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Implementation of audio biostimulators and IOT in STEM learning to enhance the quantity of herbal medicinal plants in Indonesia

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Abstract

This research aims to enhance the contribution of science learning in higher education using a Science, Technology, Engineering and Mathematics (STEM) approach to assist Indonesia's farmers' herbal medicinal plant communities. The technology implemented in this project-based learning at the Department of Natural Science Education, Yogyakarta State University is the Audio BioStimulator (ABS) and multi-sensors based on the Internet of Things (IoT). These sound waves function to open leaf stomata during photosynthesis optimizing nutrient absorption. On the other hand, IoT comprises a sensor system that measures physical variables encompassing soil composition, air quality, fertiliser concentration, pH levels, pressure and temperature. This system creates optