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform for students to build an IoT-based control system. In essence, in order for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog. Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms based on the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice, media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides that, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes an important contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is: the second sub-section describes related works, whereas the third subsection discusses the research method. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms (Sulistyanto et al., 2018). However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Meanwhile, Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks (Lu, Liaw, Wu, & Hung, 2019). Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science (Ediyani et al., 2020). Previous research has different research methods and objectives from the research in this article. Previous research reviews existing research related to the development of learning media. The object of research in the previous article is not related to oyster mushroom cultivation and is not related to the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them (Nongthombam et al., 2021). The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms (Zawadzka et al., 2022). The difference between this previous research and the research in this article is in the purpose of the study. The previous study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO (Desnanjaya & Sugiartawan, 2022). However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type of microcontroller used. In addition, the difference between previous research and research in this article is that previous research was not intended as a medium for student learning in mushroom cultivation and how to build (practice) IoT-based control systems, as researched in this article.

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation (Nadzirah, Savitri, & Novijanto, 2022). Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study. In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control (Sun, 2022). This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production (Okuda, 2022). This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

TABLE 1 Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

A review of several recent related works shows that this research differs from previous research; specifically, the research model used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Methods

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems (Anggrawan, Mayadi, Satria, & Putra, 2022; Dima & Maassen, 2018). The process stages in the Waterfall model are sequential from the beginning to the next step (Bassil, 2012). The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 (Anggrawan, Mayadi, et al., 2022).

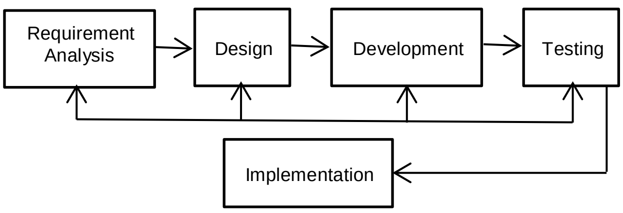

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities (Anggrawan, Hadi, & Satria, 2022).

The programming languages used are C++ and PHP in this research. Although various programming languages exist (Anggrawan, Satria, Mayadi, & Dasriani, 2021), each offers its advantages in application development programs (Anggrawan, Mayadi, et al., 2022; Anggrawan, Nuraini, Mayadi, & Satria, 2021). The PHP coding language enables the embodiment of Web-based application programs (Anggrawan, Satria, Nuraini, et al., 2021). The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in controlling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or via the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants and Survey

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale which consisted of gradations from very satisfied to very dissatisfied and very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Results and Discussion

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5 with humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to build hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest.

Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system in cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

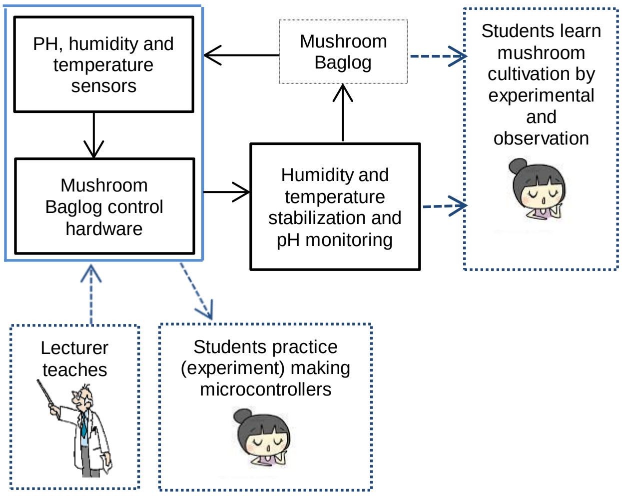

Figure 2 The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

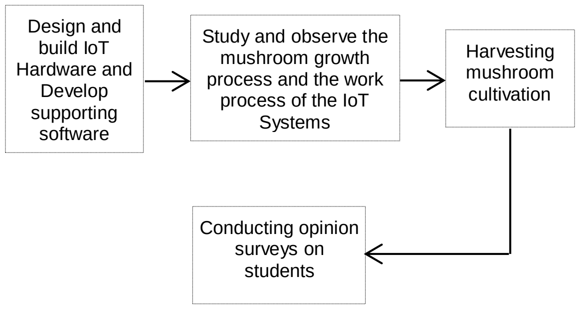

Figure 3 Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

TABLE 2 Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

TABLE 3 Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0- 14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^0C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

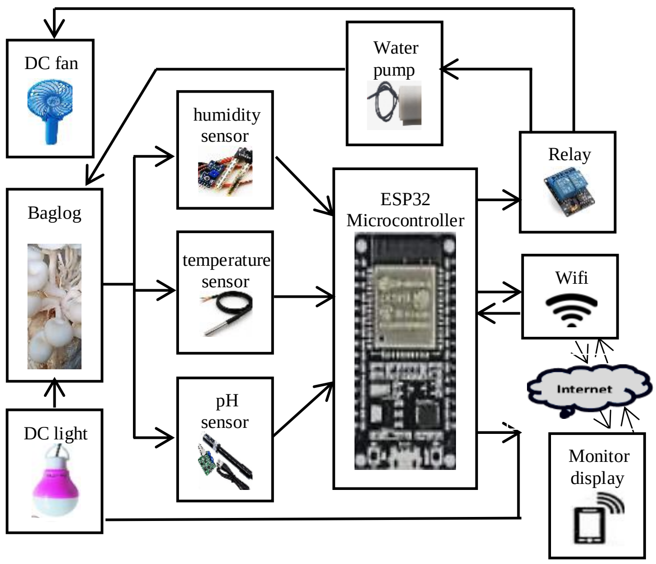

Figure 4 Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

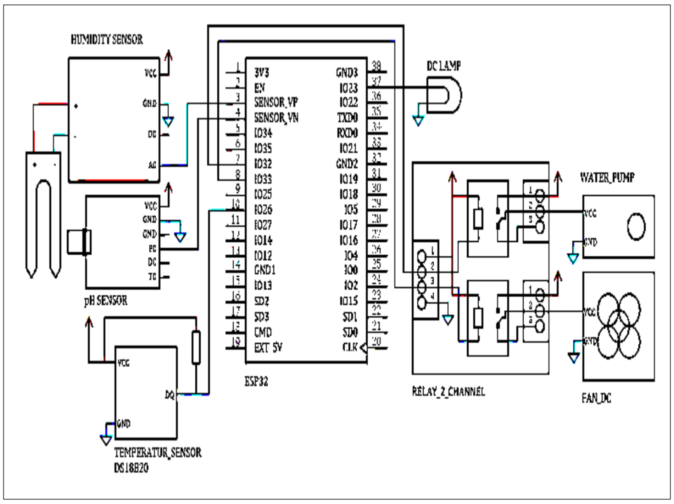

Figure 5 Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels, and then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires an intelligent or smart.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the results of the Baglog air temperature control accuracy test results produced by the developed system. As for testing the air temperature level of Baglog whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. This means that the Baglog environmental temperature control system on the oyster mushroom cultivation control system developed has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

TABLE 4 Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor is useful in measuring Baglog's humidity conditions, whether it is moist, dry or wet (see Table 5). If the humidity measurement value is below 300, it means that Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it means it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

TABLE 5 The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

TABLE 6 Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
.	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

The pH sensor is useful for checking the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of checking the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation control system developed has an accuracy of up to 98.03%.

TABLE 7 Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

4.5. Implementation

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog with manual control over water pH, temperature and humidity from Baglog. In contrast, the second Baglog container is Baglog with the control of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6 Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7 Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figure 6 shows a Baglog container with manual control over water pH, temperature and humidity while Figure 7 shows a Baglog container with automatic control over water pH, temperature and humidity Baglog with a hardware and software system developed. Meanwhile, Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and humidity in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8 Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9 Oyster mushroom growth with automatic control of water pH, temperature and humidity in Baglog when it is 27 days old

Figure 10 Oyster mushroom growth with automatic control of water pH, temperature and humidity in Baglog when it is 1 month old

Figure 11 Oyster mushroom growth with manual control of water pH, temperature and humidity in Baglog when at the age 1 month 15 days

Figure 12 Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of 1 month 3 days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature and humidity in Baglog, it is proven to bring important benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods (Puliafito et al., 2019). An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda , previous researchers (2022).

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

TABLE 8 Students' satisfaction of practicum learning

Students perception	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

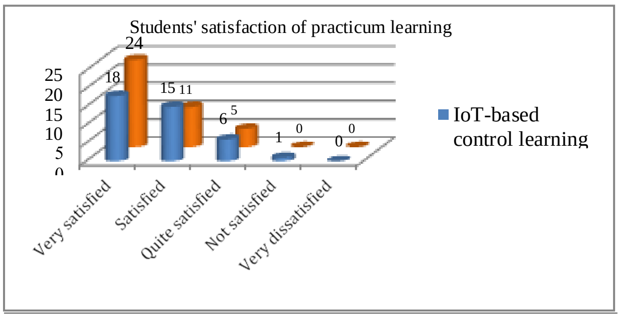

Figure 13 Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

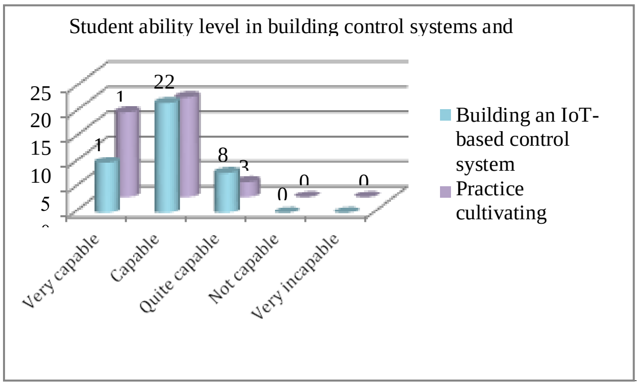

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research carried out educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done.

6. Limitations and future study

The drawback of this research is that students practice learning only on cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

Data availability statement

The work presented here is an original work. Raw data will be provided if anyone needs it and further questions can be directed to the authors according to their fields.

Ethics statement

This study involved Information Technology study program students who took part in IoT-based control system learning practices, and all authors (lecturers and supervisors) participated in this research for publication.

Author contributions

All authors have a role in the work of this article. The order of the names of the authors adjusts to the magnitude of the role of each author. All authors approved it for publication.

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Supplementary material

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **– Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age (Rohles, Backes, Fischbach, Amadieu, & Koenig, 2022; van Laar, van Deursen, van Dijk, & de Haan, 2017). As a result, the use of digital technology is extensive (Teoh, Ho, Dollmat, & Tan, 2022). Currently, digital technology plays a dominant role in facilitating the learning process (Srivastava & Dey, 2018). Previous research has also shown that students react positively to digital technology-based learning processes (Jones & Shao, 2011). Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology (Madni et al., 2022). IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time (Malik, Dedeoglu, Kanhere, & Jurdak, 2019; Powell, Foth, Cao, & Natanelov, 2022). Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere (Kumar et al., 2022) and supports heterogeneous automation models (Li, Zhang, Fei, Shakeel, & Samuel, 2020). So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system (Joko, Putra, & Isnawan, 2023). But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited (Madni et al., 2022).

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful (Anamosa, 2021). Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms (Suada, Sudarma, Kim, Cha, & Ohga, 2015). It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production (Okuda, 2022). In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning process (Ediyani et al., 2020). Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller (Atzori, Iera, & Morabito, 2010). IoT technology has replaced the traditional method (Puliafito, Mingozzi, Longo, Puliafito, & Rana, 2019). IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment (Sumi & Ranga, 2016), (Pardini, Rodrigues, Kozlov, Kumar, & Furtado, 2019), (Arasteh et al., 2016), (Raaijen & Daneva, 2017). Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models (Ou & Xie, 2012). As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary (Jiang, Yang, Xu, Song, & Zheng, 2019). Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices (Sun, 2022). As a result, teaching media devices has become a significant concern for colleges today (Liu, Wang, & Xiao, 2021).

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments (Babiuch, Foltynek, & Smutny, 2019). Microcontrollers are primarily for control, wireless, and automation systems (Salah & Zneid, 2020). The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work (Allafi & Iqbal, 2018). In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost (Fabregat, Belloch, Badia, & Cobos, 2020; Tueche et al., 2021). Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces (Babiuch et al., 2019). Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance (Fezari & Zakaria, 2019). The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world (Royse, 2012) and as edible mushrooms (Melanouri, Dedousi, & Diamantopoulou, 2022; Törős, El-Ramady, & Prokisch, 2022). Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk (Pathmashini, Arulnandhy, & Wijeratnam, 2009). Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug (El-Ramady et al., 2022; Raman et al., 2021), its taste (Jongman, Khare, Loeto, & Behari Khare, 2018; Raman et al., 2021) and contains lots of fiber, minerals, vitamins (Feeney et al., 2014; Raman et al., 2021), carbohydrate, and essential amino acids (Raman et al., 2021). In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial (Törős et al., 2022; Zawadzka et al., 2022). It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries (Jongman et al., 2018). However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary (Girmay, Gorems, Birhanu, & Zewdie, 2016).

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization (Girmay et al., 2016; K. Dhanalakshmi & V. Ambethgar, 2021; Sulistyanto et al., 2018), and the environment is moist or not dry and not wet (Sulistyanto et al., 2018). Other researchers have also confirmed that humid climates positively affect fungal growth and colonization (Jongman et al., 2018; Nongthombam et al., 2021). Generally, suitable temperatures range from 25-30 °C (Jongman et al., 2018) and 20-30 °C (Nongthombam et al., 2021). The pH concentration of the fungus is slightly acidic to slightly alkaline (Chang, 2007). The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 (Sultana, Hossain, Saifullah, Amin, & Chakraborty, 2018). Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux (Sultana et al., 2018).

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms (Sulistyanto et al., 2018). However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks (Lu, Liaw, Wu, & Hung, 2019). Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science (Ediyani et al., 2020). Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them (Nongthombam et al., 2021). The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms (Zawadzka et al., 2022). The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO (Desnanjaya & Sugiartawan, 2022). However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation (Nadzirah, Savitri, & Novijanto, 2022). Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control (Sun, 2022). This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production (Okuda, 2022). This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures.

Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems (Anggrawan, Mayadi, Satria, & Putra, 2022; Dima & Maassen, 2018). The process stages in the Waterfall model are sequential from the beginning to the next step (Bassil, 2012). The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 (Anggrawan, Mayadi, et al., 2022).

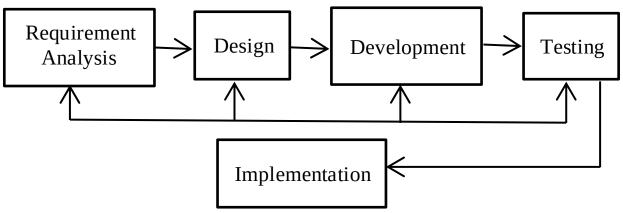


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities (Anggrawan, Hadi, & Satria, 2022).

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages (Anggrawan, Satria, Mayadi, & Dasriani, 2021), each offers its advantages in application development programs [50], (Anggrawan, Nuraini, et al., 2021). The PHP coding language enables the embodiment of Web-based application programs (Anggrawan, Satria, Nuraini, et al., 2021). The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

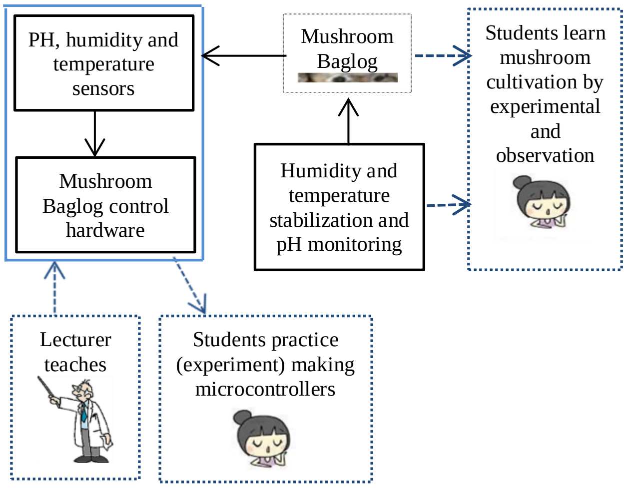
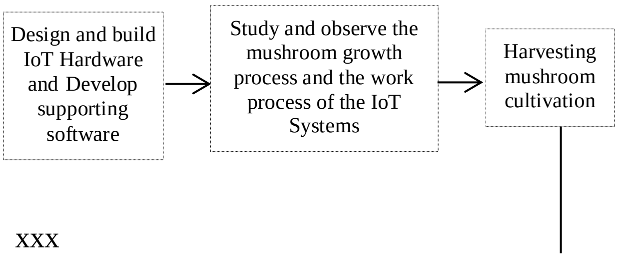


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms



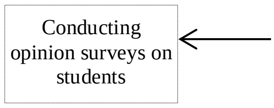


Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-	Pumping water to pour into the mushroom baglog oyster	

Device	Amount	Type/Specification	Function	Image
		330 mA		
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

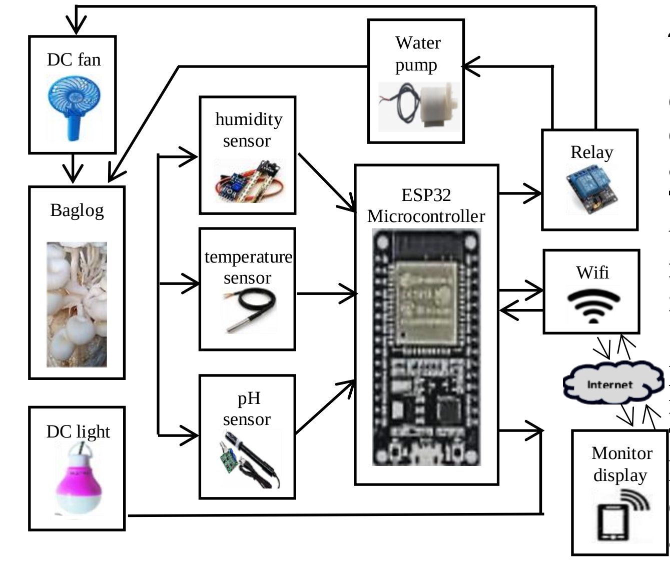


Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

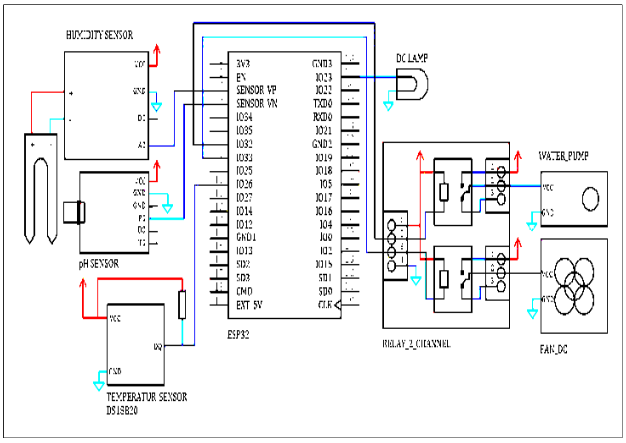


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods (Puliafito et al., 2019). An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

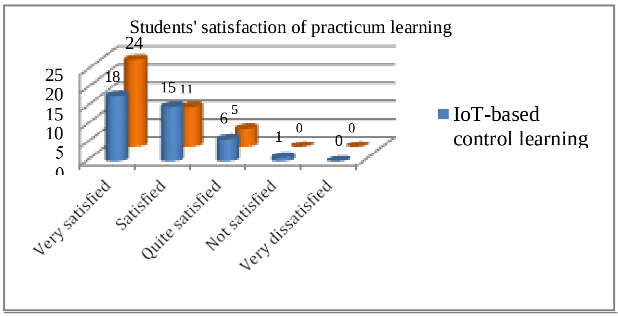


Figure *13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

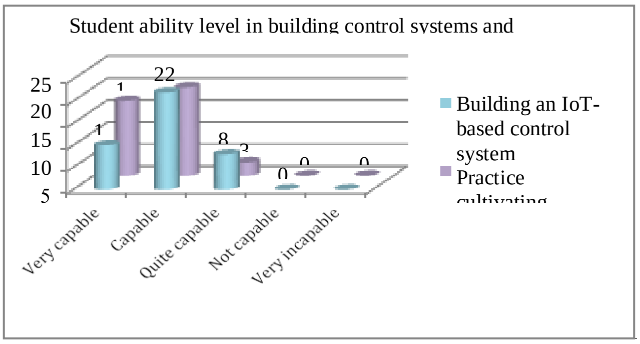


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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***Abstract* – Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

***Keywords* – practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age [1], [2]. As a result, the use of digital technology is extensive [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

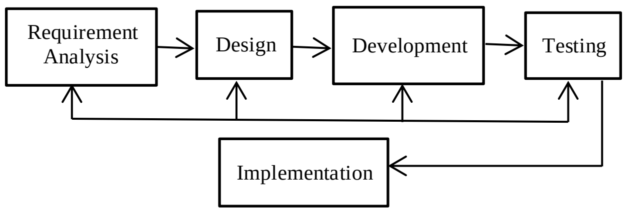


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

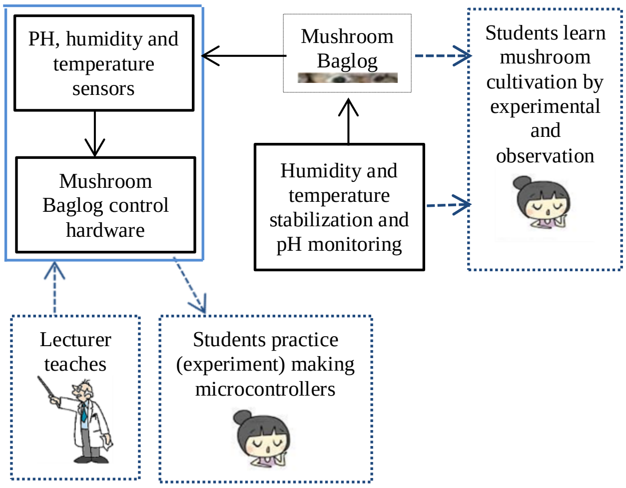


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

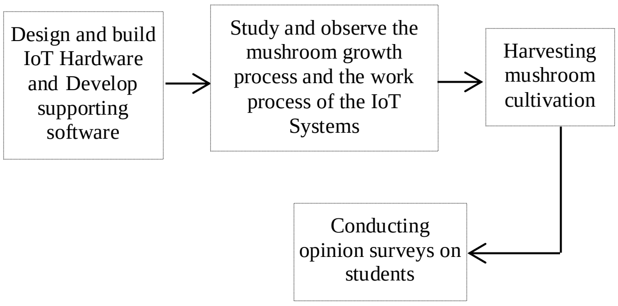


Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

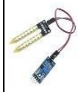
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

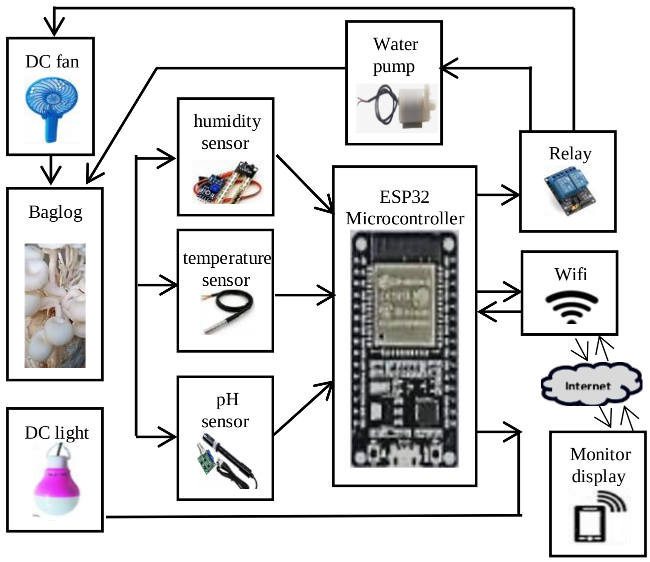


Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

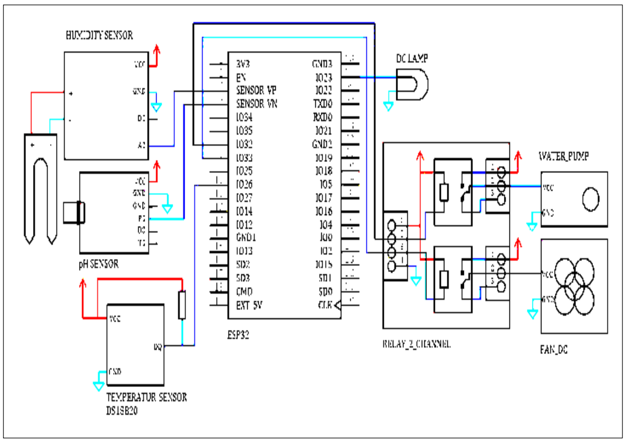


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

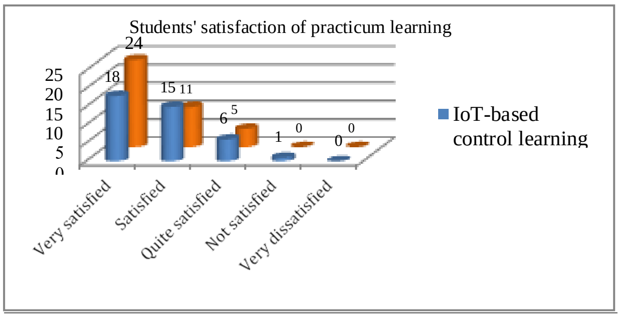


Figure *13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

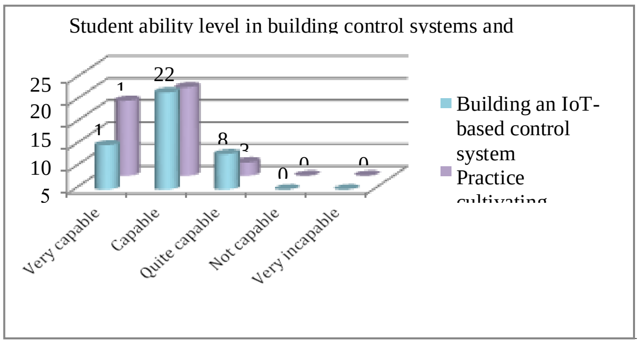


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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***Abstract* – Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

***Keywords* – practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age [1], [2]. As a result, the use of digital technology is extensive [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

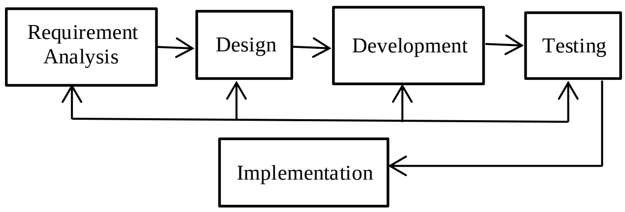

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

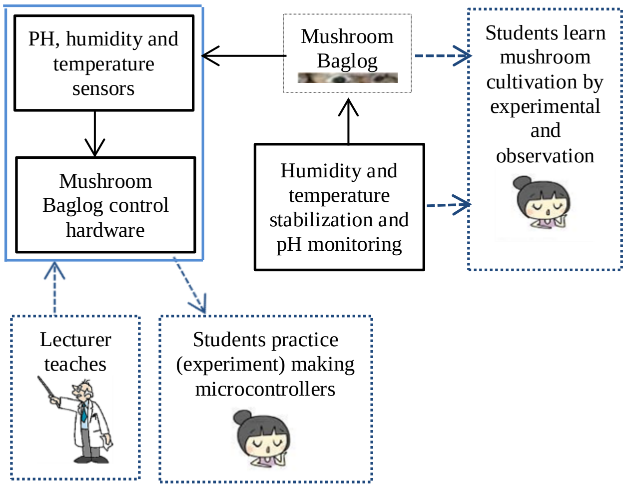

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

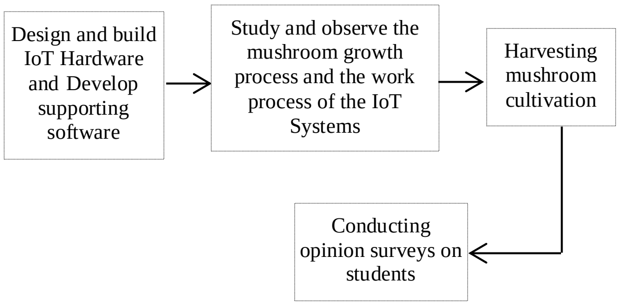

Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

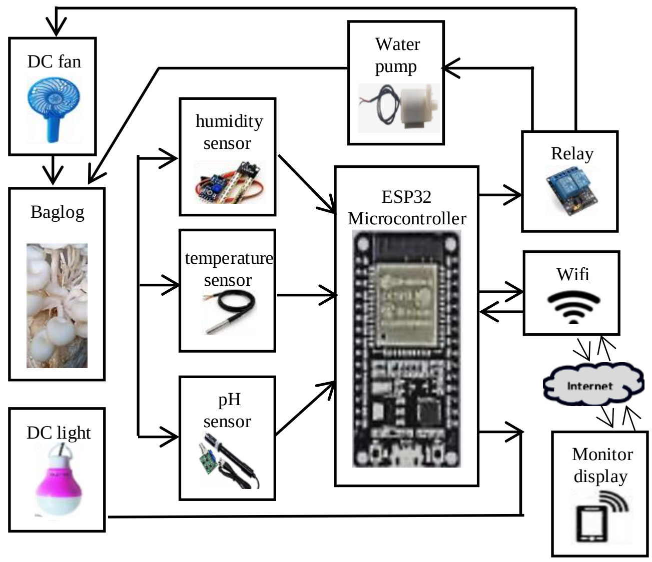

Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

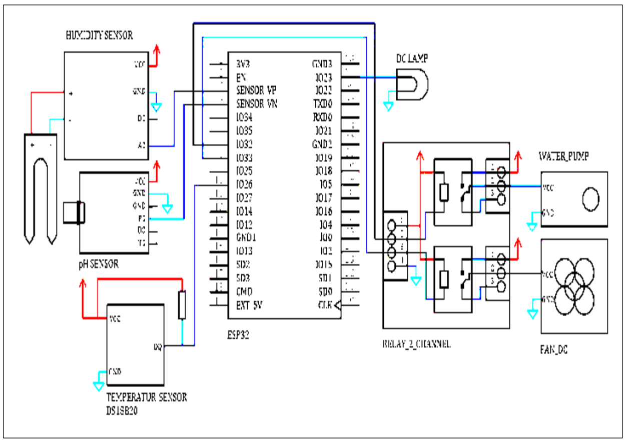

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

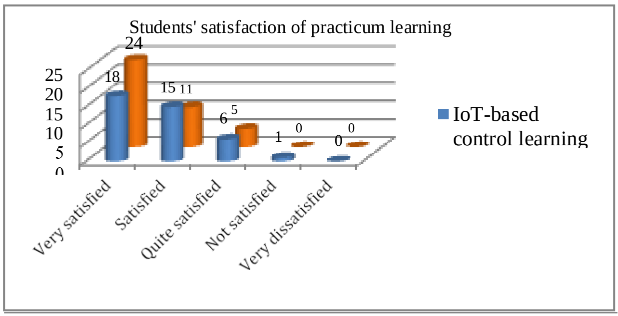

Figure 13. *Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in numbe	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

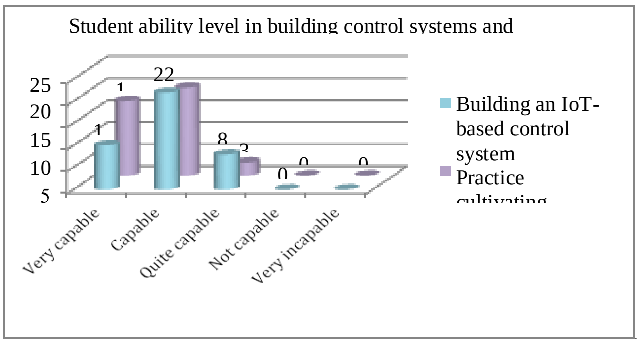

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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***Abstract* – Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

***Keywords* – practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age [1], [2]. As a result, the use of digital technology is extensive [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

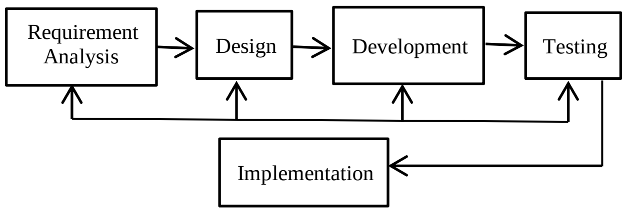

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

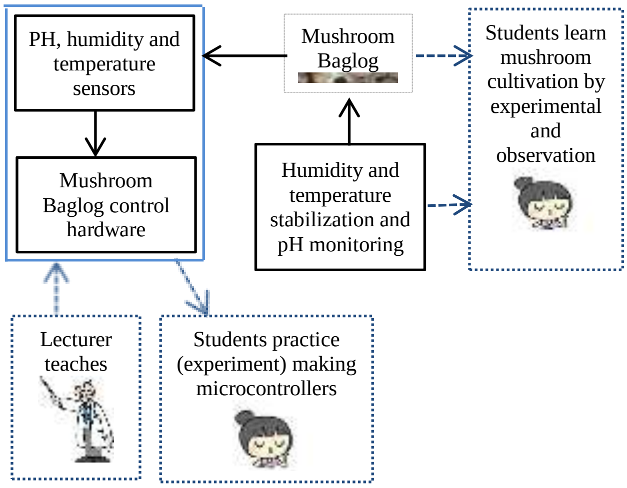

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

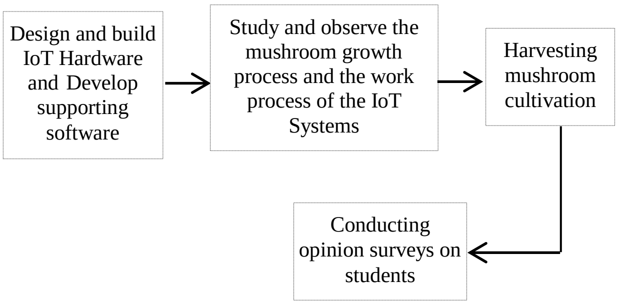

Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60℃	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

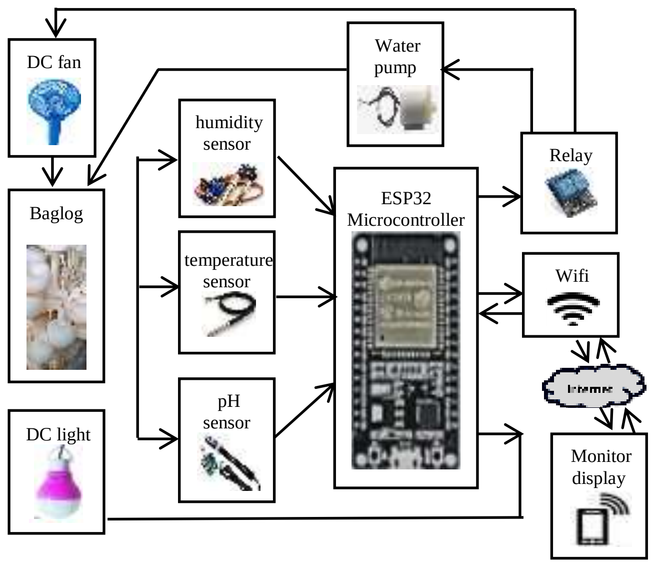

Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

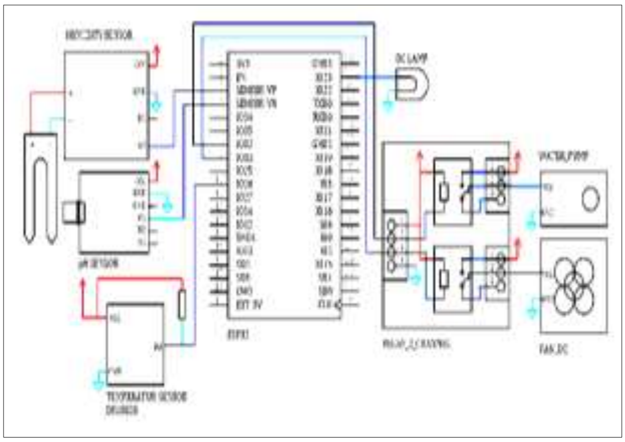

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	**Thermometer temperature**	**Baglog temperature**	**Error**	**Being in the best temperature range in mushroom cultivation**
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

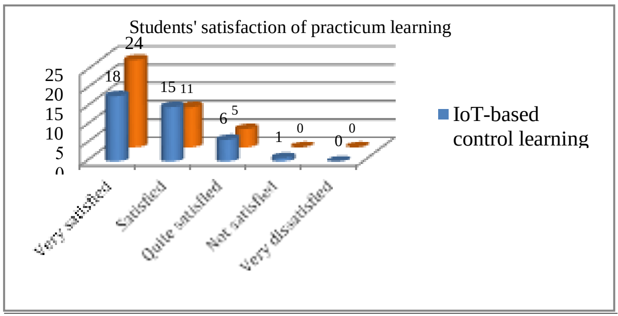

Figure 13. *Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

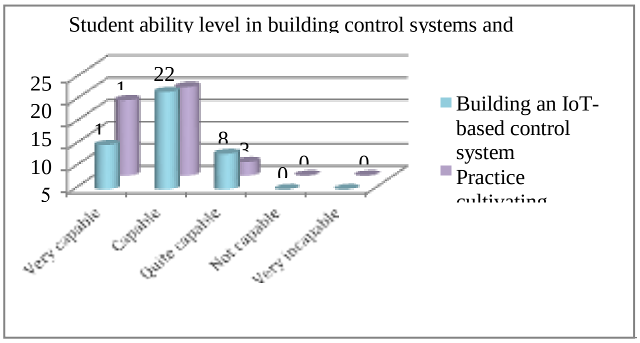

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Plagiarism check _ Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

By Anthony Anggrawan

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2014), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor: pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

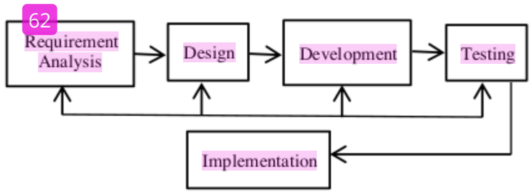

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

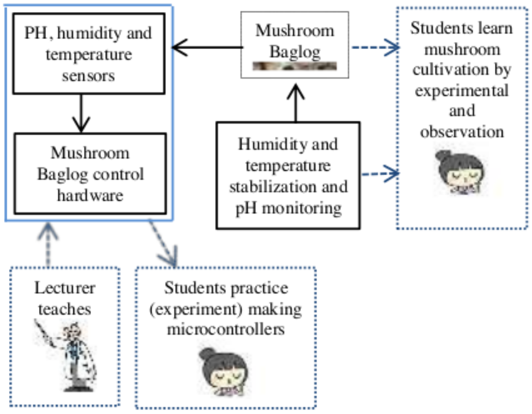

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

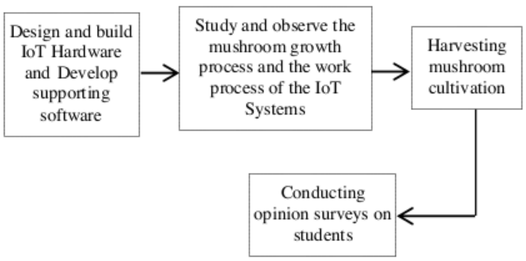

Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design volt 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

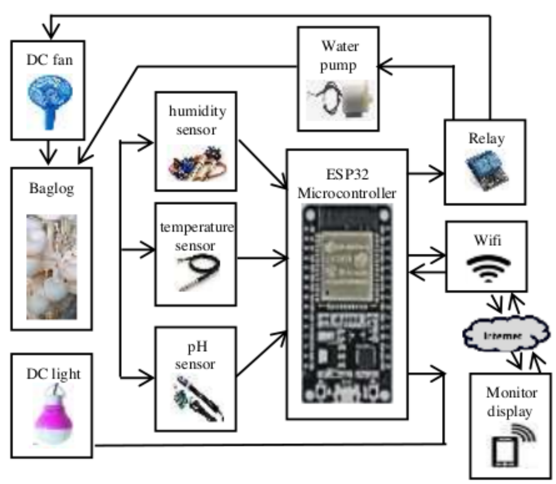

Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

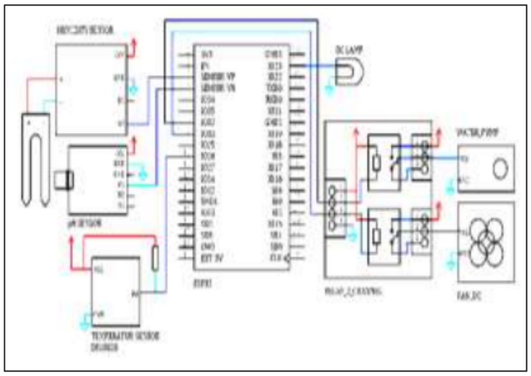

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of Baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
....	....	....	....	....
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
....	....	....	....	....
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

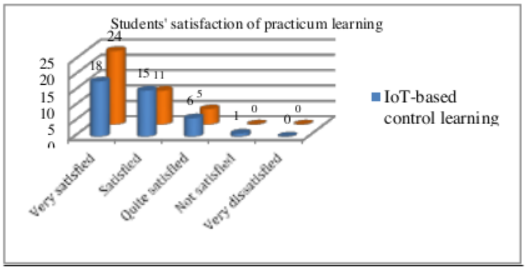

Figure *13*. *Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

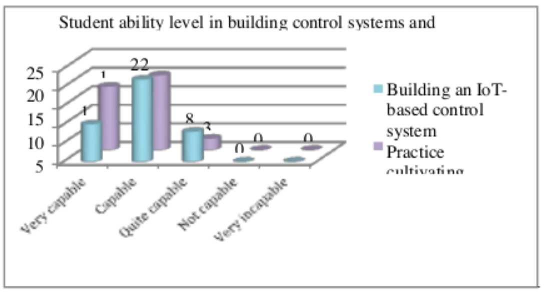

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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By Anthony Anggrawan

Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **– Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age [1], [2]. As a result, the use of digital technology is extensive [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor: pH	Sensor: Humidity	Sensor: Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

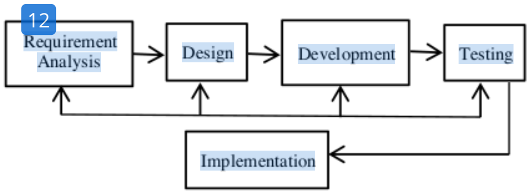

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

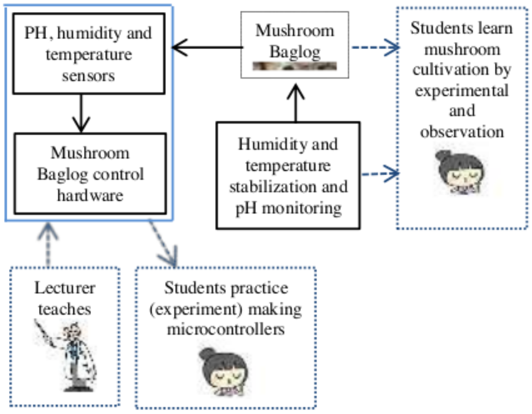

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

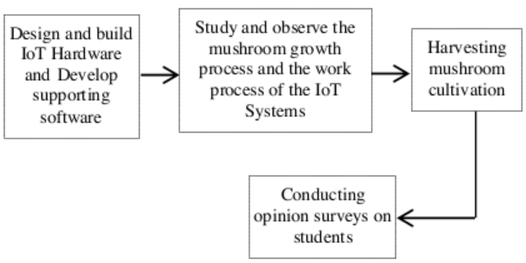

Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

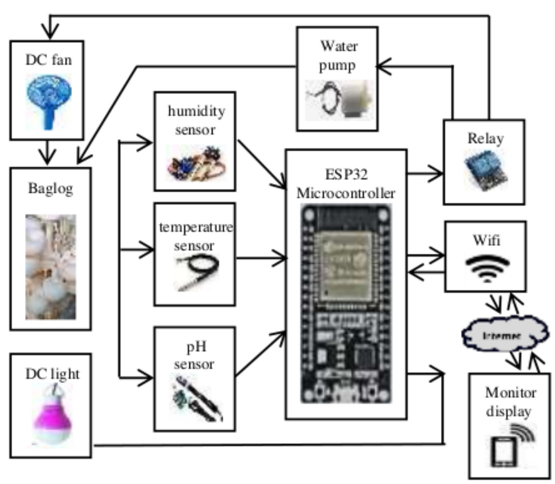

Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

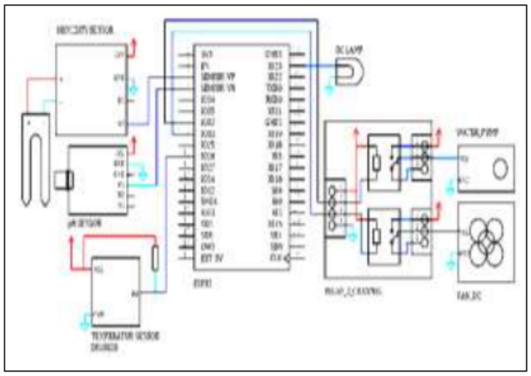

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of Baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

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The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

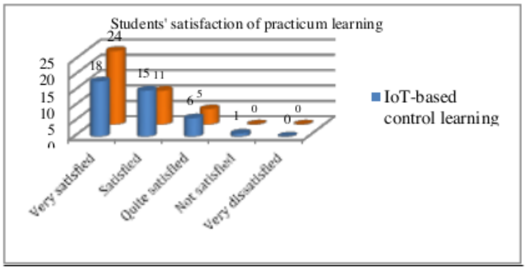

Figure *13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

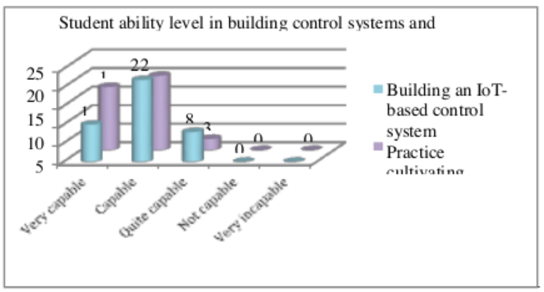

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **– Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– practical learning, control system, mushrooms, internet of things, education technology**

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1. Introduction

Education is increasingly moving toward the digital age [1], [2]. As a result, the use of digital technology is extensive [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning

process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices has become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41]–[43], and the environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to

be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Table 1. Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

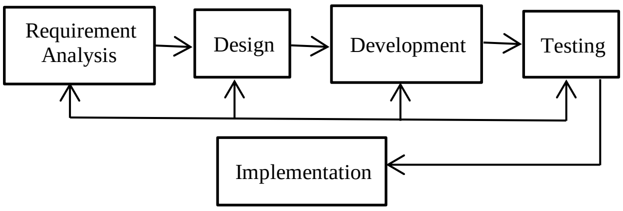


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The programming languages used are C++ and PHP in this research. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

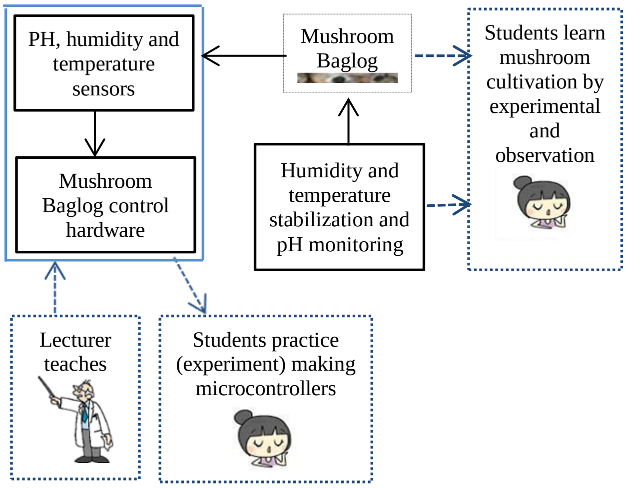


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

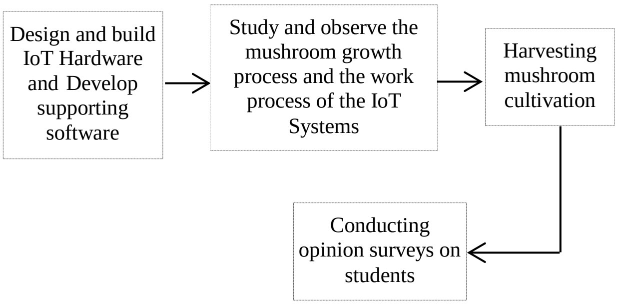


Figure 3. Learning Stages of IoT Design and Mushroom Cultivation for Students

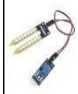
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60℃	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

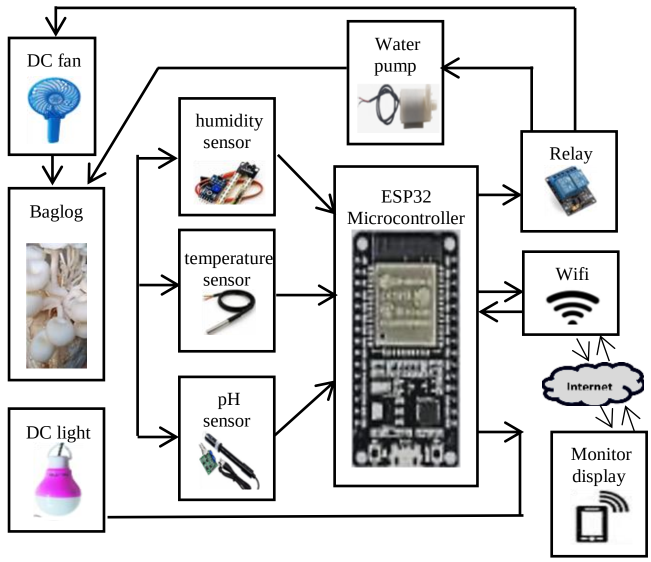


Figure 4. Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

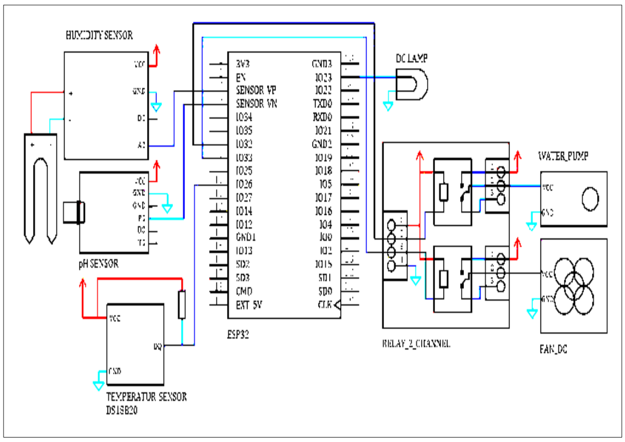


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

Table 4. Temperature control system test results

No	**Thermometer temperature**	**Baglog temperature**	**Error**	**Being in the best temperature range in mushroom cultivation**
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator

produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

4.5.1. *Oyster mushroom cultivation*

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog, with manual control over water pH, temperature, and humidity from Baglog. In contrast, the second Baglog container is Baglog, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in

Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda, previous researchers (2022).

4.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

Table 7. Students' satisfaction with practicum learning

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

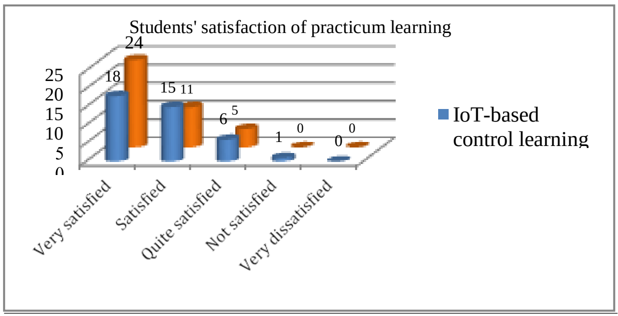


Figure *13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

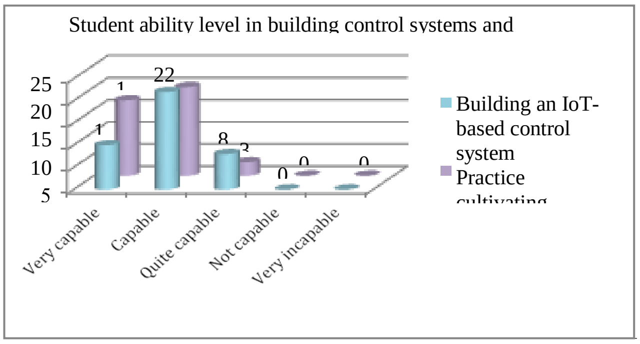


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research conducted educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **– ~~Even though~~Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age ~~[1], [2]. As~~ and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports ~~to~~ the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, as well as the rapid growth of mycelium and substrate colonization [41], [42], [43], and the [n1]environment is moist or not dry and not wet [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), [n2]had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

1. Related Works

Sulistyanto et al. [42] (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms [42]. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (2019)[47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks [47]. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15](2020) explained the vital role of learning media in developing science [15]. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44](2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them [44]. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40](2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms [40]. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

#*Table 1. Comparison between the lLatest pPrior rRelated wWork and this aArticle*

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

Nadzirah et al. [49](2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation [49]. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews Tthe future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

2. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [50], [51]. The process stages in the Waterfall model are sequential from the beginning to the next step [52]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [51].

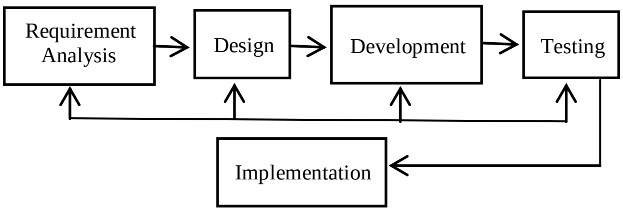

Figure 1. The Waterfall model of system development in this study

2.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms ~~in this study~~ incorporates~~has~~ automation to regulate ~~control~~ the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. ~~maintain the stability of Baglog's temperature and humidity at all times.~~ This automation is achieved through the ~~occurs in~~ collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [53].

The research employs two programming languages, namely ~~The programming languages used are~~ C++ and PHP~~ in this research~~. Although there are various kinds of programming languages [54], each offers its advantages in application development programs [50], [55]. The PHP coding language enables the embodiment of Web-based application programs [56]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system ~~in this study~~; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language ~~–~~has its advantages in building application programs.

2.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. ~~This study surveyed to collect quantitative data ordinal~~. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument ~~in this study~~ used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

3. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

3.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

3.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described ~~to~~ the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

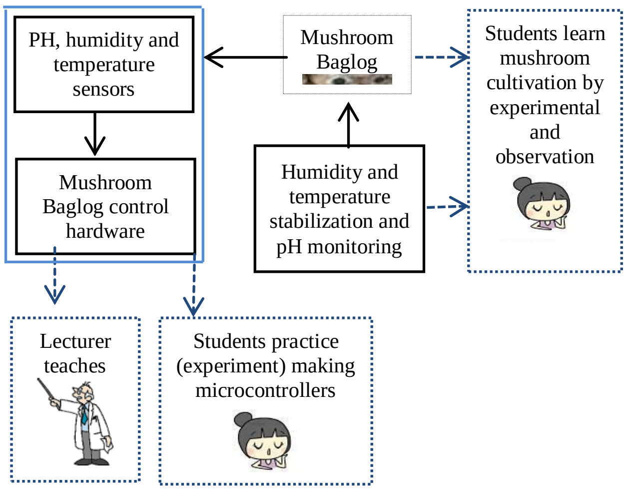

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

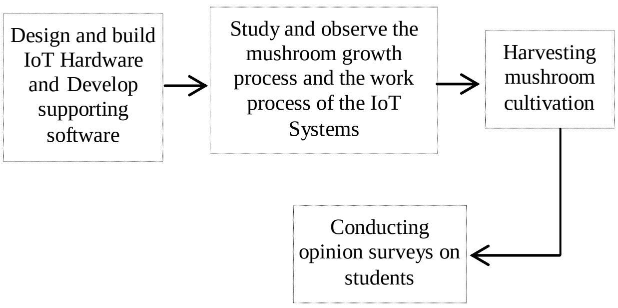

Figure 3. Learning s~~S~~tages of IoT d~~D~~esign and m~~M~~ushroom c~~C~~ultivation for s~~S~~tudents

3.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements.~~.~~ The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

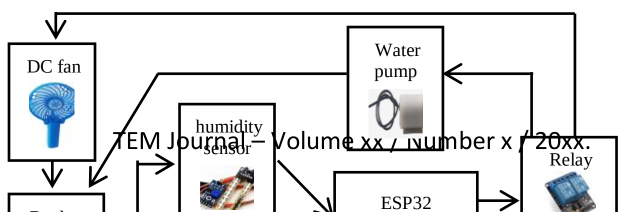

Figure 4. Block d~~D~~iagram of IoT m~~M~~icrocontroller h~~H~~ardware for o~~O~~yster m~~M~~ushroom c~~C~~ultivation

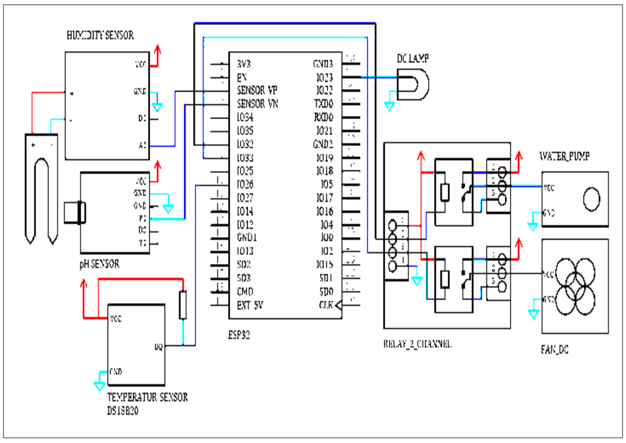

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers ~~used as monitors~~ can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, ~~for the pH of the water,~~ when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.[n3]

3.4. Testing

The requirement analysis stage is ~~the stage of~~ determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge[n4]. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range ~~in this study shows that~~ the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. ~~Or still in the best temperature range in oyster mushroom cultivation.~~

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes

10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

3.5. Implementation[n5]

3.5.1. Oyster M~~m~~ushroom C~~c~~ultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is Baglog container~~ is Baglog~~, with manual control over water pH, temperature, and humidity~~ from Baglog~~. In contrast, the second is Baglog container~~ is Baglog~~, with the management of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.[n6]

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size f~~F~~or example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.~~,~~ ~~as revealed by Okuda, previous researchers (2022).~~

4.5.1. 3.5.2. *A survey to find out the results of student practicum learning*

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 7, Figure 13, Table 8, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda ~~(2022).~~[14].

Table 7. [e7]*Students' satisfaction with practicum learning*

Students perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

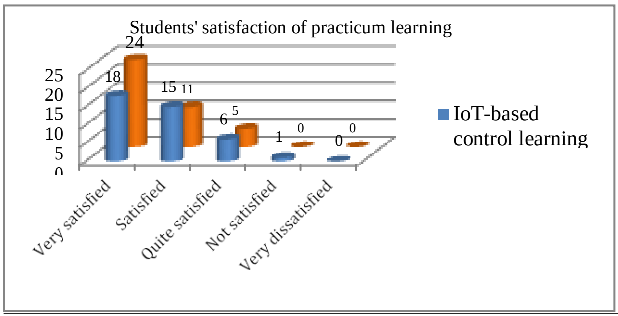

Figure *13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT*

Table 8. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

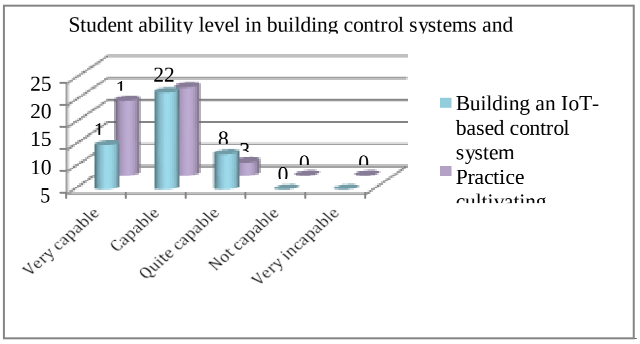

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research implemented ~~conducted~~ educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, ~~most students stated that~~ most students have the ability to build an IoT-based control system and demonstrated proficiency~~also~~ in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5%

capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). [n8]Another novel scientific finding in this study is the~~o~~ elimination~~e~~ of the dark side of stagnation in mushroom production ~~as feared by Okuda researchers (2022)~~ to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim ~~researching~~ to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive (Rohles, Backes, Fischbach, Amadieu, & Koenig, 2022; van Laar, van Deursen, van Dijk, & de Haan, 2017), (Teoh, Ho, Dollmat, & Tan, 2022). Currently, digital technology plays a dominant role in facilitating the learning process (Srivastava & Dey, 2018). Previous research has also shown that students react positively to digital technology-based learning processes (Jones & Shao, 2011). Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology (Madni et al., 2022). IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time (Malik, Dedeoglu, Kanhere, & Jurdak, 2019; Powell, Foth, Cao, & Natanelov, 2022). Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere (Kumar et al., 2022) and supports heterogeneous automation models (Li, Zhang, Fei, Shakeel, & Samuel, 2020). So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system (Joko, Putra, & Isnawan, 2023). But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited (Madni et al., 2022).
Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful (Anamosa, 2021). Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms (Suada, Sudarma, Kim, Cha, & Ohga, 2015). It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom

production (Okuda, 2022). In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning process (Ediyani et al., 2020). Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller (Atzori, Iera, & Morabito, 2010). IoT technology has replaced the traditional method (Puliafito, Mingozzi, Longo, Puliafito, & Rana, 2019). IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment (Sumi & Ranga, 2016), (Pardini, Rodrigues, Kozlov, Kumar, & Furtado, 2019), (Arasteh et al., 2016), (Raaijen & Daneva, 2017). Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models (Ou & Xie, 2012). As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary (Jiang, Yang, Xu, Song, & Zheng, 2019). Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices (Sun, 2022). As a result, teaching media devices have become a significant concern for colleges today (Liu, Wang, & Xiao, 2021).

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments (Babiuch, Foltynek, & Smutny, 2019). Microcontrollers are primarily for control, wireless, and automation systems (Salah & Zneid, 2020). The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work (Allafi & Iqbal, 2018). In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost (Fabregat, Belloch, Badia, & Cobos, 2020; Tueche et al., 2021). Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces (Babiuch et al., 2019). Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance (Fezari & Zakaria, 2019). The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world (Royse, 2012) and as edible mushrooms (Melanouri, Dedousi, & Diamantopoulou, 2022; Törős, El-Ramady, & Prokisch, 2022). Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk (Pathmashini, Arulnandhy, & Wijeratnam, 2009). Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug (El-Ramady et al., 2022; Raman et al., 2021a), its taste (Jongman, Khare, Loeto, & Behari Khare, 2018; Raman et al., 2021a) and contains lots of fiber, minerals, vitamins (Feeney et al., 2014; Raman et al., 2021a), carbohydrate, and essential amino acids (Raman et al., 2021a). In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial (Törős et al., 2022; Zawadzka et al., 2022). It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries (Jongman et al., 2018). However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary (Girmay, Gorems, Birhanu, & Zewdie, 2016).

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization (Girmay et al., 2016), (Sulistyanto et al., 2018), (Chitra, Dhanalakshm, Indra, & Ambethgar, 2021), and in a humid or not dry and not wet environment (Sulistyanto et al., 2018). Other researchers have also confirmed that humid climates positively affect fungal growth and colonization (Jongman et al., 2018; Nongthombam et al., 2021). Generally, suitable temperatures range from 25-30 °C (Jongman et al., 2018) and 20-30 °C (Nongthombam et al., 2021). The pH concentration of the fungus is slightly acidic to slightly alkaline (Chang, 2007). The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 (Sultana, Hossain, Saifullah, Amin, & Chakraborty, 2018). Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux (Sultana et al., 2018).

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by (Lu, Liaw, Wu, & Hung, 2019), (Ediyani et al., 2020), (Nongthombam et al., 2021), (Zawadzka et al., 2022), and (Okuda, 2022), none of them aim to be educational media tools for students as this research. Besides that, a previous study by (Sulistyanto et al., 2018) and (Desnanjaya & Sugiartawan, 2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), (Lu et al., 2019), (Ediyani et al., 2020), (Nongthombam et al., 2021), (Raman et al., 2021b), (Zawadzka et al., 2022), Okuda (Okuda, 2022), (Törős, El-Ramady, & Prokisch, 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022), and (Melanouri et al., 2022) had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (Sulistyanto et al., 2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu (Lu et al., 2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. (Ediyani et al., 2020) explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. (Nongthombam et al., 2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (Liu et al., 2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (Zawadzka et al., 2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed (Desnanjaya & Sugiartawan, 2022). However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. (Nadzirah et al., 2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Hum idity	Tempe rature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control (Sun, 2022). This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed (Okuda, 2022). This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems (Anggrawan, Mayadi, Satria, & Putra, 2022; Dima & Maassen, 2018). The process stages in the Waterfall model are sequential from the beginning to the next step (Bassil, 2012). The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 (Anggrawan, Mayadi, et al., 2022).

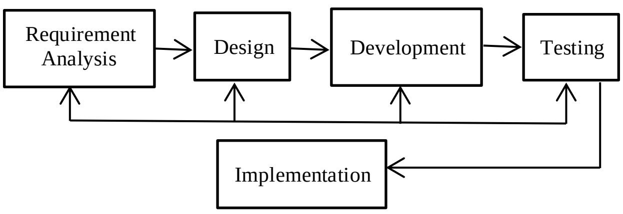

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities (Anggrawan, Hadi, & Satria, 2022).

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages (Anggrawan, Satria, Mayadi, & Dasriani, 2021), each offers its advantages in application development programs [50], (Anggrawan, Nuraini, et al., 2021). The PHP coding language enables the embodiment of Web-based application programs (Anggrawan, Satria, Nuraini, et al., 2021). The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

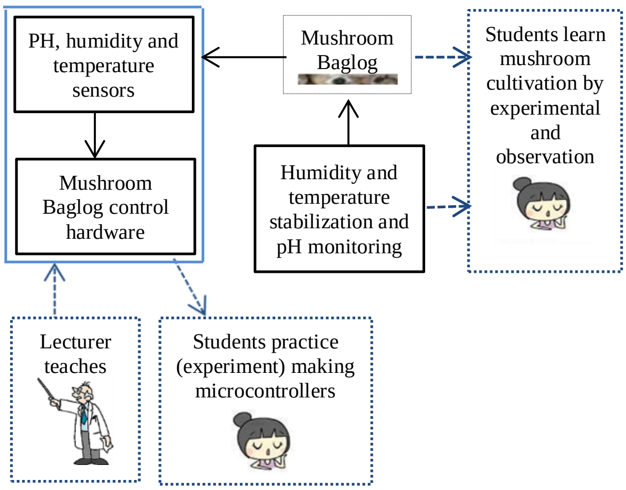

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

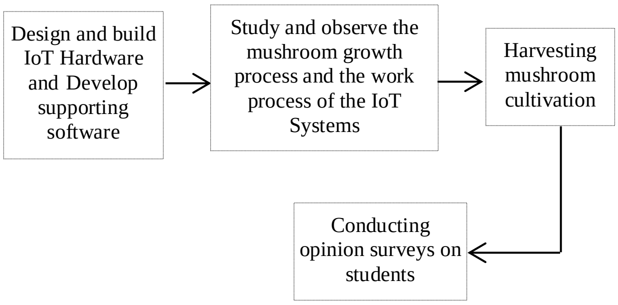

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V	Serves to detect the pH level (Read the pH	

Device	Amount	Type/Specification	Function	Image
		DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60℃	value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125⁰C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

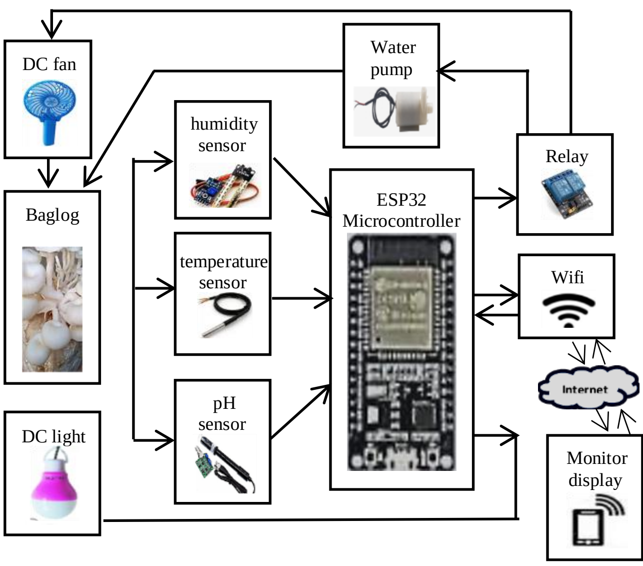

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

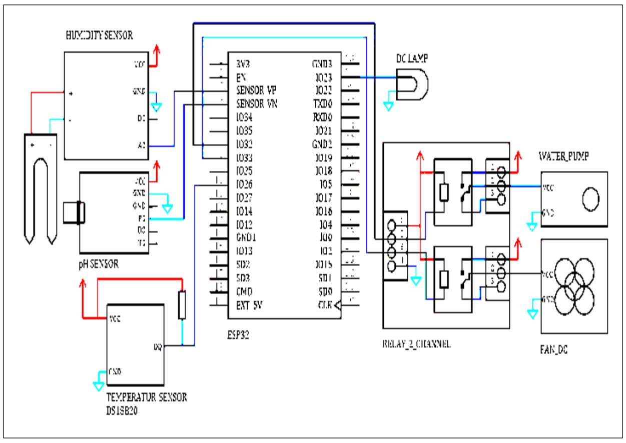

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level.

Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods (Puliafito et al., 2019). An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (Okuda, 2022).

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

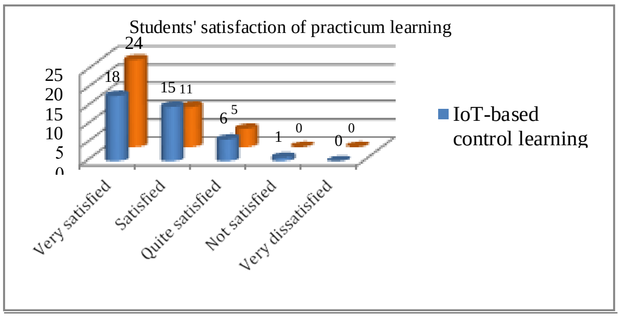

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

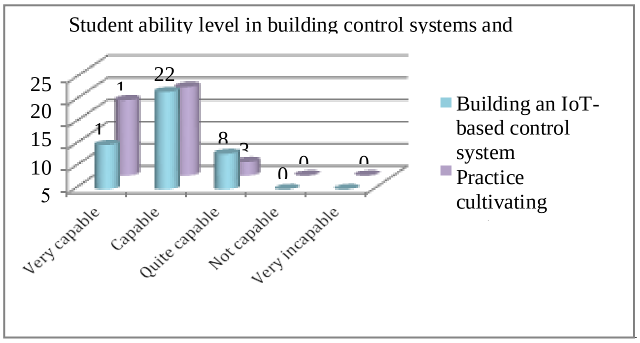

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

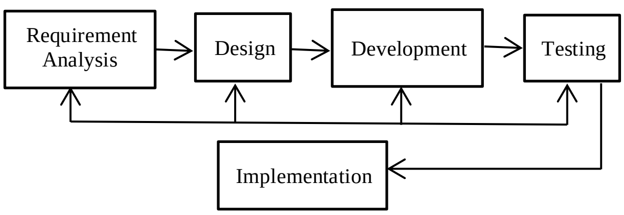


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

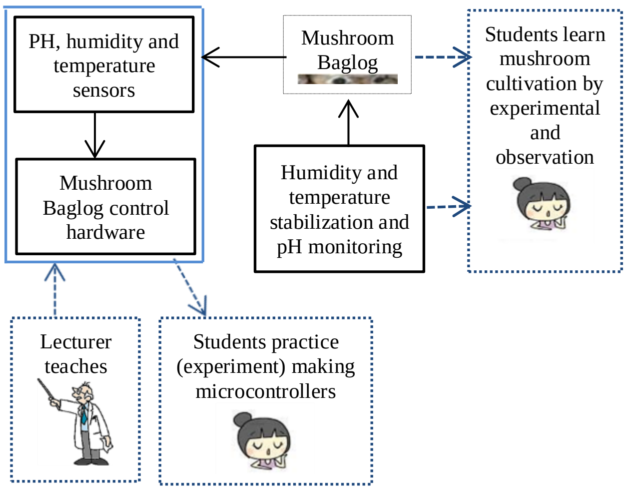


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

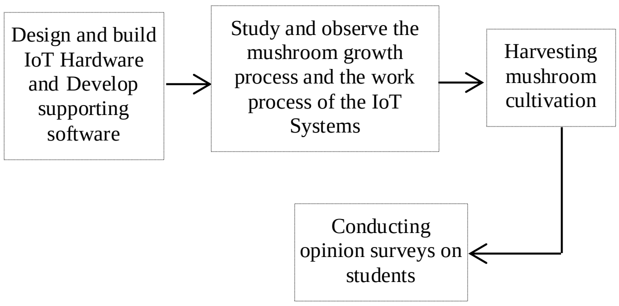


Figure 3. Learning stages of IoT design and mushroom cultivation for students

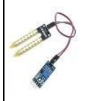
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

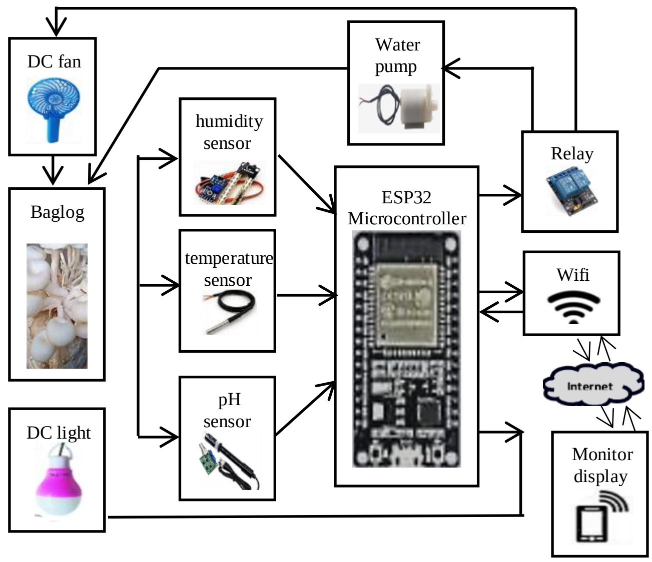


Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

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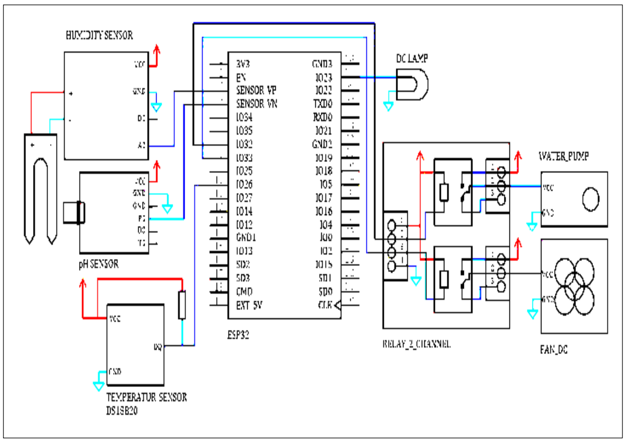

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

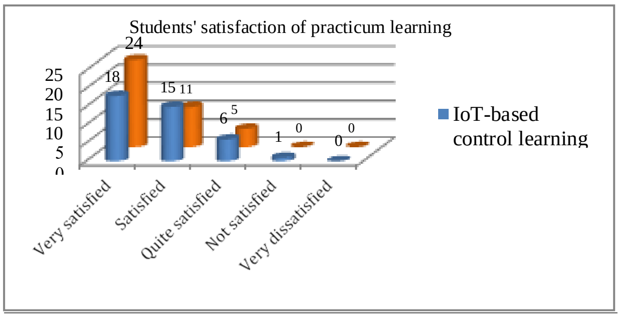

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

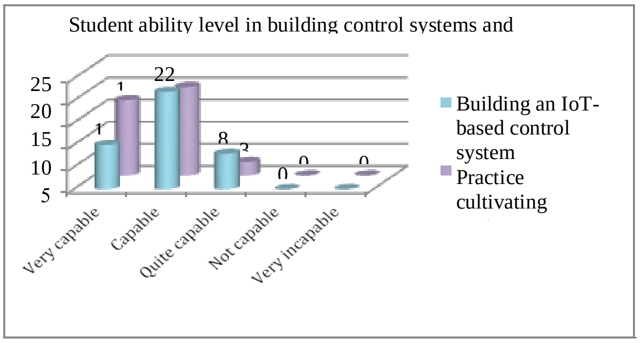

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

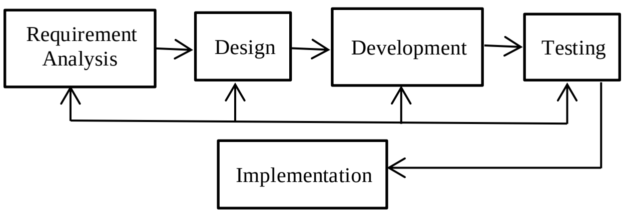

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

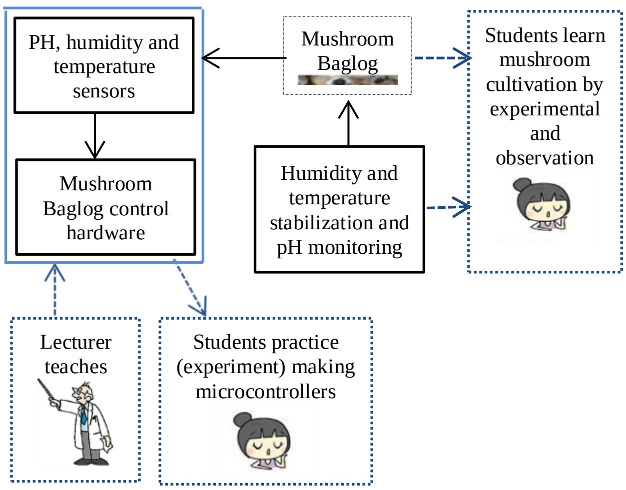

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

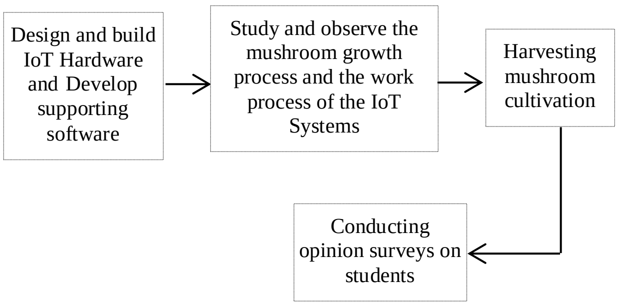

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

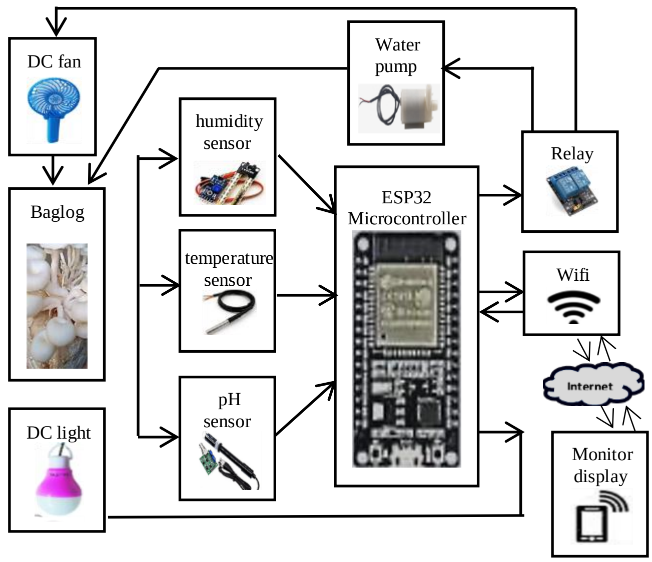

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

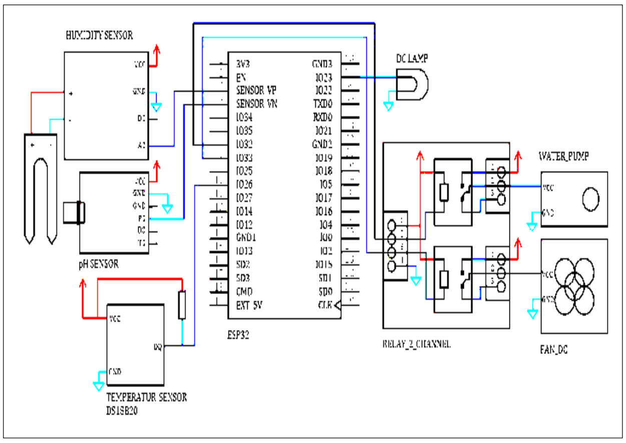

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	**Baglog humidity conditions**
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	**Moisture meter**	**Baglog Moisture**	**Error**	**Baglog humidity conditions**
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	**pH meter (EZ9901)**	**Water pH**	**Error**	**Water pH level**
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. *Implementation*

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

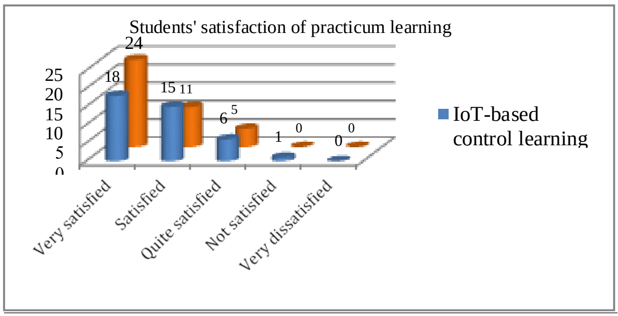

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

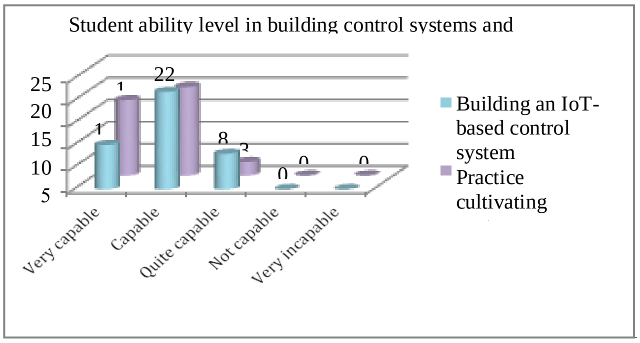

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Plagiarism Check_Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

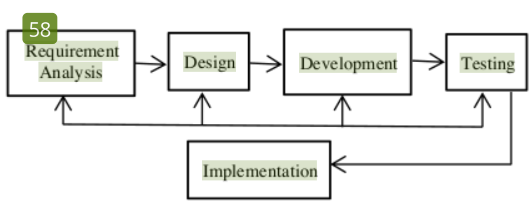

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

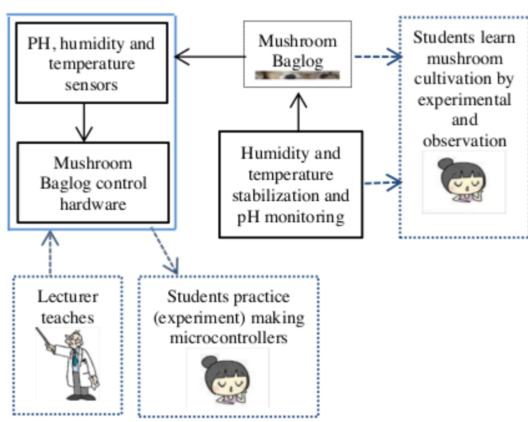

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

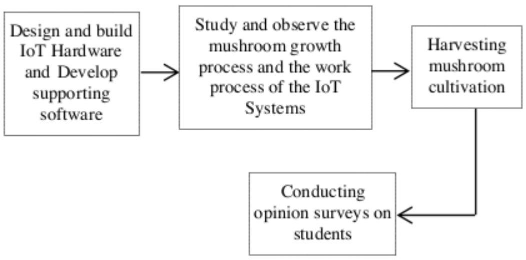

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: <1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-220 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

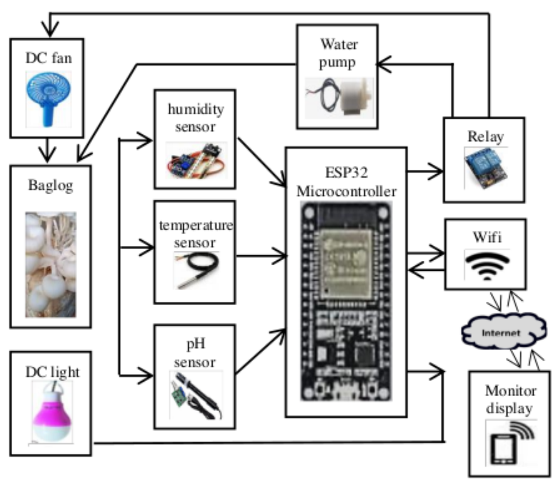

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

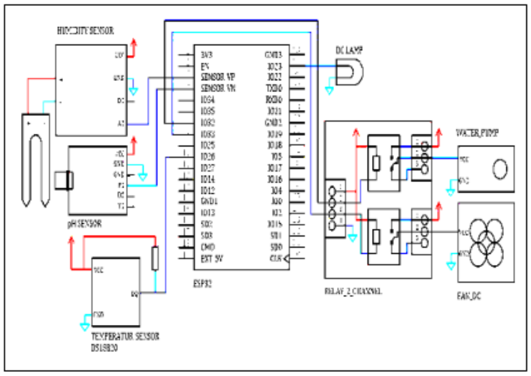

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
....	....	....	....	....
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

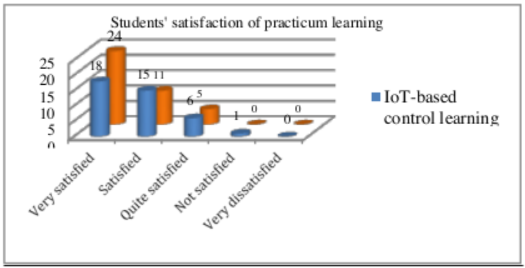

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

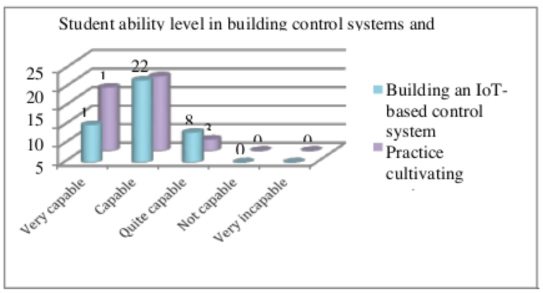

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media device for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

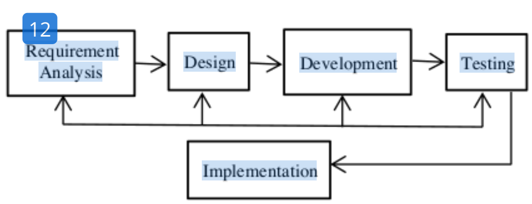

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

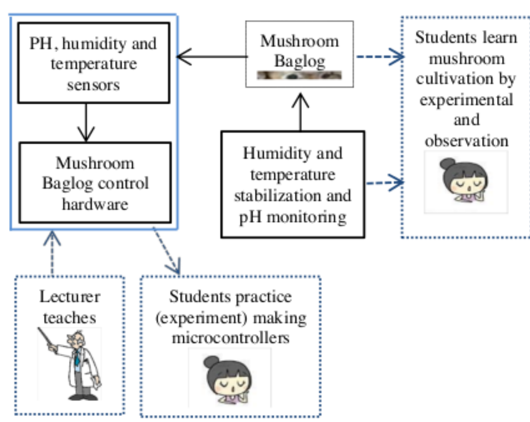

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

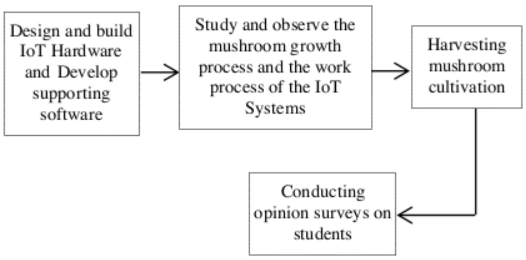

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: <1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

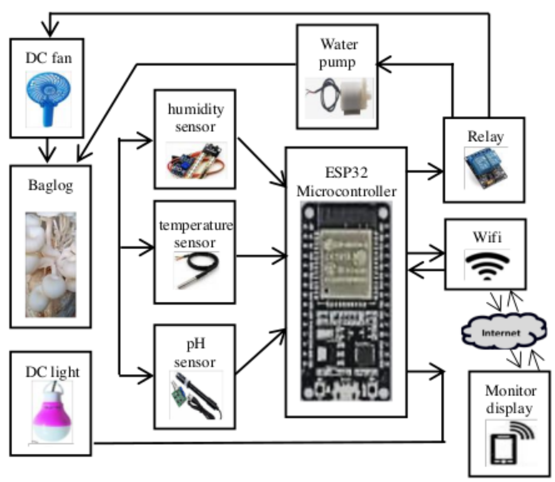

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

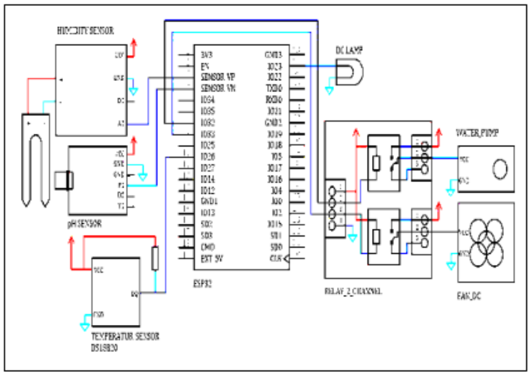

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is ~~the stage of~~ determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

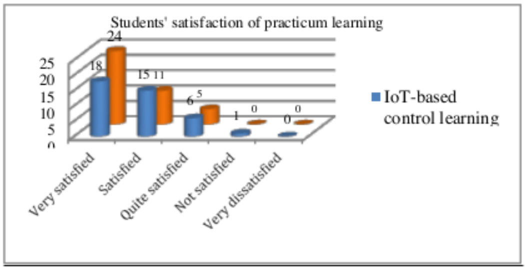

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

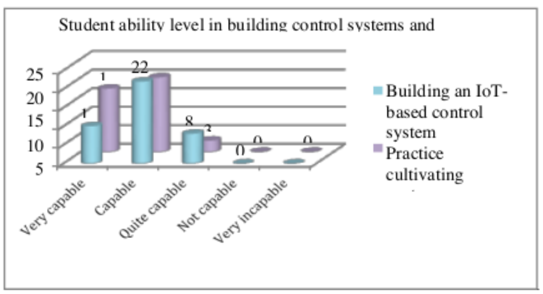

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

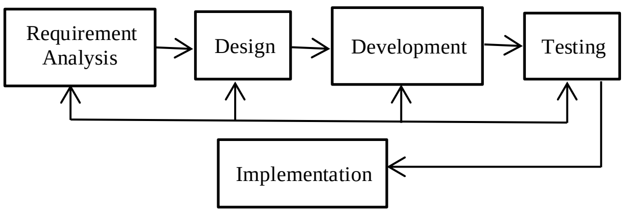


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

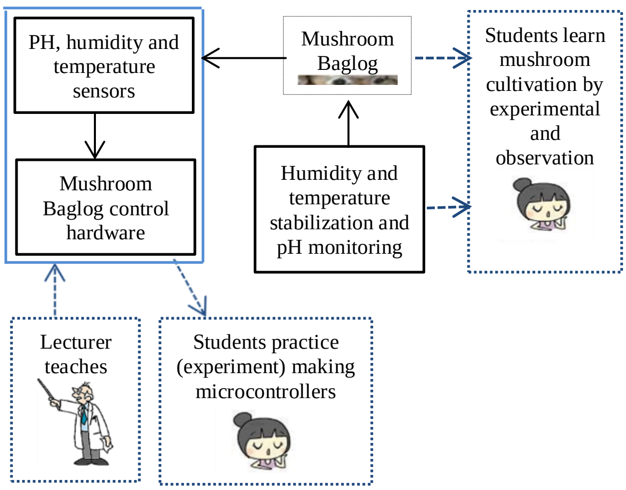


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

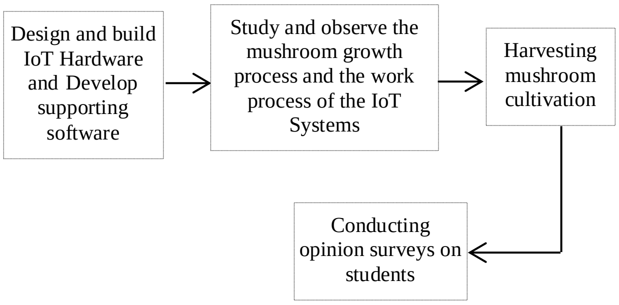


Figure 3. Learning stages of IoT design and mushroom cultivation for students

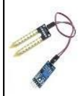
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

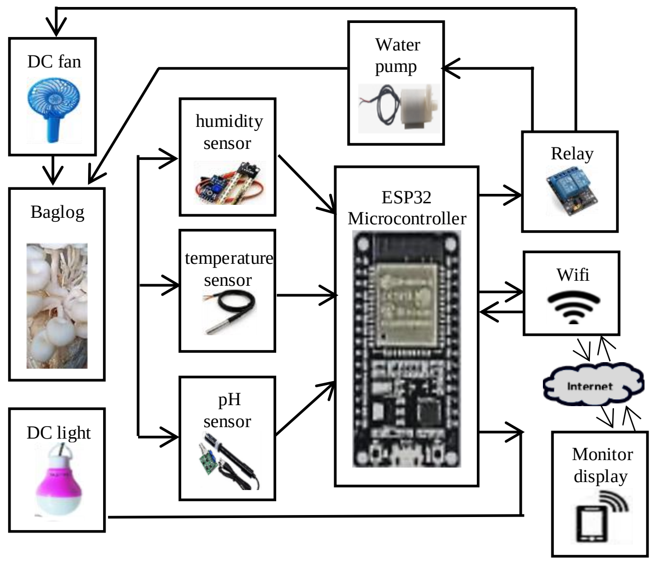


Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

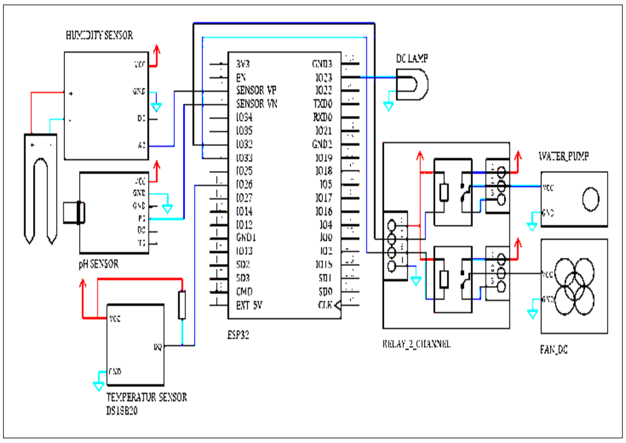


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.
Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

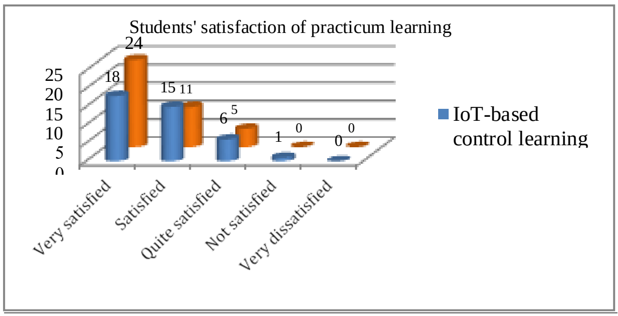


Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

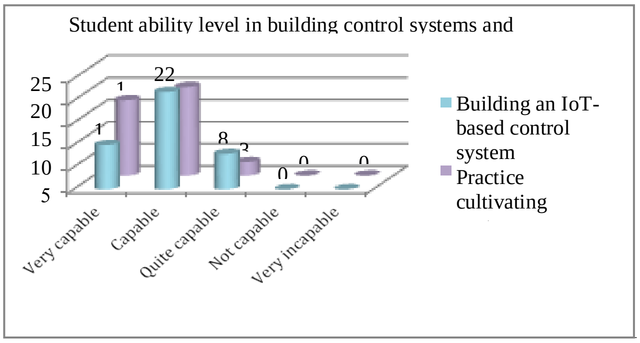


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

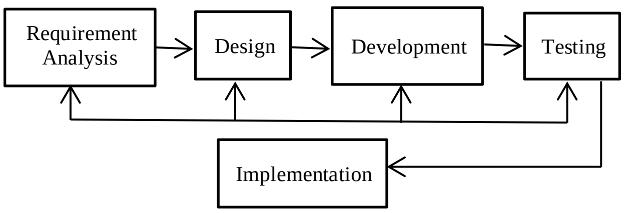


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

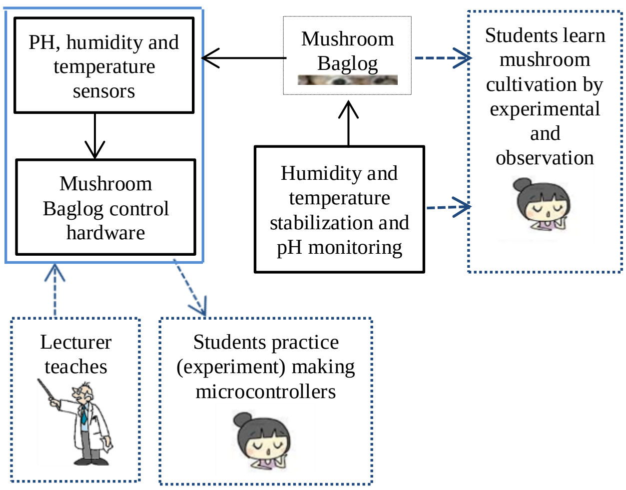


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

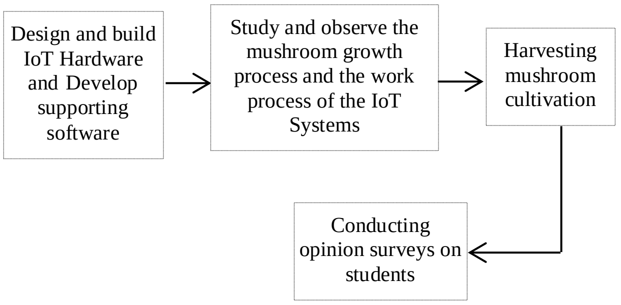


Figure 3. Learning stages of IoT design and mushroom cultivation for students

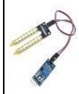
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

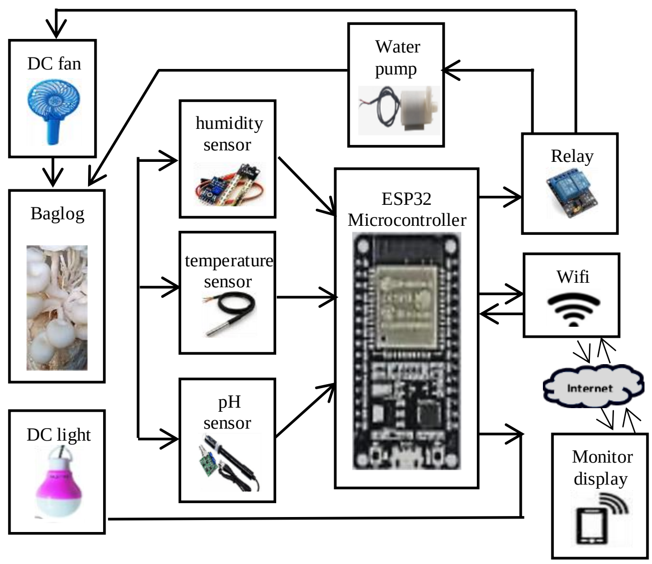


Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

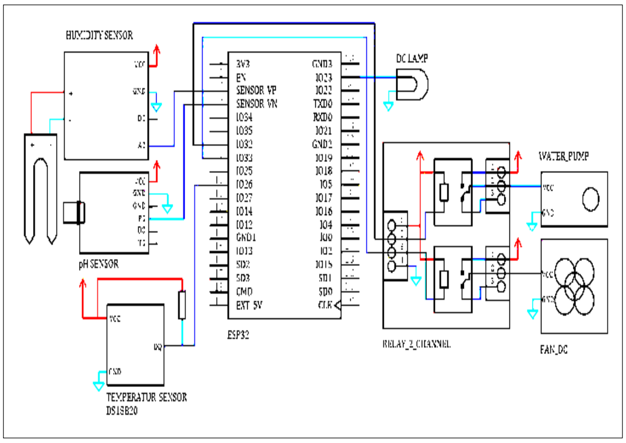


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

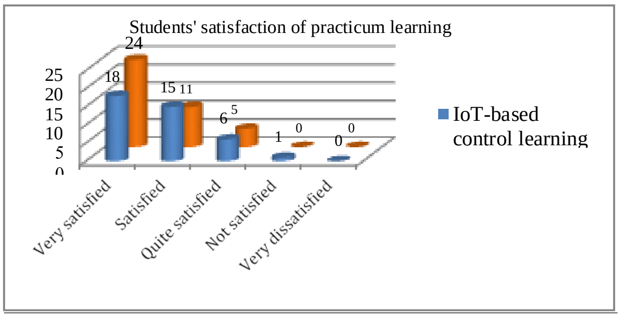


Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

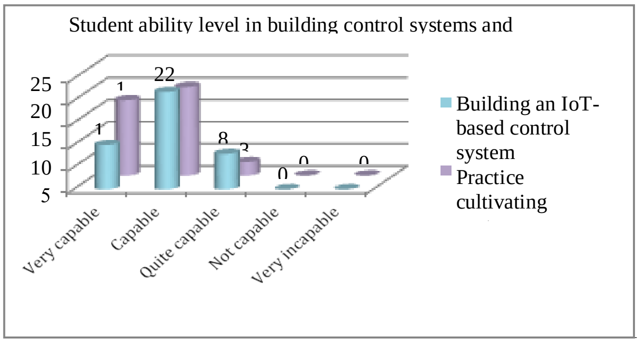


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [50], El-Ramady et al. [37], Nadzirah et al. [51] and Melanouri et al. [34].

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The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

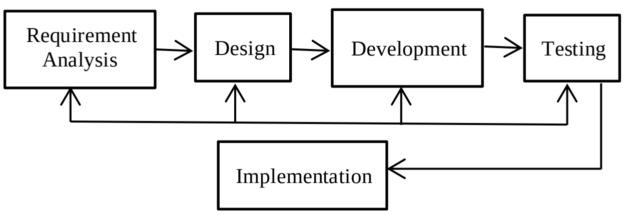

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

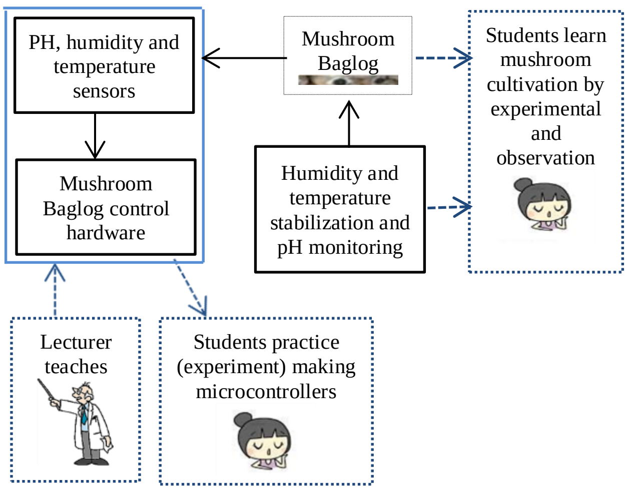

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

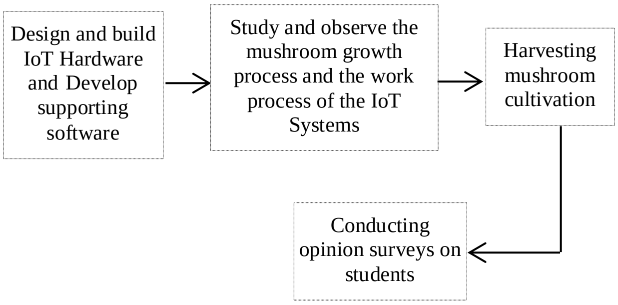

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125⁰C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

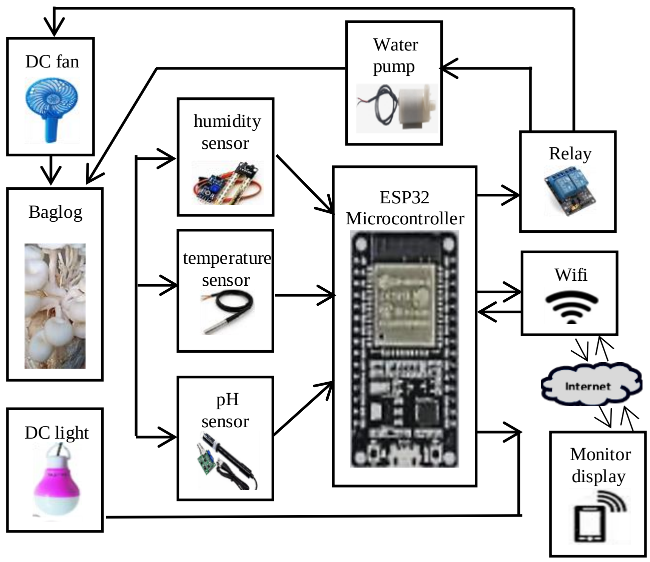

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

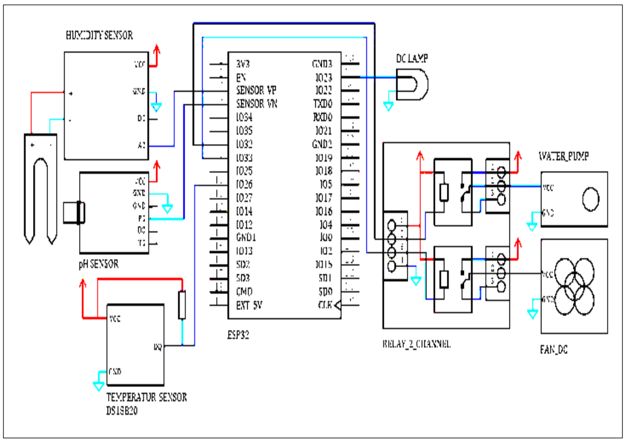

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

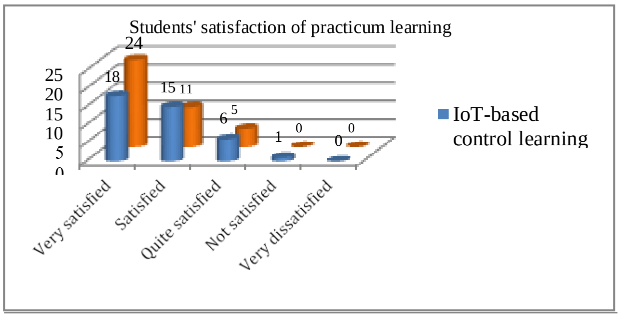

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

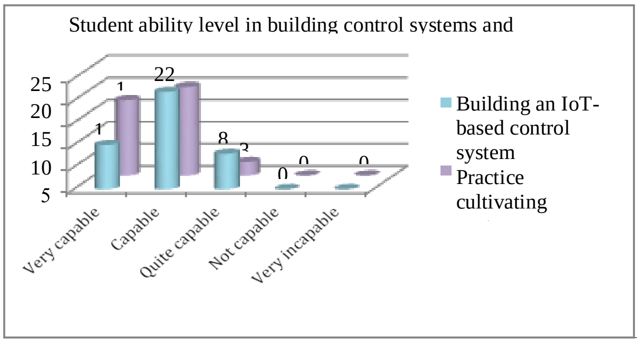

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30℃, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 ℃ [38] and 20-30 ℃ [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [49], [40], Okuda [14], [50], [37], [51], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [51] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [52], [53]. The process stages in the Waterfall model are sequential from the beginning to the next step [54]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [53].

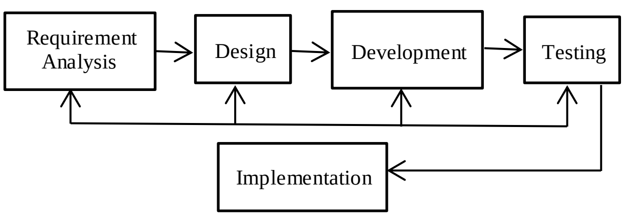

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [55].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [56], each offers its advantages in application development programs [50], [57]. The PHP coding language enables the embodiment of Web-based application programs [58]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

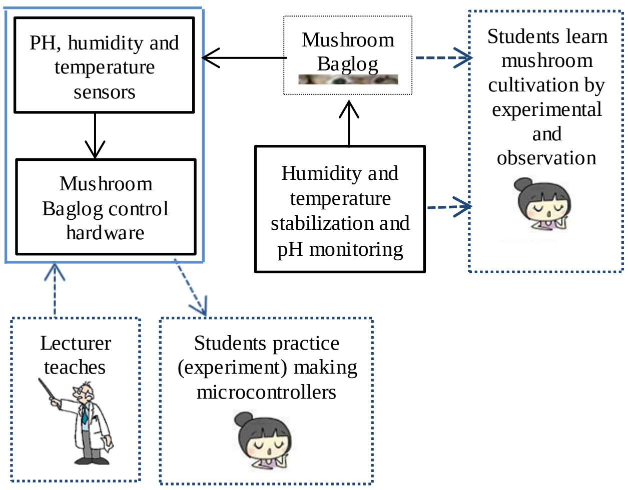

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

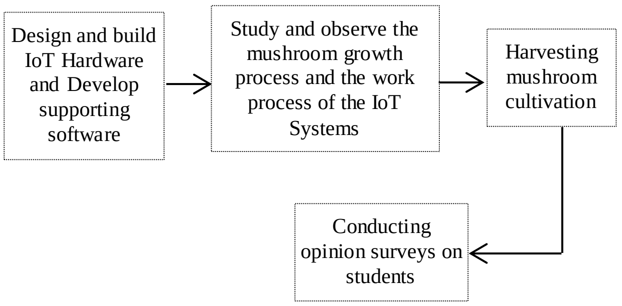

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

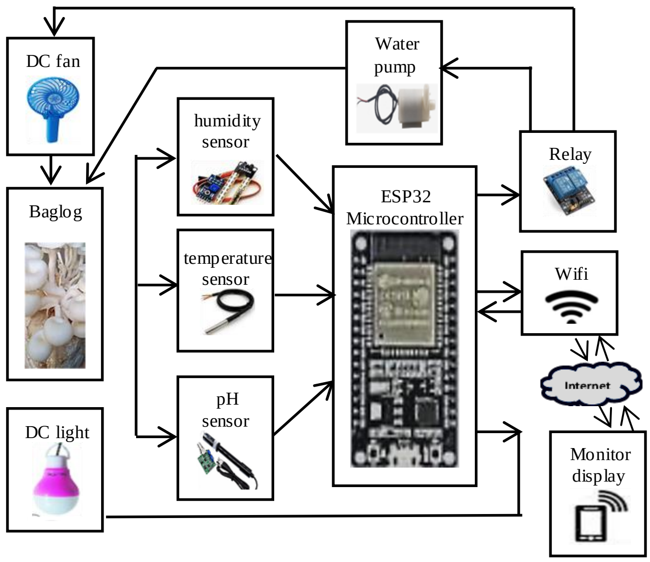

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

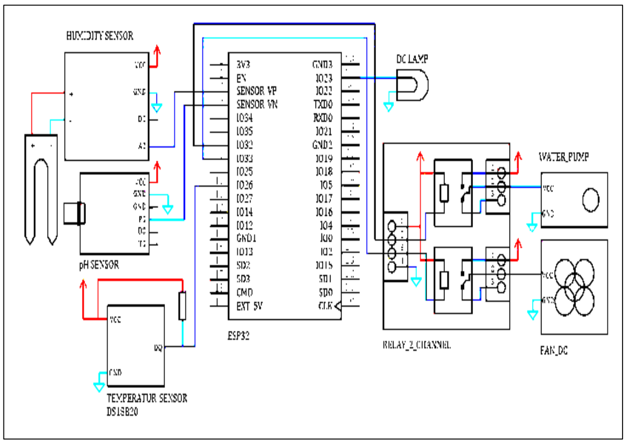

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

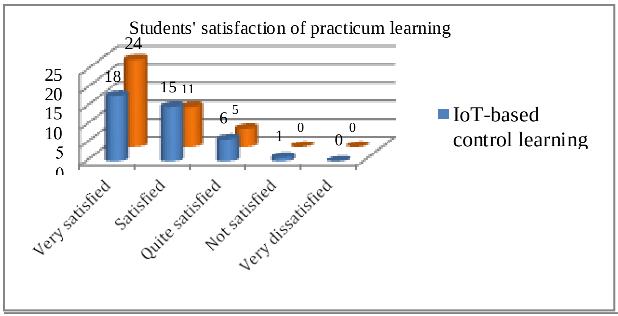

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

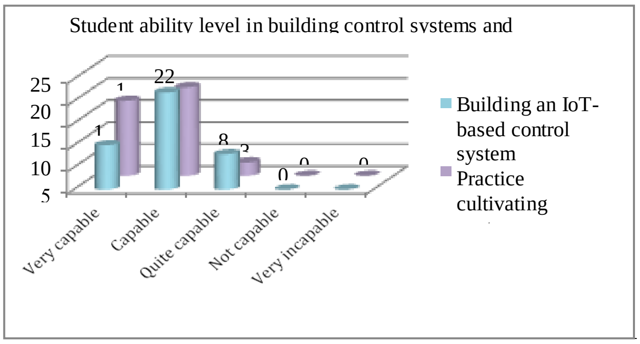

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang (2007), Royse (2012), Feeney et al. (2014), Sultana et al., (2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Raman et al. (2021), Zawadzka et al. (2022), Okuda (2022), Törős et al. (2022), El-Ramady et al. (2022), Nadzirah et al. (2022) and Melanouri et al. (2022).

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

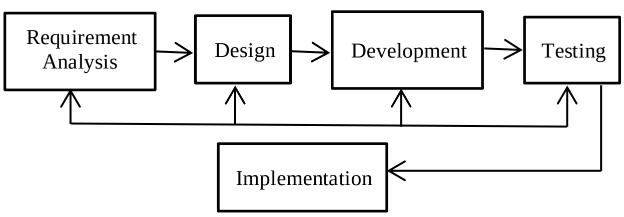

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49], [56]. The PHP coding language enables the embodiment of Web-based application programs [57]. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

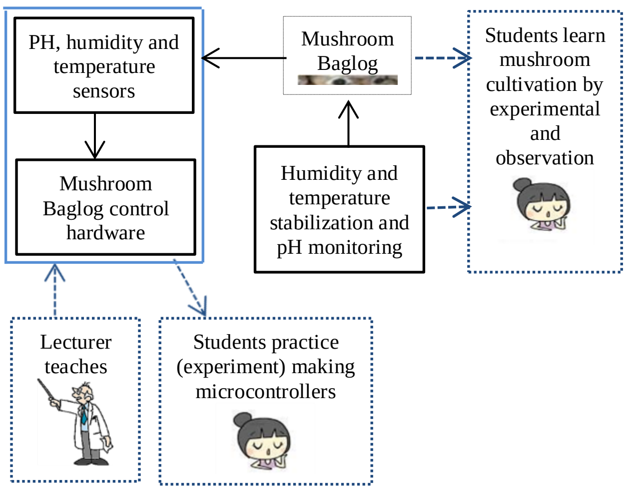

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

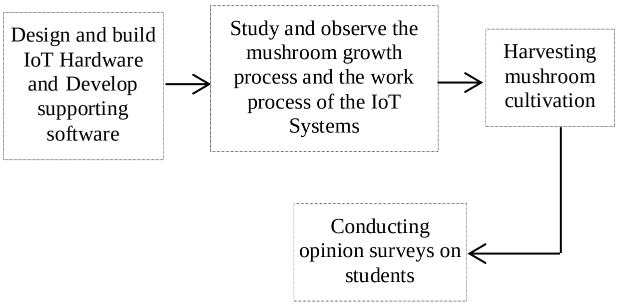

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

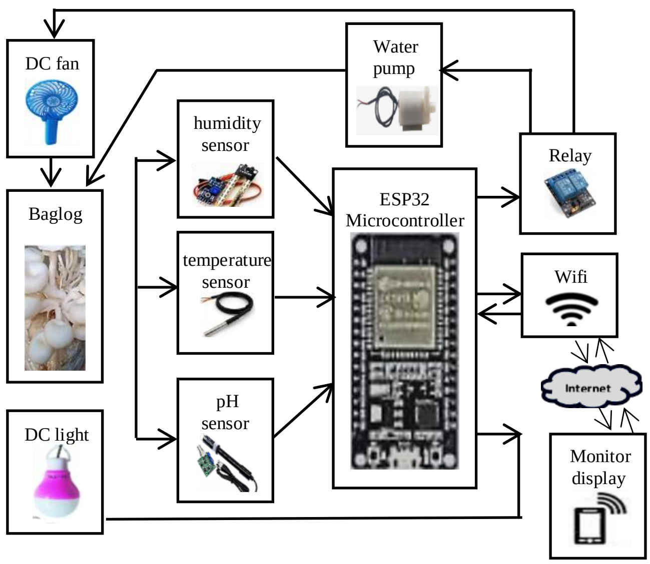

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

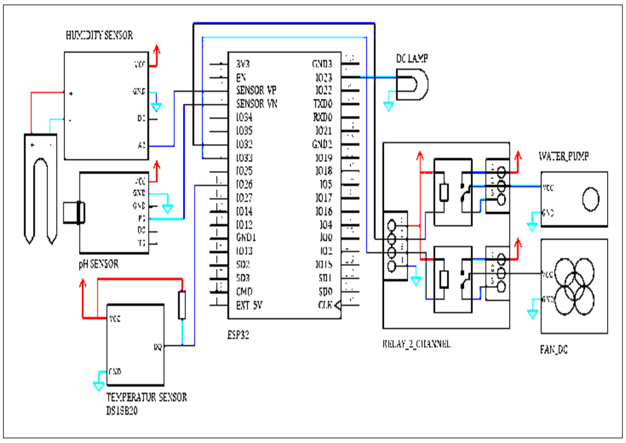

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually

controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

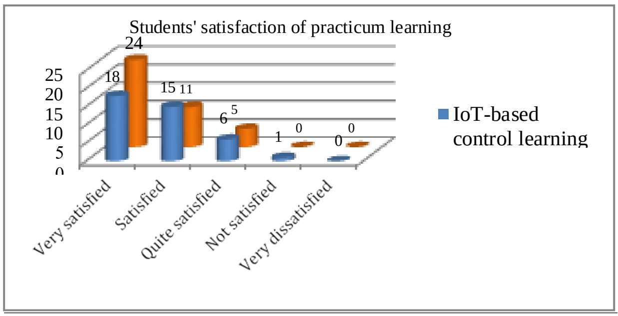

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

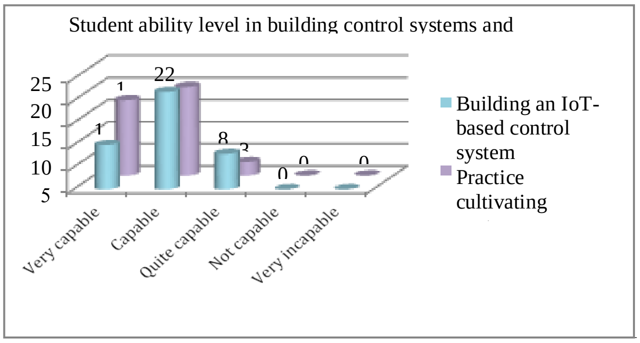

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

The study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

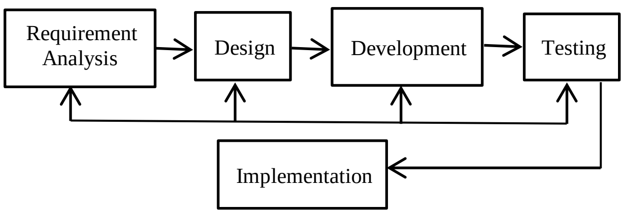

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49]. The PHP coding language enables the embodiment of Web-based application programs. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

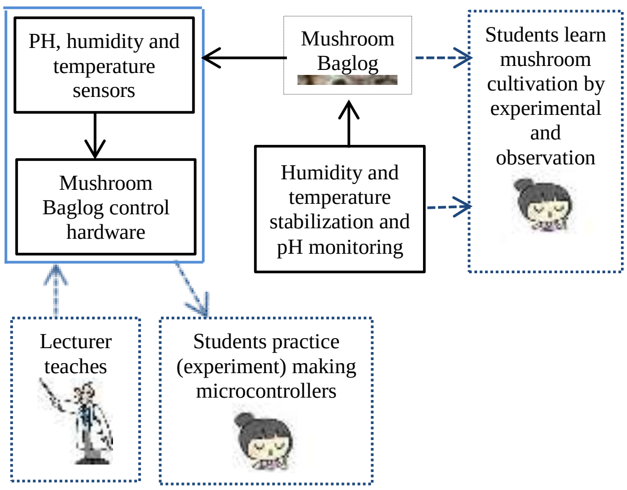

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

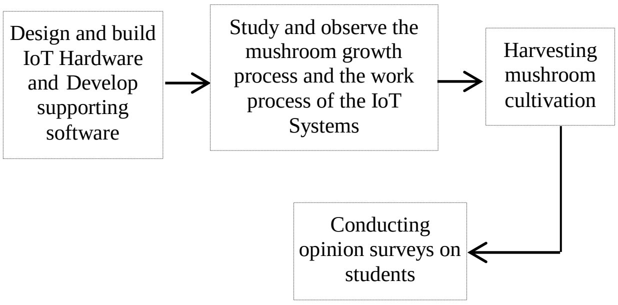

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

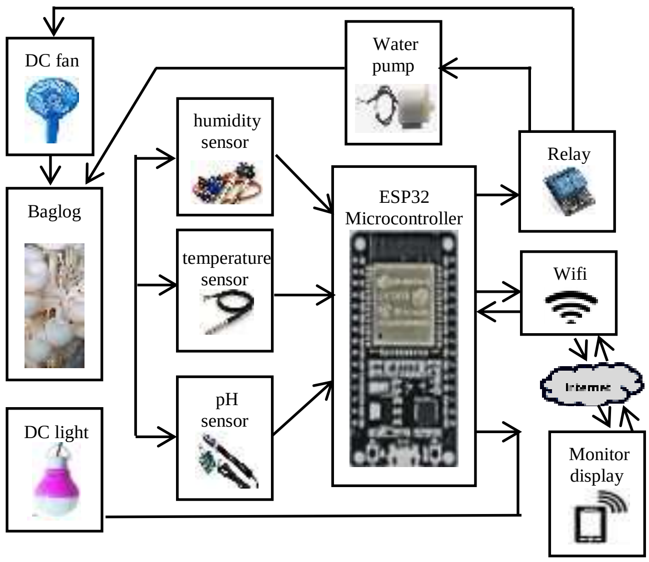

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

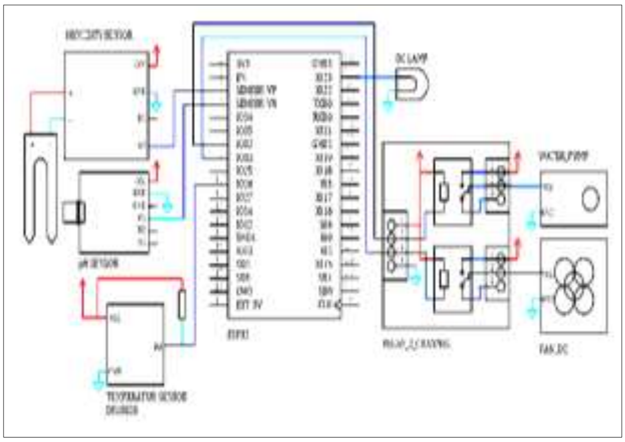

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

The results of the sensor system accuracy test in this study not only show the performance of the sensors used in this study but also show the superiority of this research which was not carried out by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is

controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom

production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

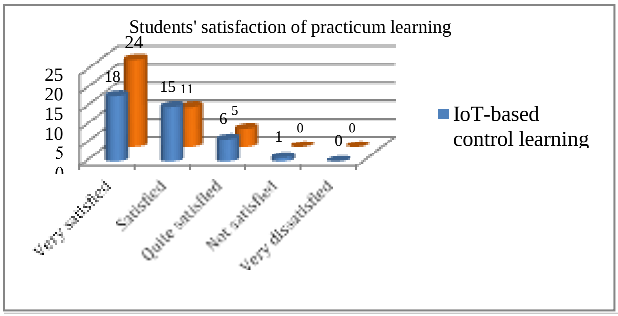

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

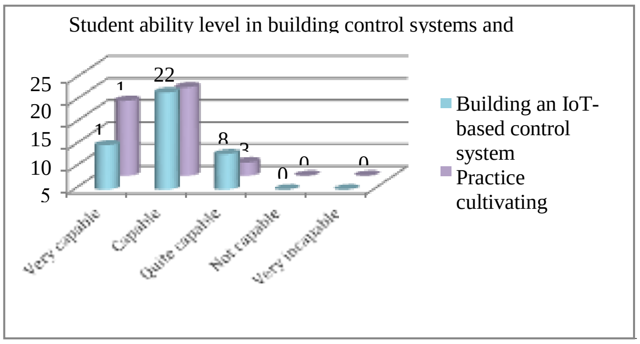

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies. Besides that the study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

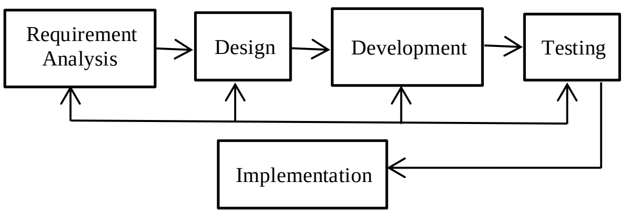

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49]. The PHP coding language enables the embodiment of Web-based application programs. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

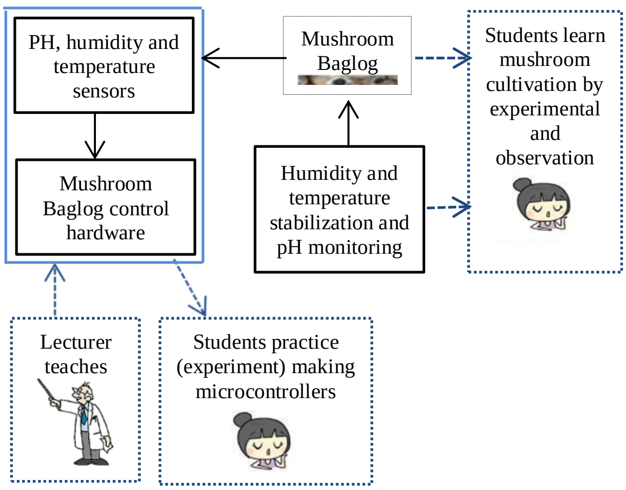

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

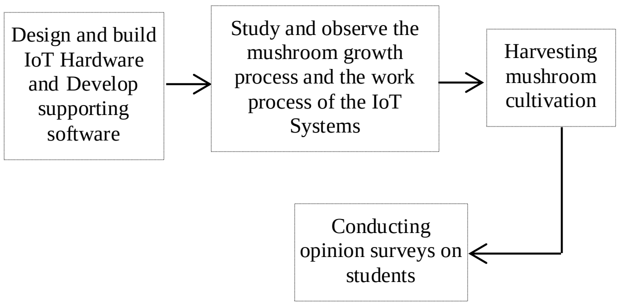

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

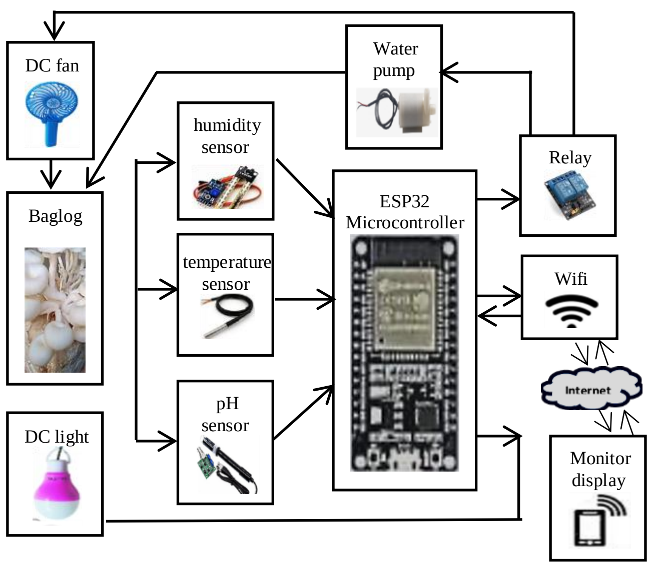

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

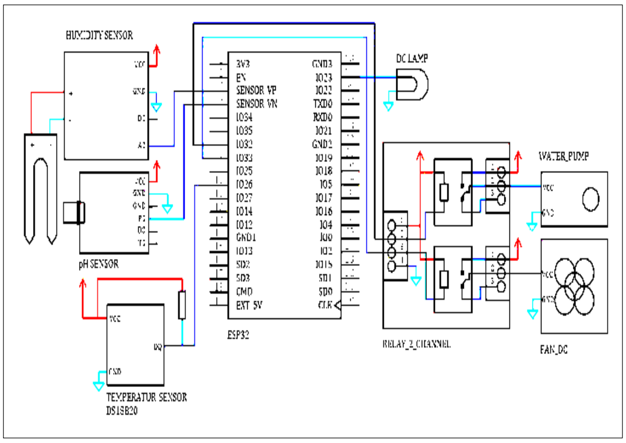

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.
Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

The results of the sensor system accuracy test in this study not only show the performance of the sensors used in this study but also show the superiority of this research which was not carried out by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is

controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom

production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

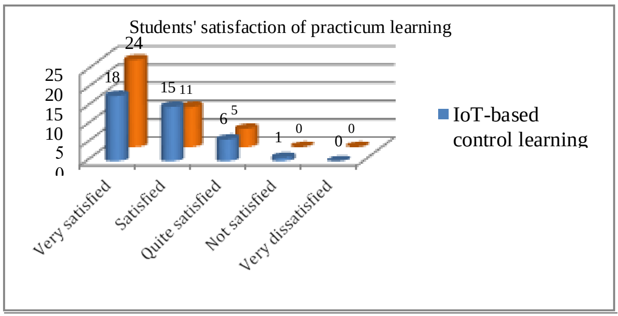

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

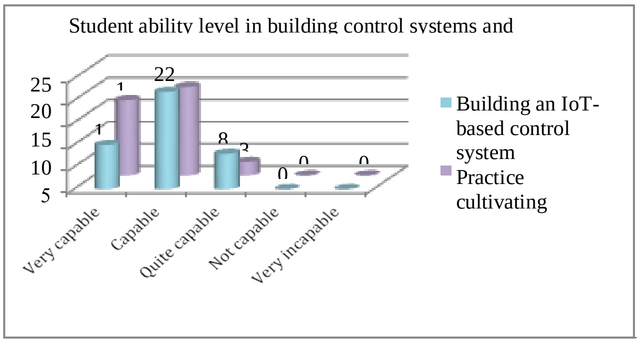

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies. Besides that the study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Hum idity	Tempe rature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

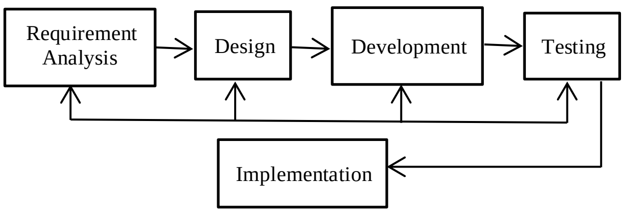


Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49]. The PHP coding language enables the embodiment of Web-based application programs. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

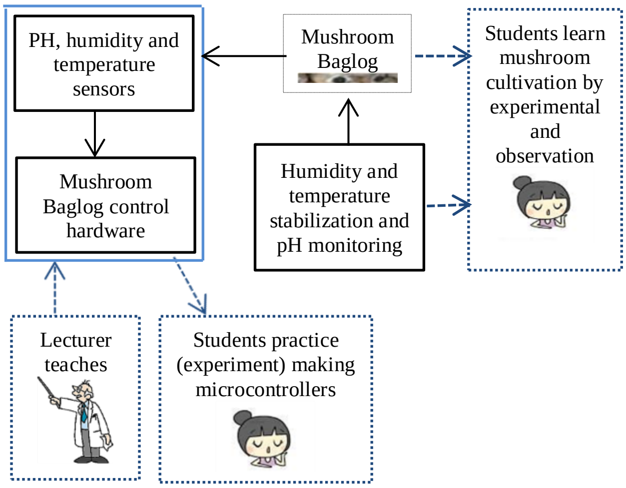


Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

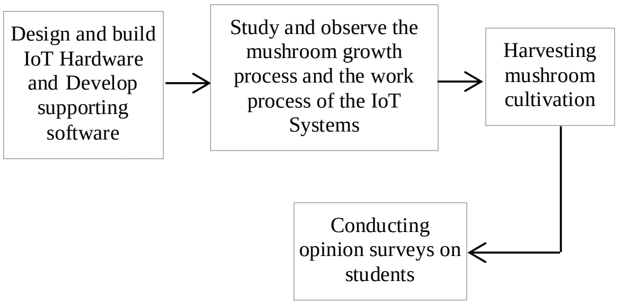


Figure 3. Learning stages of IoT design and mushroom cultivation for students

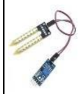
4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

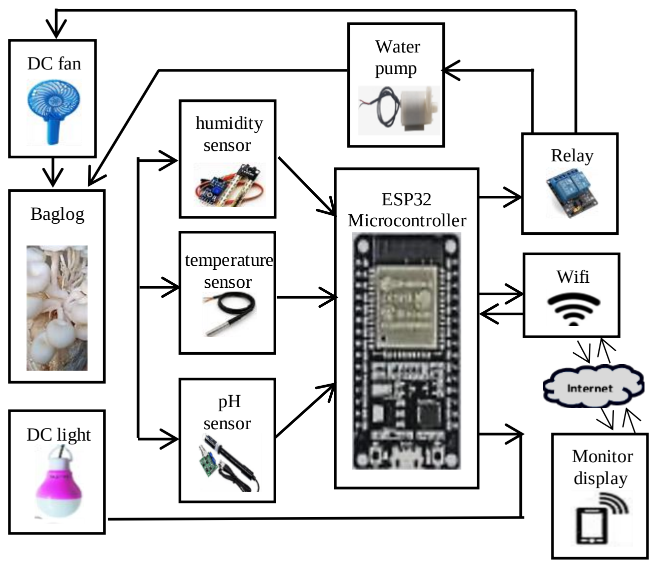


Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

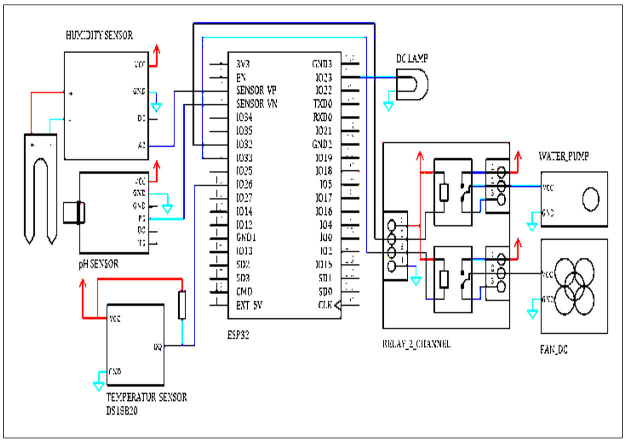


Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

The results of the sensor system accuracy test in this study not only show the performance of the sensors used in this study but also show the superiority of this research which was not carried out by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is

controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom

production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

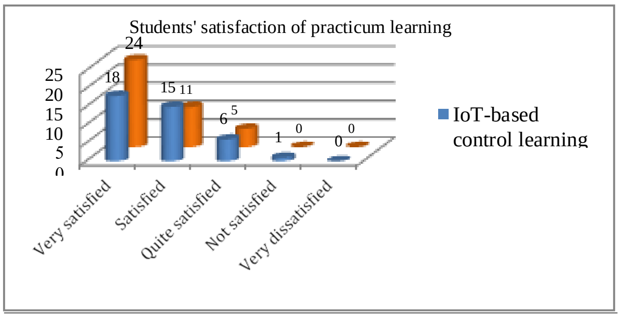


Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

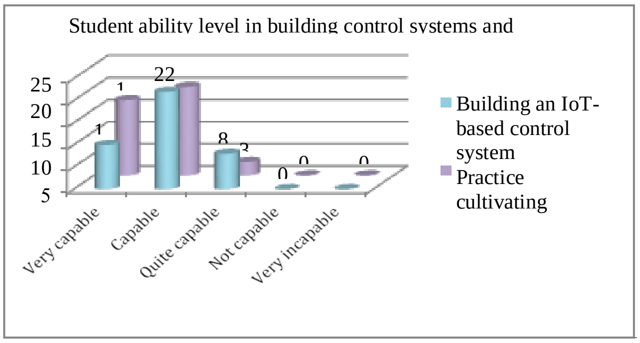


Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies. Besides that the study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Plagiarism Check_Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

By Anthony Anggrawan

Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

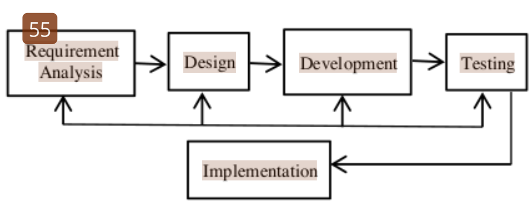

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49]. The PHP coding language enables the embodiment of Web-based application programs. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

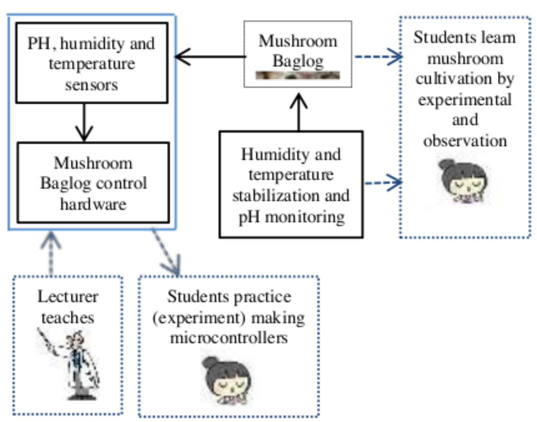

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

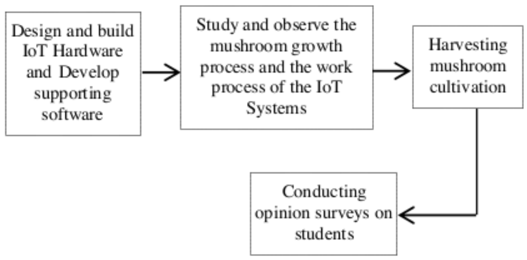

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: <1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^{0}C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-220 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

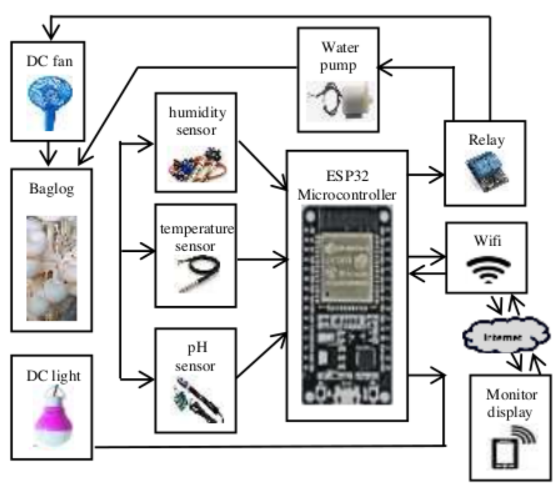

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

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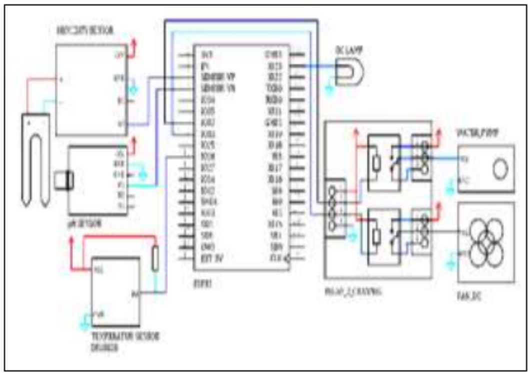

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of bag water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

The results of the sensor system accuracy test in this study not only show the performance of the sensors used in this study but also show the superiority of this research which was not carried out by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is

controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom

production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

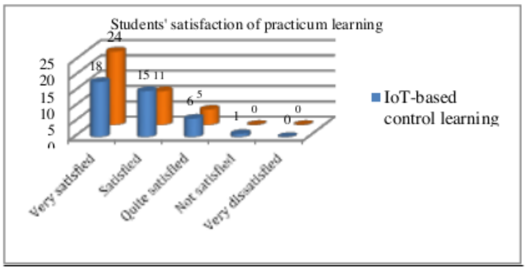

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

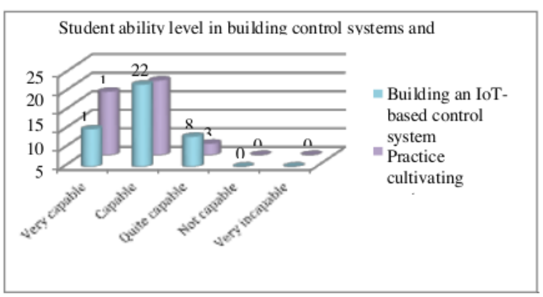

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies. Besides that the study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Plagiarism Check_Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

By Anthony Anggrawan

Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

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Abstract **–Whereas the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means that learning media and IoT research in education are still challenging for researchers. Bearing in mind mushroom cultivators do not understand what actions must be considered when cultivating mushrooms, and oyster mushroom cultivation frequently fails due to uncontrolled Baglog environmental conditions. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The research method combines experimental, surveys, and observation procedures. The research succeeded in carrying out educational activities with results that satisfied students and enabled most students to build an IoT-based control system and cultivate oyster mushrooms. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Furthermore, the study's conclusions remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.**

Keywords **– Practical learning, control system, mushrooms, internet of things, education technology.**

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1. Introduction

Education is increasingly moving toward the digital age and as a result, the use of digital technology is extensive [1], [2], [3]. Currently, digital technology plays a dominant role in facilitating the learning process [4]. Previous research has also shown that students react positively to digital technology-based learning processes [5]. Meanwhile, IoT, one of the digital technology innovations, has become a research concern in education and the application of the latest technology [6]. IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real time [7], [8]. Moreover, IoT technology utilization allows control to be done automatically and monitored from anywhere [9] and supports heterogeneous automation models [10]. So that is why, teachers prepare students to enter changes from digital to digital systems IoT intelligent automation system [11]. But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited [6].

Cultivating mushrooms often face difficulties for beginners. How to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful [12]. Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms [13]. It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production [14]. In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of

delivering teaching information in the learning process [15]. Therefore, this study aims to build a learning media device for students using IoT digital technology to cultivate oyster mushrooms.

IoT is the future communication technology equipped with a microcontroller [16]. IoT technology has replaced the traditional method [17]. IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment [18], [19], [20], [21]. Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models [22]. As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary [23]. Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices [24]. As a result, teaching media devices have become a significant concern for colleges today [25].

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments [26]. Microcontrollers are primarily for control, wireless, and automation systems [27]. The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The NodeMCU ESP32 microcontroller used in this study supports web servers and real-time work [28]. In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost [29], [30]. Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces [26]. Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance [31]. The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller supports the creation IoT application system. Meanwhile, Oyster mushrooms are mushrooms that are widely cultivated throughout the world [32] and as edible mushrooms [33], [34]. Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk [35]. Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug [36], [37], its taste [36], [38] and contains lots of fiber, minerals, vitamins [36], [39], carbohydrate, and essential amino acids [36]. In addition, oyster leaves are an important source for the human diet, anti-inflammatory, anti-diabetic, antifungal, antiviral, and antibacterial [33], [40]. It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries [38]. However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary [41].

Oyster mushrooms can grow at temperatures between 18 to 30°C, with rapid growth of mycelium and substrate colonization [41], [42], [43], and in a humid or not dry and not wet environment [42]. Other researchers have also confirmed that humid climates positively affect fungal growth and colonization [38], [44]. Generally, suitable temperatures range from 25-30 °C [38] and 20-30 °C [44]. The pH concentration of the fungus is slightly acidic to slightly alkaline [45]. The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 [46]. Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water thrice daily and lighting around 300-500 lux [46].

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform to build an IoT-based control system. In essence, for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog.

Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms using the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by [47], [15], [44], [40], and [14], none of them aim to be educational media tools for students as this research. Besides that, a previous study by

[42] and [48] on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Likewise with previous studies, including the research conducted by [45], [32], [39], [46], [47], [15], [44], [36], [40], Okuda [14], [49], [37], [50], and [34] had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes a significant contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is as follows: the second sub-section describes related works, whereas the third subsection discusses the research methodology. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. [42] proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms. However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Lu [47] proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks. Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. Accordingly, this previous research did not have the same aims and methods as this article's. Eliyani et al. [15] explained the vital role of learning media in developing science. Previous research has different research methods and objectives from the analysis in this article. Previous research reviews existing research related to the development of learning media. The object of study in the last article is not associated with oyster mushroom cultivation or the use of IoT technology as research in this article.

Jenita Nongthombam et al. [44] reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them. The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu [25] proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. The previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. [40] conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms. The difference between this previous research and the research in this article is in the purpose of the study. The last study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO is proposed [48]. However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type used. In addition, as examined in this article, previous research was not intended as a medium for student learning in mushroom cultivation and how to practice an IoT-based control system.

Nadzirah et al. [50] conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation. Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study.

Table 1. Comparison between the latest prior related work and this article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey, and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

In contrast, a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control [24]. This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. The future sustainability of mushroom cultivation or production is reviewed [14]. This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

A review of several recent related works shows that this article's research differs from previous research; specifically, the research method used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Research Methodology

This research combines experimental techniques, survey, and observation methods gather comprehensive data. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems [51], [52]. The process stages in the Waterfall model are sequential from the beginning to the next step [53]. The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 [52].

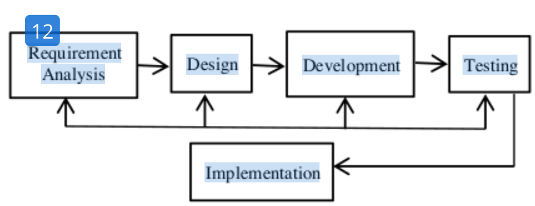

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system used in this study for cultivating oyster mushrooms incorporates automation to regulate the pH of the water and ensure consistent temperature and humidity levels for cultivating oyster mushrooms. This automation is achieved through the collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities [54].

The research employs two programming languages, namely C++ and PHP. Although there are various kinds of programming languages [55], each offers its advantages in application development programs [49]. The PHP coding language enables the embodiment of Web-based application programs. The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in handling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants

This study utilized a survey method to gather ordinal quantitative data. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument used is a Likert measurement scale consisting of gradations from very satisfied to very dissatisfied, very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Result and Discussion

This subsection explains the research results according to this study's Waterfall system development model.

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C++ programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C++ programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5, humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms.

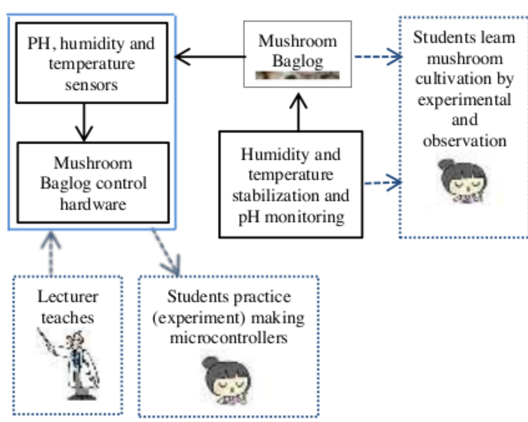

Figure 2. The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

First, the lecturer directed students on how to make hardware and control software for mushroom cultivation; then, the lecturer described the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest. Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system for cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

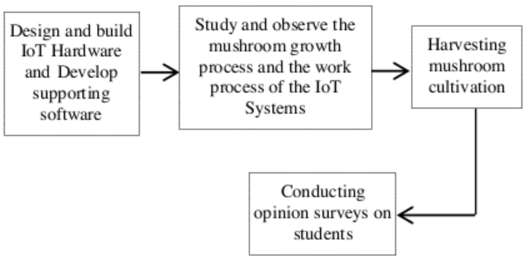

Figure 3. Learning stages of IoT design and mushroom cultivation for students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

Table 2. Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

Table 3. Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0-14PH, Resolution: ±0.15PH, Response time: <1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125°C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-230 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

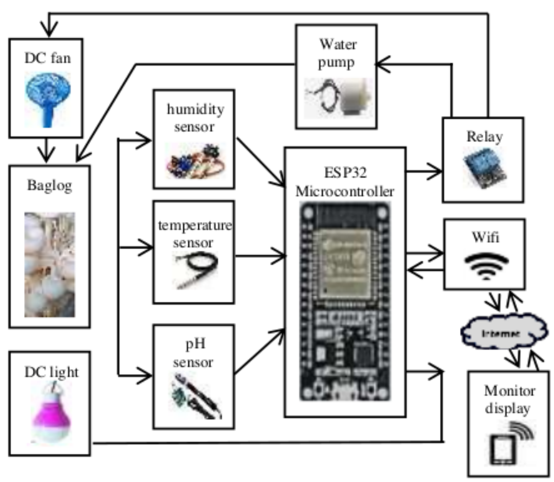

Figure 4. Block diagram of IoT microcontroller hardware for oyster mushroom cultivation

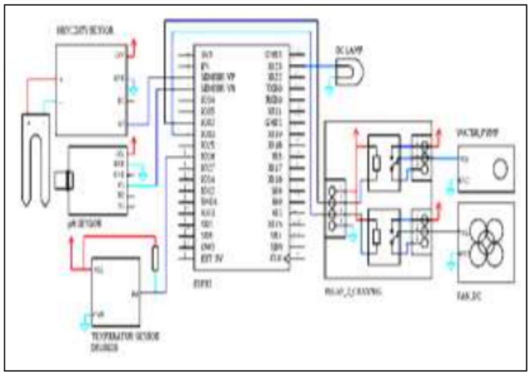

Figure 5. Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, when the pH of the water does not meet the requirements, pH stability of the water is carried out so that Baglog is then sprayed with a pH that meets the required pH standard.

4.4. Testing

The requirement analysis stage is determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires intelligence or innovation.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of bag water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the Baglog air temperature control accuracy. As for testing the air temperature level of Baglog, whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile testing the accuracy of the temperature produced by the Baglog air temperature control system is to compare it with the temperature produced by a thermometer. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. It means the Baglog environmental temperature control system has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range, the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius.

Table 4. Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor helps measure Baglog's humidity conditions, whether moist, dry, or wet (see Table 5). If the humidity measurement value is below 300, Baglog is wet. If the sensor measurement value is between 300 to 700 it indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest

error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

Table 5. The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

Table 6. Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

Table 7. Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

The pH sensor helps check the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of studying the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation system developed has an accuracy of up to 98.03%.

The results of the sensor system accuracy test in this study not only show the performance of the sensors used in this study but also show the superiority of this research which was not carried out by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

4.5. Implementation

The implementation stage is the stage of embodiment of oyster mushroom cultivation and an opinion survey on satisfaction and the success rate of student learning in the practice of mushroom cultivation.

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first is a Baglog container with manual control over water pH, temperature and humidity in Baglog. In contrast, the second is the Baglog container, with the management of water pH, temperature, and humidity controlled by a developed hardware and software system.

Figure 6. Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7. Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is

controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size for example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and moisture in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is 27 days old

Figure 10. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 11. Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when at the age of one month 15 days

Figure 12. Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of one month and three days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature, and humidity in Baglog, is proven to bring significant benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods [17]. An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future.

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated have the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom

production) in the future, as doubted by previous researcher Okuda [14].

Table 8. Students' satisfaction with practicum learning

Students Perception	Students' satisfaction with learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

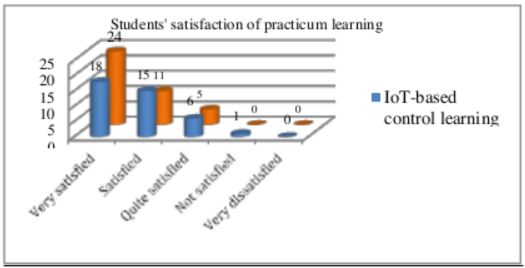

Figure 13. Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in numbe	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

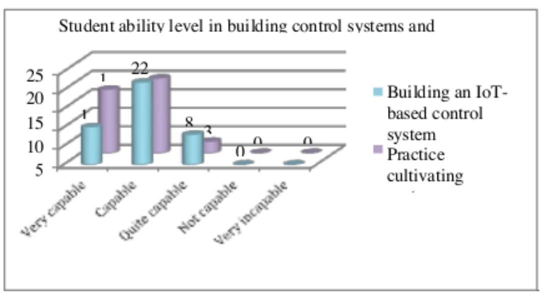

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

4. Conclusion

This research educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students have the ability to build an IoT-based control system and demonstrated proficiency in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system; Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies. Besides that the study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. Another novel scientific finding in this study is the elimination of the dark side of stagnation in mushroom production to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is its aim to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done. The drawback of this research is that students practice learning only about cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

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Practical Learning to Build an IoT-Based Oyster Mushroom Control and Cultivation System and Its Learning Effects for Students

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Even though the Internet of Things (IoT) has become a research concern in education, the learning media in IoT is still minimal, and IoT-based research for education is still limited. It means the learning media and research of IoT in student education are still challenging for researchers. In the meantime, mushroom cultivators do not understand what actions must be considered when cultivating mushrooms. Besides that, oyster mushroom cultivation also often fails due to Baglog's environmental conditions, which do not support the cultivation of oyster mushrooms. Also, by remembering, the development of educational technology has demanded efforts to use technology as a learning medium in learning. Therefore this study aims to develop an IoT-based control system for oyster mushroom cultivation as a student practical lesson media and its learning effects for students. The stages of developing a control system and cultivating oyster mushrooms in this study use the Waterfall model. This research method combines experimental, surveys, and observation procedures. This research succeeded in carrying out educational activities with results that satisfied students and made most students able to build an IoT-based control system and cultivate oyster mushrooms. This study found that the growth of oyster mushrooms whose Baglog environment was managed by an IoT-based system automatically grew faster, and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods. This study's findings also remove the dark side of concerns about the continuation of oyster mushroom production by previous researchers.

KEYWORDS

practical learning, control system, cultivating oyster mushrooms, internet of things, education technology

1. Introduction

Education is increasingly moving toward the digital age (Rohles, Backes, Fischbach, Amadieu, & Koenig, 2022; van Laar, van Deursen, van Dijk, & de Haan, 2017). Currently, digital technology plays a dominant role in facilitating the learning process (Srivastava & Dey, 2018). Previous research has also shown that students react positively to digital technology-based learning processes (Jones & Shao, 2011). Meanwhile, IoT, one of the digital technology innovations, has become a research concern in the field of education and the application of the latest technology (Madni et al., 2022). IoT technology is developing rapidly, and its benefits can be highly accurate in various fields in real-time (Malik, Dedeoglu, Kanhere, & Jurdak, 2019; Powell, Foth, Cao, & Natanelov, 2022).

IoT technology utilization allows control to be done automatically and monitored from anywhere (Kumar et al., 2022) and supports heterogeneous automation models (Li, Zhang, Fei, Shakeel, & Samuel, 2020). But unfortunately, the learning media of IoT in education is still tiny, and IoT-based research for education is still limited (Madni et al., 2022). In other words, the application of IoT in education is still a challenge for researchers. Or in other words, the application of IoT in education is still a challenge for researchers. Moreover, the learning, whether producing satisfactory competencies, are essential (Xue, Xu, Wu, & Hu, 2023).

In the meantime, cultivating mushrooms often faces problems/difficulties for beginners, how to make it happen, and what needs to be paid attention to when cultivating mushrooms to be successful (Anamosa, 2021). Besides that, the failure of oyster mushroom cultivation is often due to the Baglog environment condition, which does not support the growth of oyster mushrooms (Suada, Sudarma, Kim, Cha, & Ohga, 2015). It means that the learning media for learning oyster mushroom cultivation and automatic control of environmental conditions in Baglog oyster mushroom cultivation is necessary. Moreover, educational activities for developing mushroom production are essential for the future sustainable development of mushroom production (Okuda, 2022). In addition, the development of educational technology has encouraged efforts to continuously update the use of technology as a learning medium in learning. In other words, advances in educational technology have demanded that school teachers use technology as learning media to improve the quality of delivering teaching information in the learning process (Ediyani et al., 2020). Besides that, in teaching students how to achieve these skills is a teaching practice challenge (Adıgüzel, Aşık, Bulut, Kaya, & Özel, 2023). Therefore, this study aims to build a learning media device for students based on IoT digital technology to cultivate oyster mushrooms and its learning effects for students.

IoT is the future communication technology equipped with a microcontroller (Atzori, Iera, & Morabito, 2010). IoT technology has replaced the traditional method (Puliafito, Mingozzi, Longo, Puliafito, & Rana, 2019). IoT can monitor and control other equipment and support the realization of intelligent systems in various fields, including education, health, and the environment (Arasteh et al., 2016; Pardini, Rodrigues, Kozlov, Kumar, & Furtado, 2019; Raaijen & Daneva, 2017; Sumi & Ranga, 2016). Besides that, the advantage of IoT is that it allows combining various other technologies to create effective and efficient models (Ou & Xie, 2012). As a result, IoT has received significant attention worldwide as an advanced information technology revolutionary (Jiang, Yang, Xu, Song, & Zheng, 2019). Moreover, the advancement of IoT technology provides a lot of research space for improvements in usage practices in developing digital learning media devices (Sun, 2022). As a result, teaching media devices has become a significant concern for colleges today (Liu, Wang, & Xiao, 2021).

This study uses a microcontroller integrated circuit to embody the built system hardware control. The microcontroller is a microcomputer to carry out the desired operations according to the developed computer program and other supporting hardware. Microcontrollers usually use sensors to control and monitor controlled or monitored environments (Babiuch, Foltynek, & Smutny, 2019). Microcontrollers are primarily for control, wireless, and automation systems (Salah & Zneid, 2020). The microcontroller type chosen to develop a one hundred percent control system is tailored to the needs.

The microcontroller used is NodeMCU ESP32. The ESP32 microcontroller supports web servers and real-time work (Allafi & Iqbal, 2018). In addition, nodeMCU ESP32 is a combo system-on-chip microcontroller with low power consumption and cost (Fabregat, Belloch, Badia, & Cobos, 2020; Tueche et al., 2021). Besides that, the ESP32 microcontroller facilitates dual-mode blue tooth, large-capacity flash memory, and other interfaces (Babiuch et al., 2019). Another advantage of NodeMCU ESP32 is that it has the best Radio Frequency (RF) capability and performance (Fezari & Zakaria, 2019). The ESP32 microcontroller is the successor of the ESP8266 microcontroller. Moreover, this ESP32 microcontroller provides an in-chip wifi module, so this microcontroller support to creation IoT application system.

In the meantime, Oyster mushrooms are widely cultivated worldwide (Royse, 2012) and as edible mushrooms (Melanouri, Dedousi, & Diamantopoulou, 2022; Törős, El-Ramady, & Prokisch, 2022). Oyster mushrooms can be cultivated in many growing media, such as straw, sawdust, and rice husk (Pathmashini, Arulnandhy, & Wijeratnam, 2009). Oyster mushroom is a favorite food because of their protein nutritional content as an immune boosting drug (El-Ramady et al., 2022; Raman et al., 2021), its taste (Jongman, Khare, Loeto, & Behari Khare, 2018; Raman et al., 2021) and contains lots of fiber, minerals, vitamins (Feeney et al., 2014; Raman et al., 2021), carbohydrate, and essential amino acids (Raman et al., 2021). In addition, oyster leaves are an important source for the human diet, antiinflammatory, antidiabetic, antifungal, antiviral, and antibacterial (Törős et al., 2022; Zawadzka et al., 2022). It means the increase in oyster mushroom yields presents a solution to overcome malnutrition in most developing countries (Jongman et al., 2018). However, due to the lack of technological knowledge in mushroom cultivation, research on mushroom cultivation is necessary (Girmay, Gorems, Birhanu, & Zewdie, 2016).

Oyster mushrooms can grow at temperatures between 18 to 30°C as well as the rapid growth of mycelium and substrate colonization (Girmay et al., 2016; K. Dhanalakshmi & V. Ambethgar, 2021; Sulistyanto et al., 2018), and the environment moist or not dry and not wet (Sulistyanto et al., 2018). Other researchers have also confirmed that humid environments positively affect fungal growth and colonization (Jongman et al., 2018; Nongthombam et al., 2021). Generally, suitable temperatures range from 25-30 °C (Jongman et al., 2018) and 20-30 °C (Nongthombam et al., 2021). The pH concentration of the fungus is slightly acidic to slightly alkaline (Chang, 2007). The suitable pH for the growth of oyster mushrooms is around 5.5 and 6.5 (Sultana, Hossain, Saifullah, Amin, & Chakraborty, 2018). Watering conditions on Baglog mushroom seeds daily with a specific frequency create humidity conditions. Baglog's environment becomes humid by spraying water three times daily and lighting around 300-500 lux (Sultana et al., 2018).

This study developed a learning model to monitor fertility levels from Baglog (mushroom seedling container) based on the content pH (or power of Hydrogen), humidity, and temperature of Baglog from oyster mushroom cultivation. The embodiment of the IoT-based learning model for oyster mushroom cultivation developed in this study is a miniature model. The learning model developed is a learning medium for students to cultivate oyster mushrooms and a learning platform for students to build an IoT-based control system. In essence, in order for the cultivation of oyster mushrooms to be successful or for the mushrooms to grow fertile (quality), it is necessary to pay attention to the environmental conditions (pH, temperature, and humidity) of Baglog. Generally, Baglog's environmental conditions in mushroom cultivation are usually only done by oyster mushroom farmers based on estimates and just experience. In contrast, as the oyster mushroom cultivation learning miniature device in this study, the IoT system will automatically control the Baglog's environmental conditions so that Baglog's pH, temperature, and humidity are controlled. This research aims to provide hands-on practical learning for students to build IoT-based control systems and cultivate mushrooms based on the latest technology. In addition, a further implication of the results of this study is that the built miniature model is helpful as an example of a learning model for students about building IoT control circuit systems in mushroom cultivation and student practice, media directly in mushroom cultivation.

Although there are relatively many previous studies related to mushroom cultivation, including research by Lu, Liaw, Wu, & Hung (2019), Ediyani et al. (2020), Nongthombam et al. (2021), Zawadzka et al. (2022), and Okuda (2022), none of them aim to be educational media tools for students as this research. Besides that, a previous study by Sulistyanto et al. (2018) and Desnanjaya and Sugiartawan (2022) on oyster mushroom cultivation, even though it was based on IoT, has the limitation of not controlling the pH of Baglog water, but only controlling humidity and temperature of Baglog. Besides that, this previous research is not a prototype model for learning media and practices for students in building IoT and learning media for mushroom cultivation, as this article does. Besides that, previous studies, including the research conducted by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah, Savitri, & Novijanto, 2022) and (Melanouri et al., 2022), had the limitation of not testing the accuracy of the sensor system used, while this research completes the accuracy test of the sensors used. In short, the articles in this study are novel and unique compared to other articles. Besides that, this research makes an important contribution as a learning medium for students and can be practiced in the community for mushroom cultivation for farmers.

The rest of the discussion structure in this paper is: the second sub-section describes related works, whereas the third subsection discusses the research method. The fourth subchapter reveals the results of the research and its discussion. Finally, the fifth sub-section is the Conclusion, which presents research findings, novelties, and suggestions for further study.

2. Related Works

Sulistyanto et al. (2018) proposed using Fuzzy Logic to control the temperature and humidity of oyster mushrooms (Sulistyanto et al., 2018). However, this previous research did not test the temperature and humidity of system accuracy as the research in this article. Besides that, the prior research was not equipped with control over Baglog pH. Furthermore, the microcontroller used in the previous research is not the same type as the microcontroller used in this study. In addition, the difference between the previous research and the research in this article is that the previous research was not intended as a medium for student learning in mushroom cultivation as the research in this article (previous research did not asses the learning achievement of students in mushroom cultivation learning).

Meanwhile, Lu (2019) proposed a system for estimating the growth rate of fungi through the size and number of fungi-based deep-learning convolutional neural networks (Lu, Liaw, Wu, & Hung, 2019). Even though previous research has the same focus as the research in this article, namely related to mushroom cultivation, this earlier research proposed a system to estimate the speed of mushroom growth through the size and number of mushrooms. In contrast, the research in the article in this study tested the success of mushroom cultivation by automatically controlling the environmental conditions of Mushroom Baglog. So this previous research did not have the same aims and methods as this article's. Eliyani et al. (2020) explained the vital role of learning media in developing science (Ediyani et al., 2020). Previous research has different research methods and objectives from the research in this article. Previous research reviews existing research related to the development of learning media. The object of research in the previous article is not related to oyster mushroom cultivation and is not related to the use of IoT technology as research in this article.

Jenita Nongthombam et al. (2021) reviewed the factors that cause disease in oyster mushrooms and effective ways to overcome them (Nongthombam et al., 2021). The previous research had different methods and objectives than the research conducted in this article. The previous research was review research, while the research in this article is experimental. Besides that, prior research is not a study for learning models as the research carried out in this article. Meanwhile, Liu (2021) proposed an online management platform structure to manage classroom usage based on IoT technology. This previous research has the same concern in developing IoT-based system devices as the research in this article. The difference lies in the objectives, objects, and research methods. This previous research was unrelated to oyster mushroom cultivation and did not build IoT devices except propose a design model for controlling class management.

Zawadzka et al. (2022) conducted a study on the effect of light on the retention of vitamins, minerals, and polyphenols in the stems and caps of cultivated oyster mushrooms (Zawadzka et al., 2022). The difference between this previous research and the research in this article is in the purpose of the study. The previous study was not building a learning media on how to cultivate oyster mushrooms based on IoT, as in the article in this study, but rather evaluating the effect of cultivation on vitamins and minerals from oyster mushrooms. Meanwhile, Desnanjaya and Sugiartawan (2022) proposed a tool controlling temperature and humidity in oyster mushroom cultivation based on Arduino UNO (Desnanjaya & Sugiartawan, 2022). However, this previous research did not test the system's pH, temperature, and humidity accuracy like the research in this article. Furthermore, the type of microcontroller used in this previous study differs from the type of microcontroller used. In addition, the difference between previous research and research in this article is that previous research was not intended as a medium for student learning in mushroom cultivation and how to build (practice) IoT-based control systems, as researched in this article.

Nadzirah et al. (2022) conducted training on oyster mushroom cultivation for students. This study provides training on the prospects for oyster mushroom cultivation (Nadzirah, Savitri, & Novijanto, 2022). Thus this previous study is very different from this research which built a system for automatic control of the Baglog oyster mushroom environment and practicing oyster cultivation, which was not present in the previous study. In contrast, Sun (2022) proposed a digital media content creation system concerning advances in IoT technology, the Web, and fuzzy control (Sun, 2022). This previous research has different methods, objectives, and objects studied compared to the research in this article. The similarity of prior research with this research lies only in the importance of the embodiment of a design system based on IoT technology. In the meantime, Okuda (2022) reviews the future sustainability of mushroom cultivation or production (Okuda, 2022). This previous research and the research in this article both focus on the development of mushroom cultivation but are entirely different in topic, objectives, and research methods.

TABLE 1 Comparison between Latest Prior Related Work and this Article

Research by	Research Method	Use/Build Control System IoT				IoT Controller Type	System Accuracy test	Aims as Learning Media	Mushroom cultivation nursery trials	Description
		IoT	Sensor							
			pH	Humidity	Temperature					
Sulistyanto et al. (2018)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Proposed the use of Fuzzy Logic to control the temperature and humidity of oyster mushrooms
Lu (2019)	System Design	No	No	No	No	None	No	No	Yes	Proposed a system that can predict the growth rate of mushrooms by measuring the size and calculating the number of mushrooms to use deep learning convolutional neural networks
Ediyani et al. (2020)	Review	No	No	No	No	None	No	No	No	Describe the importance of learning media in developing knowledge
Nongthombam et al. (2021)	Review	No	No	No	No	None	No	No	No	Reviewing the causative factors and how to control oyster mushroom disease.
Liu (2021)	System Design	Yes	No	No	No	None	No	No	No	Proposed an IoT-based class management embodiment that can control classroom utilization.
Zawadzka et al., (2022)	Evaluation	No	No	No	No	None	No	No	No	Evaluating the effect of light on mushroom cultivation on retention of vitamins, minerals, and polyphenols.
Desnanjaya and Sugiartawan (2022)	Experiment	Yes	No	Yes	Yes	Arduino Uno	No	No	No	Made a tool to monitor the temperature and humidity of oyster mushroom cultivation based on Arduino UNO.
Nadzirah et al. (2022)	Theory and Training	No	No	No	No	None	No	Yes	No	Conduct training on prospects for oyster mushroom cultivation
Sun (2022)	System Design	Yes	No	No	No	None	No	No	No	Analyzing the creation of digital media content by utilizing IoT
Okuda (2022)	Review	No	No	No	No	None	No	No	No	Reviewing the sustainable side of sustainable mushroom cultivation or production in the future
Our/this research	Experiment, Survey and Observation	Yes	Yes	Yes	Yes	ESP32	Yes	Yes	Yes	Our research builds IoT-based learning media for oyster mushroom cultivation

A review of several recent related works shows that this research differs from previous research; specifically, the research model used combines experimental and survey procedures. Likewise, this study conducted field trials and accuracy tests on learning model devices built to control pH, humidity, and temperature in Baglog oyster mushroom cultivation. Another novelty of this research is that the system model produced is a miniature model of student learning media in mushroom cultivation and a learning model for building an IoT-based control system (see Table 1).

3. Methods

This research combines experimental, survey, and observation methods. The sequence of stages of the system design development of learning media devices for oyster mushroom cultivation based on the IoT used in this research is the Waterfall model. The waterfall model is a management model for developing systems (Anggrawan, Mayadi, Satria, & Putra, 2022; Dima & Maassen, 2018). The process stages in the Waterfall model are sequential from the beginning to the next step (Bassil, 2012). The waterfall model process consists of five stages: requirement analysis, design, development, testing, and implementation, as shown in Figure 1 (Anggrawan, Mayadi, et al., 2022).

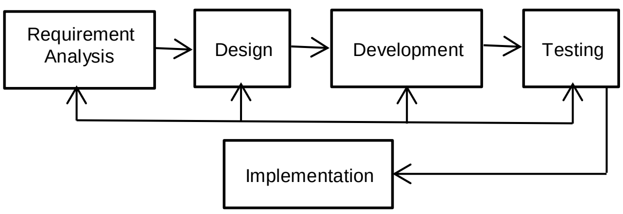

Figure 1. The Waterfall model of system development in this study

3.1. Research Design

The IoT control system for cultivating oyster mushrooms in this study has automation to control the pH of the water and maintain the stability of Baglog's temperature and humidity at all times. This automation occurs in collaboration with the system microcontroller designed in this study. The main component of the microcontroller system in this study is ESP32. In addition, ESP32 has Wifi and Bluetooth facilities (Anggrawan, Hadi, & Satria, 2022).

The programming languages used are C++ and PHP in this research. Although various programming languages exist (Anggrawan, Satria, Mayadi, & Dasriani, 2021), each offers its advantages in application development programs (Anggrawan, Mayadi, et al., 2022; Anggrawan, Nuraini, Mayadi, & Satria, 2021). The PHP coding language enables the embodiment of Web-based application programs (Anggrawan, Satria, Nuraini, et al., 2021). The coding program of the C++ programming language in this study plays a role in controlling the work of the microcontroller hardware in controlling the work of all hardware supporting the work of sensors, lights, fans, and water pumps. In contrast, the PHP coding program played a role in the embodiment of the IoT system in this study; in this case, the water pH level, temperature, and humidity of Baglog can be monitored via the website or via the internet anytime and anywhere by a computer monitoring unit via the internet. C++ and PHP are popular programming languages used. Each computer programming language has its advantages in building application programs.

3.2. Research Participants and Survey

This study surveyed to collect quantitative data ordinal. The survey data samples were 40 practicum class students, semester 6, 2021/2022 academic year, in the Informatics Technology study program at Bumigora University, Indonesia. The survey instrument in this study used a Likert measurement scale which consisted of gradations from very satisfied to very dissatisfied and very capable, and very incapable. The survey was conducted to get students' opinions on learning to build IoT-based control hardware or on learning media for oyster mushroom cultivation, as well as, at the same time, knowing the level of student learning success through the learning media built in this study. In short, a survey questionnaire was intended to measure the effectiveness of student learning outcomes in building IoT systems and in oyster mushroom cultivation.

4. Results and Discussion

4.1. Requirement Analysis

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system can monitor pH, humidity, and temperature levels. Then the system built can neutralize abnormal pH, temperature, and humidity to normal (meet the requirements). It means that this research requires an intelligent or innovative application of system hardware control. The smart application built with the PHP programming language is to realize an IoT system, namely data on water pH, temperature, and humidity in Baglog, so that it can be monitored from a computer monitor anywhere via the internet.

Meanwhile, the C programming language regulates the work of sensor hardware and other devices on the NodeMCU ESP32 microcontroller in the system to control pH, temperature, and humidity in Baglog oyster mushroom cultivation. Through the ESP32 microcontroller, the C programming language application program built and installed in it detects the pH, humidity, and temperature level of Baglog oyster mushrooms produced by three sensors. The sensor inputs' pH, humidity, and temperature levels are the reference for the control program in the microcontroller to determine the pH of fertilizer or water for spraying Baglog Mushrooms and to stabilize Humidity and Temperature on Baglog Mushrooms. The best pH level in oyster mushroom cultivation is 5.5-6.5 with humid Baglog conditions and an ambient temperature of 18-30°C.

4.2. Design

Figure 2 shows the method or stages of the student learning process in designing/building an IoT Baglog mushroom control system and cultivating oyster mushrooms. First, the lecturer directed students on how to build hardware and control software for mushroom cultivation; then, the lecturer described to the students step by step how to cultivate mushrooms, starting from the oyster mushroom Baglog prototype until the mushrooms were ready for harvest.

Then students in groups under the guidance of lecturers realize a miniature model of an IoT-based control system in cultivating oyster mushrooms. Briefly, the stages or learning models for students in developing IoT microcontroller technology and oyster mushroom cultivation, including knowing student learning success or student opinion responses to learning outcomes in this study, are shown in Figure 3.

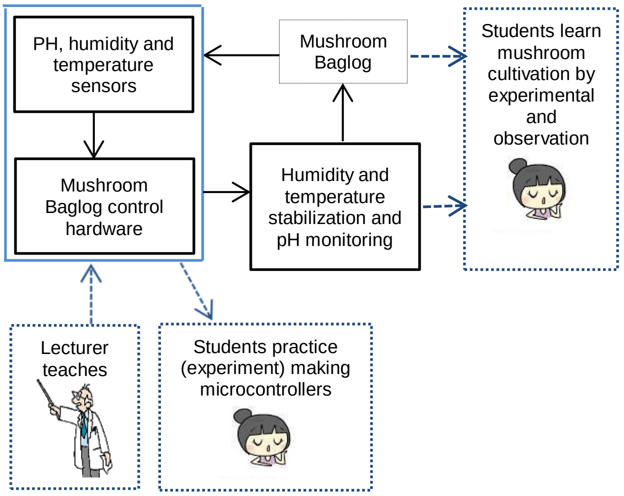

Figure 2 The stages of the student learning process in building the Baglog IoT system and cultivating oyster mushrooms

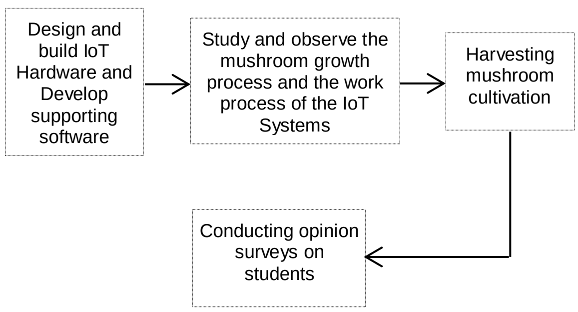

Figure 3 Learning Stages of IoT Design and Mushroom Cultivation for Students

4.3. Development

At the development stage, the researcher built a hardware prototype of the oyster mushroom Baglog control system and demonstrated its construction to students. Table 2 shows the software requirements in this study. Meanwhile, Table 3 shows hardware requirements. The embodiment of the hardware in this study includes the design block diagram followed by a circuit board schematic design to control and facilitate Baglog's environmental needs automatically and monitor Baglog's environment, both pH, temperature, and humidity Baglog. Figure 4 and Figure 5 show the block diagram and circuit diagram of the IoT Microcontroller hardware for oyster mushroom cultivation.

TABLE 2 Required software

Software	Function
Arduino IDE (Integrated Development Environment) Software	Serves as a media editor for writing, compiling, and uploading the coding program that is built into the microcontroller board.
C++ and PHP computer language (coding program)	As a programming language for building application programs (coding programs) whose role is to regulate the work of circuits and hardware sensor systems to work as desired

TABLE 3 Required hardware

Device	Amount	Type/Specification	Function	Image
Humidity Unit	1	Moisture sensor FC-28 LM393 based design voltage: 3.3V-5V DC, Soil Probe dimension: Approx. 6cm x 3cm Board size: 3cm x 1.5cm	Detects humidity levels in the Baglog environment (hygrometer) or is a humidity sensor module	
pH Sensor unit	1	pH Electrode E201-BNC, Operating voltage: 3.3V-5V DC, Range: 0- 14PH, Resolution: ±0.15PH, Response time: ＜1s, Measure temperature: 0-60°C	Serves to detect the pH level (Read the pH value of the water used watering the baglog)	
Temperature sensor	1	DS18B20, Operating voltage: 3V-5.6V DC. Conversion time: < 750ms, temperature range: -55 to 125^0C, current consumption: 1 mA	As a digital temperature sensor to measure air temperature	
Water pump	1	A submersible pump, working voltage: 3-5V DC, Current Consumption: 120-330 mA	Pumping water to pour into the mushroom baglog oyster	
DC Fan	1	Li-ion battery fan, Input voltage 5V, Input current 0.5-1A	used for cooling air temperature	
DC light	1	Operating voltage: 5V DC	Useful for raising the air temperature	
Controller	1	ESP32, Xtensa dual-core, 32-bit LX6 microprocessor, 520KB SRAM, Wifi 802.11 b/g/n	As a controller for hardware to function in accordance with built software	

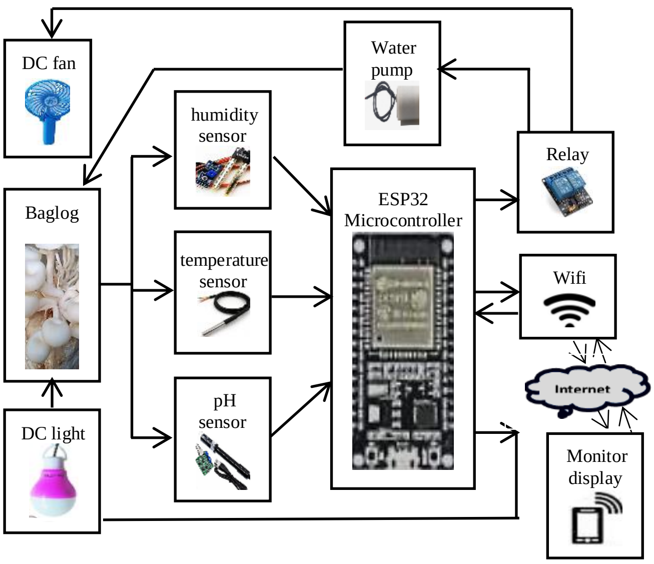

Figure 4 Block Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

The system hardware works as follows: the display monitor (computer monitor screen) displays the level of water pH, temperature, and humidity in Baglog. Devices/computers used as monitors can monitor from anywhere and at any time because the information from the pH, temperature, and humidity sensors in the ESP-32 microcontroller hardware unit is forwarded via internet wifi to be received by the monitor computer (IoT-based). When the microcontroller receives abnormal temperature sensor data (not according to the desired temperature reference), the microcontroller will turn on the fan to reduce the temperature level in Baglog or turn on the lights to increase the temperature in the Baglog environment. Likewise, if the humidity in Baglog is abnormal (out of the proper reference or Baglog has reduced water content), the microcontroller will spray water to increase Baglog humidity. Likewise, for the pH of the water, when the pH of the water used to water Baglog does not meet the requirements, stabilization of the pH of the water is carried out by renewing the Baglog spraying water whose pH meets the requirements.

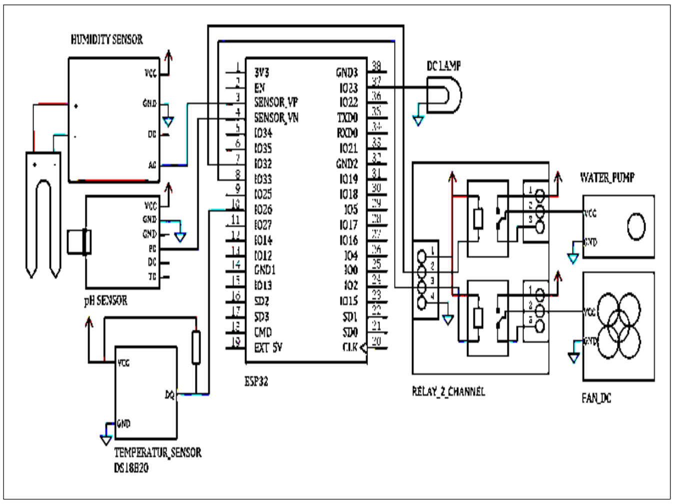

Figure 5 Circuit Diagram of IoT Microcontroller Hardware for Oyster Mushroom Cultivation

4.4. Testing

The requirement analysis stage is the stage of determining the research or system requirements. The designed system is IoT-based, where the system is able to monitor pH, humidity, and temperature levels, and then the system built can neutralize abnormal pH, temperature, and moisture to normal (meet the requirements). It means that this research requires an intelligent or smart.

The testing phase is the trial stage of the hardware prototype and the application program of the oyster mushroom Baglog control system that was developed. The results of the trials show that the system hardware and software systems can work according to design to control Baglog humidity and temperature and monitor the pH of Baglog water. The system works successfully at the desired Baglog temperature and moisture. When the temperature increases, the fan works, and the fan stops working when the temperature reaches the desired temperature level. Conversely, when the humidity in Baglog is low (dry), the system will drive a water pump to water Baglog.

The test results also show that the developed system controls Baglog water's pH well. This means that the pH of baglog water is controlled at the appropriate pH level. Table 4 shows the results of the work test of the Baglog air temperature control system and the results of the Baglog air temperature control accuracy test results produced by the developed system. As for testing the air temperature level of Baglog whether it works at the desired temperature level by looking at the temperature displayed on the display monitor from the computer monitoring system unit.

Meanwhile, testing the accuracy of the temperature produced by the Baglog air temperature control system is by comparing the temperature produced by the temperature control system Baglog with the temperature generated by the thermometer temperature gauge. The highest error in measuring ambient temperature in Baglog is 7.14%, and the lowest error in measuring environmental temperature Baglog is 0%. This means that the Baglog environmental temperature control system on the oyster mushroom cultivation control system developed has an accuracy of up to 92.86%.

Based on the test results of Baglog's environmental temperature range in this study shows that the temperature control system hardware developed in this study works well and manages to regulate Baglog's environmental temperature range between 26 to 29 degrees Celsius. Or still in the best temperature range in oyster mushroom cultivation.

TABLE 4 Temperature control system test results

No	Thermometer temperature	Baglog temperature	Error	Being in the best temperature range in mushroom cultivation
1	29°C	28°C	3.45%	Yes
2	29°C	29°C	0.00%	Yes
3	28°C	27°C	3.57%	Yes
4	28°C	26°C	7.14%	Yes
5	26°C	26°C	0.00%	Yes
6	28°C	27°C	3.57%	Yes
7	26°C	26°C	0.00%	Yes
8	28°C	27°C	3.57%	Yes
9	26°C	26°C	0.00%	Yes
10	27°C	26°C	3.70%	Yes
….	….	….	….	….
27	29°C	28°C	3.45%	Yes
28	28°C	26°C	7.14%	Yes
29	28°C	27°C	3.57%	Yes
30	27°C	27°C	0.00%	Yes

The FC-28 moisture sensor is useful in measuring Baglog's humidity conditions, whether it is moist, dry or wet (see Table 5). If the humidity measurement value is below 300, it means that Baglog is wet. If the sensor measurement value is between 300 to 700 indicates that the Baglog is moist. Meanwhile, if the humidity sensor is above the value of 700, it means it shows Baglog is dry and requires watering. Table 6 shows the results of testing the working of the Baglog humidity control system and the results of testing the accuracy of the Baglog humidity regulator produced by the developed system. The condition of the moisture of the oyster mushroom Baglog is damp or works at the required humidity, namely not dry and not wet (see Table 6). The highest error in measuring humidity level in Baglog is 4.00%. In other words, the humidity control system in the oyster mushroom Baglog environment that was developed has an accuracy of 96.00%.

TABLE 5 The relationship between the analog value of the moisture sensor and Baglog humidity conditions

Analog value of Moisture sensor FC-28	Baglog humidity conditions
Under 300	Wet
300 to 700	Moist
Over 700	Dry

TABLE 6 Humidity control system test results

No	Moisture meter	Baglog Moisture	Error	Baglog humidity conditions
1	415	409	1.45%	Moist
2	330	323	2.12%	Moist
3	390	388	0.51%	Moist
4	385	376	2.34%	Moist
5	430	419	2.56%	Moist
6	330	323	2.12%	Moist
7	320	309	3.44%	Moist
8	425	415	2.35%	Moist
9	410	409	0.24%	Moist
10	435	430	1.15%	Moist
….	….	….	….	….
27	385	382	0.78%	Moist
28	325	312	4.00%	Moist
29	480	377	0.79%	Moist
30	405	400	1.23%	Moist

The pH sensor is useful for checking the pH level used to water the oyster mushroom Baglog. Table 7 shows the results of checking the water pH level of the control system developed. The pH level of the water used to water the oyster mushroom Baglog works at the pH level required for oyster mushroom cultivation (see Table 7). The highest error in measuring the water pH of Baglog is 1.97%. It means that the water pH control system on the oyster mushroom cultivation control system developed has an accuracy of up to 98.03%.

TABLE 7 Test results of the control system on the water pH level

No	pH meter (EZ9901)	Water pH	Error	Water pH level
1	5,89	5.83	1.02%	At the desired pH level
2	5,87	5.84	0.51%	At the desired pH level
3	5,89	5.86	0.51%	At the desired pH level
4	5,95	5.89	1.01%	At the desired pH level
5	5,89	5.86	0.51%	At the desired pH level
6	5,98	5.92	1.00%	At the desired pH level
7	6,02	5.94	1.33%	At the desired pH level
8	5,97	5.91	1.01%	At the desired pH level
9	5,96	5.95	0.17%	At the desired pH level
10	6,08	5.96	1.97%	At the desired pH level
….	….	….	….	….
27	6,14	6.03	1.79%	At the desired pH level
28	6,21	6.12	1.45%	At the desired pH level
29	6,13	6.06	1.14%	At the desired pH level
30	6,05	5.97	1.32%	At the desired pH level

4.5. Implementation

4.5.1. Oyster mushroom cultivation

The main implementation stage is the oyster mushroom cultivation stage. The implementation of oyster mushroom cultivation was carried out in two different containers or baglogs. The first Baglog container is Baglog with manual control over water pH, temperature and humidity from Baglog. In contrast, the second Baglog container is Baglog with the control of water pH, temperature, and humidity Baglog which is controlled by the developed hardware and software system.

Figure 6 Baglog container with manual control over water pH, temperature, and humidity of Baglog

Figure 7 Baglog container with automatic control over water pH, temperature, and humidity of Baglog by developed hardware and software systems

Figure 6 shows a Baglog container with manual control over water pH, temperature and humidity while Figure 7 shows a Baglog container with automatic control over water pH, temperature and humidity Baglog with a hardware and software system developed. Meanwhile, Figures 8, 9, 10, 11, and 12 visually compared the development of oyster mushroom growth in Baglog between Baglog containers with manual control and automatic control over the water pH, temperature, and temperature humidity of Baglog. It is clear visually that the growth of oyster mushrooms whose Baglog is controlled by an automated IoT-based system is growing faster (faster harvest time). Besides that, the mushroom size For example, in terms of the speed of growth of oyster mushrooms, it takes one to get the size of the mushrooms that grow the same size, with manual control over water pH, temperature, and humidity in Baglog one month or 30 days.

In contrast, automatic control over water pH, temperature, and humidity in Baglog takes 27 days (see Figures 8 and 9). Another example: the speed of mushroom growth until ready for harvest by manually controlling water pH, temperature, and humidity in Baglog takes one month and 15 days. Whereas automatically controlling water pH, temperature, and humidity in Baglog takes only one month and three days (see Figures 11 and 12).

Figure 8 Oyster mushroom growth with manual control of water pH, temperature, and humidity in Baglog when it is one month old

Figure 9 Oyster mushroom growth with automatic control of water pH, temperature and humidity in Baglog when it is 27 days old

Figure 10 Oyster mushroom growth with automatic control of water pH, temperature and humidity in Baglog when it is 1 month old

Figure 11 Oyster mushroom growth with manual control of water pH, temperature and humidity in Baglog when at the age 1 month 15 days

Figure 12 Oyster mushroom growth with automatic control of water pH, temperature, and humidity in Baglog when at the age of 1 month 3 days (ready to harvest)

In short, by processing Baglog oyster mushrooms with IoT-based automatic control of water pH, temperature and humidity in Baglog, it is proven to bring important benefits for the community to be more successful in oyster mushroom cultivation. This finding reinforces the opinion of previous researchers that IoT technology has replaced traditional methods (Puliafito et al., 2019). An important implication of this research is to provide scientific certainty that mushroom cultivation with an IoT-based microcontroller as a bright solution creates sustainable mushroom cultivation in the future and eliminates worries of stalled oyster mushroom production in the future, as revealed by Okuda , previous researchers (2022).

4.5.2. A survey to find out the results of student practicum learning

The results of student practicum learning in building an IoT-based control system and cultivating oyster mushrooms (for one month and one week) showed that most students were very satisfied with the practical learning of building IoT and cultivating oyster mushrooms. Besides that, most of the students stated has the ability to build an IoT-based control system and also in oyster mushroom cultivation (see Table 8, Figure 13, Table 9, and Figure 14). The findings of this study succeeded in carrying out educational activities for developing mushroom production for students, which is a straightforward solution for creating sustainable mushroom production in the future. Or in other words, as a solution to solving the problem of the dark side of sustainable mushroom cultivation (mushroom production) in the future, as doubted by previous researcher Okuda (2022).

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TABLE 8 Students' satisfaction of practicum learning

Students perception	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very satisfied	18	45	24	60
Satisfied	15	37.5	11	27.5
Quite satisfied	6	15.0	5	12.5
Not satisfied	1	2.5	0	0
Very dissatisfied	0	0.	0	0

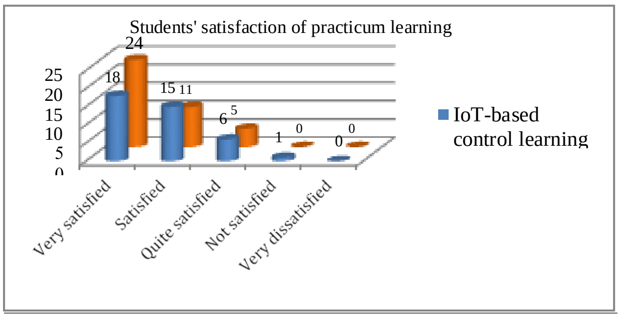

Figure 13 Students' perceptions of practicum learning to build a control system and cultivate oyster mushrooms based on IoT

Table 9. Students' ability level of practicum learning

Students Ability	Students' satisfaction in learning			
	In IoT-based control		In Cultivate oyster mushrooms	
	in number	In percent	in number	In percent
Very capable	10	25	17	42.5
Capable	22	55	20	50
Quite capable	8	20	3	7.5
Not capable	0	0	0	0
Very incapable	0	0.	0	0

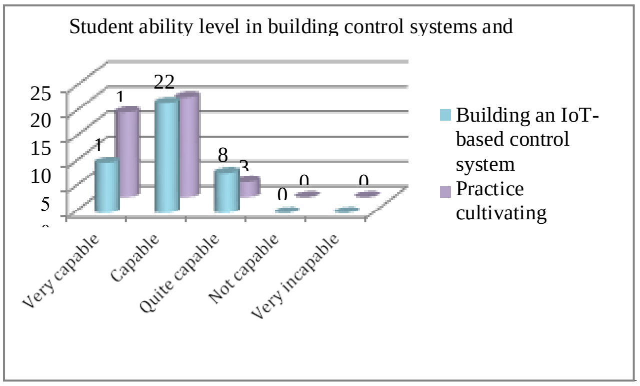

Figure 14. Students' perceptions of their ability to build an IoT-based control system and oyster mushroom cultivation

5. Conclusion

This research carried out educational activities with satisfactory results for most students who learned by direct practice (experiments) to build IoT and cultivate oyster mushrooms. In addition, most students stated that most students have the ability to build an IoT-based control system and also in oyster mushroom cultivation. Up to 45% of students are very satisfied, and 37.5% are satisfied with practical learning to build an IoT-based control system. Meanwhile, as many as 15% of students are quite satisfied learning to practice IoT-based system control. Student satisfaction in learning the practice of oyster mushroom cultivation is as much as 60% very satisfied, 27.5% satisfied, and as much as 15% quite satisfied.

In contrast, up to 25% of students are very capable, and 55% are capable of practical learning to build an IoT-based control system. Meanwhile, as many as 20% of students are quite capable of practical learning to build IoT-based system control. Student capability in learning the practice of oyster mushroom cultivation is as much as 42.5% very capable, 27.5% capable, and as much as 15% quite capable (please see Table 8).

This study found that the growth of oyster mushrooms whose Baglog was controlled by an automated IoT-based system grew faster (faster harvest), and the size of the oyster mushrooms produced was larger than Baglog whose environment was managed manually. In addition, the developed oyster mushroom cultivation environment temperature control system has an accuracy of up to 92.86%. Meanwhile, the control system built to control environmental humidity Baglog oyster mushroom has an accuracy of up to 96.00%, and the pH of the water for sprinkling Baglog oyster mushroom water has an accuracy of 98.03%.

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by (Chang, 2007), (Royse, 2012), (Feeney et al., 2014), (Sultana et al., 2018), Lu et al. (2019), Ediyani et al. (2020), Nongthombam et al. (2021), (Raman et al., 2021), Zawadzka et al. (2022), Okuda (2022), (Törős et al., 2022), (El-Ramady et al., 2022), (Nadzirah et al., 2022) and (Melanouri et al., 2022)

This study's findings reinforce previous researchers' opinion that IoT technology has replaced traditional methods (Puliafito et al., 2019). Another novel scientific finding in this study is to eliminate the dark side of stagnation in mushroom production as feared by Okuda researchers (2022) to become a certainty for sustainable mushroom production in the future. The uniqueness of this research is researching to build learning of oyster mushroom cultivation practices with an IoT-based control system that previous researchers have never done.

6. Limitations and future study

The drawback of this research is that students practice learning only on cultivating oyster mushrooms in the prototype model and only on types of oyster mushrooms. In addition, experiments were only carried out on prototype models without paying attention to the size of the place from Baglog, production costs, and tested hardware durability, all of which are suggestions for further research.

Data availability statement

The work presented here is an original work. Raw data will be provided if anyone needs it and further questions can be directed to the authors according to their fields.

Ethics statement

This study involved Information Technology study program students who took part in IoT-based control system learning practices, and all authors (lecturers and supervisors) participated in this research for publication.

Author contributions

All authors have a role in the work of this article. The order of the names of the authors adjusts to the magnitude of the role of each author. All authors approved it for publication.

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Supplementary material

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Author(s):
Anthony Anggrawan , Christofer Satria, Muhammad Zulfikri

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Author's Signature & Date

Anthony Anggrawan **Christofer Satria** **Muhammad Zulfikri** **14 August 2023**

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Re: Poslato sa sajta

12 messages

TEM Journal <temjournal@gmail.com> Tue, May 16, 2023 at 2:00 PM
To: anthony.anggrawan@universitasbumigora.ac.id

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On Sat, May 13, 2023 at 12:48 AM <anthony.anggrawan@universitasbumigora.ac.id> wrote:

> Form details below.
>
> First Name: Anthony

> Last Name: Anggrawan
> Email: anthony.anggrawan@universitasbumigora.ac.id
> Comments: Hopefully, our manuscript meets the requirements for publication in the TEM Journal

---

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id> Tue, May 16, 2023 at 6:57 PM
To: TEM Journal <temjournal@gmail.com>

Dear
Editorial Board office

Thank God that our manuscript has been forwarded to the reviewers. We hereby confirm that we are willing to pay a publication fee of 600 euros if our manuscript passes the review process and meets the journal's TEM standards.
God bless you and TEM Journal.

Sincerely yours
Anthony Anggrawan
[Quoted text hidden]

TEM Journal <temjournal@gmail.com> Tue, Jun 27, 2023 at 2:00 PM
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Dear Anthony Anggrawan,

The paper's originality is good.
We are sending you the originality report considering your paper.

Your work is currently in the process of review, and it will be finished as soon as possible.

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>
To: TEM Journal <temjournal@gmail.com>
Fri, Jun 30, 2023 at 8:34 PM

Dear
Editorial Board office
TEM Journal

Thank you for sending a file regarding the originality of our work. Thank you also that our work is currently in the review process. We hope that our articles that meet the requirements of the TEM Journal can be published in the TEM Journal. Thank you very much. God bless you and TEM Journal.

Sincerely yours
Anthony Anggrawan
[Quoted text hidden]

TEM Journal <temjournal@gmail.com>
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>
Thu, Aug 3, 2023 at 2:00 PM

Dear Anthony Anggrawan,

We have received reviewer's comments on the manuscript language and technical requests.

Throughout the review we encountered a great number of sentences that should be rephrased or expanded to enhance the clarity of the text. Please make sure that all statements are precise, complete, and well structured.
For the referencing style, please check guidelines for IEEE referencing style and it is advisable to minimize the use of author names whenever possible, although it is permissible in certain cases. Please take note of this recommendation while making revisions to the paper. In terms of sentence proficiency it would be beneficial to revise the entire paper and make changes in accordance with that.
Please ensure that all headings and subheadings in this paper and future ones are accompanied by a concise introduction or are properly introduced.

Please adjust your paper according to the comments and requests provided in the document.

Send your paper back to us within 7 days from now.

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>
To: TEM Journal <temjournal@gmail.com> Fri, Aug 4, 2023 at 10:38 AM

Dear
Editorial Board office,
TEM journal

Thank you very much for the suggestions and instructions from reviewers for our article work. We, the authors, will do our best to refine our article by referring to the comments and requests in the document. We will complete our article fix before the 7-day deadline from now. We hope our article can meet the requirements of the TEM Journal and be published in the TEM Journal. Thank you very much.
God bless you and the TEM journal.

Sincerely yours
Anthony Anggrawan
[Quoted text hidden]

Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>
To: TEM Journal <temjournal@gmail.com> Wed, Aug 9, 2023 at 11:04 AM

Dear
Editorial Board office,
TEM Journal

I inform you that I have made improvements to our manuscript following the reviewer's instructions, corrections, and suggestions. File revision notes and corrections I attach to this e-mail. Hopefully what I have done is as intended by the reviewers and meets the qualifications of the TEM Journal and the Editorial Board of the TEM journal.
Thank you very much for your kindness and concern.
God bless you and the TEM Journal.

Sincerely yours
Anthony Anggrawan
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TEM Journal <temjournal@gmail.com> Thu, Aug 10, 2023 at 1:55 AM
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Dear Anthony Anggrawan,

You have new requests from the reviewers.

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id> Thu, Aug 10, 2023 at 2:13 PM
To: TEM Journal <temjournal@gmail.com>

Dear
Editorial Board office,
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Thank you very much for the valuable additional revision suggestions from the reviewers. I have made the changes according to the instructions. Hopefully what I do is in accordance with what the reviewers intended and meets the requirements of the article from the TEM journal. I also found twin citations/references [36] and [49] (namely:
[36] J. Raman et al., "Cultivation and Nutritional Value of Prominent Pleurotus spp.: An Overview," Mycobiology, vol. 49, no. 1, pp. 1–14, Jan. 2021. dan
[49] J. Raman et al., "Cultivation and Nutritional Value of Prominent Pleurotus Spp.: An Overview," Mycobiology, vol. 49, no. 1, pp. 1–14, 2021.); I have made changes to the body text citations and reference lists so that references [49] are deleted and references [50], [51], and so on are shifted one digit down both in the reference list and citations in the body text. I apologize for the author's negligence. Thank You.
God bless you and the TEM Journal.

Sincerely yours
Anthony Anggrawan
[Quoted text hidden]

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TEM Journal <temjournal@gmail.com> Thu, Aug 10, 2023 at 11:18 PM
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Dear Anthony Anggrawan,

You cannot have more than 3 self citations.
You and co-author have 5 self citations, which is not allowed.

Please update this, and take care of structure and order of used references in the document, with correlation with numbers in the References section.

Also, this section:

This research has the advantage of testing the accuracy of the sensor system used. This advantage is not shared by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46], Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El-Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34].

It is better to be introduced in the in some other section, not in the conclusion.

The conclusion section is better to be without references.

Send your updated paper within 3 days from now.

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id> Fri, Aug 11, 2023 at 11:41 AM
To: TEM Journal <temjournal@gmail.com>

Dear
Editorial Board office
TEM Journal

As per the suggestion, I have revised my article to only have more than 3 self-citations. Quotations [56] and [57] have been removed from the list of references both in the body of the text and in the list of references and the structure and order of the references are in accordance with what they should be. We've also updated and moved the text of the sentences:
"This research has an advantage in testing the accuracy of the sensor system used. This advantage was not shared by all previous related studies, including research by Chang [45], Royse [32], Feeney et al. [39], Sultana et al. [46] , Lu et al. [47], Ediyani et al. [15], Nongthombam et al. [44], Raman et al. [36] Zawadzka et al. [40], Okuda [14], Törős et al. [49], El -Ramady et al. [37], Nadzirah et al. [50] and Melanouri et al. [34]", to another subsection (the text is highlighted in yellow in the article).
Hopefully, what has been revised is in accordance with the intentions of the Reviewers of the TEM journal and has met the qualification requirements of the TEM Journal. Thank you very much for the revision suggestions provided for the improvement of our article. God bless you and the TEM journal.

Sincerely yours
Anthony Anggrawan
[Quoted text hidden]

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id> Sun, Aug 13, 2023 at 5:52 AM
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>
Cc: anthony.anggrawan17@gmail.com

---------- Forwarded message ---------
From: **TEM Journal** <temjournal@gmail.com>
Date: Sun, Aug 13, 2023 at 12:05 AM
Subject: Re: Poslato sa sajta
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Dear Anthony Anggrawan,

Your paper titled with "Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students" **has been accepted** to be published and printed in the TEM Journal Vol.12, No.3, considering the last week of August, 2023.

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Provinsi
Nusa Tenggara Barat

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Telepon seluler
+62 08311888888

Email
anthony.anggrawan@universitasbumigora.ac.id

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Building an IoT-Based Oyster Mushroom Cultivation and Control System and Its Practical Learning Effects on Students

Author(s):
Anthony Anggrawan , Christofer Satria, Muhammad Zulfikri

Institution or Company:
Bumigora University

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Author's Signature & Date



Anthony Anggrawan **Christofer Satria** **Muhammad Zulfikri** **14 August 2023**

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Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Resi PayPal Anda

1 message

service@intl.paypal.com <service@intl.paypal.com> Mon, Aug 14, 2023 at 3:08 PM
To: Anthony Anggrawan <anthony.anggrawan@universitasbumigora.ac.id>

Halo, Anthony Anggrawan

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1 message

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Reply-To: bnicreditcard@bni.co.id
To: ANTHONY.ANGGRAWAN@universitasbumigora.ac.id

Yth. Bapak/Ibu ANTHONY ANGGRAWAN,

Terima kasih atas transaksi Bapak/Ibu.

Nama Merchant	: PAYPAL *TEMPUBLISHE
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Tanggal Transaksi	: 14/08/2023 14:08
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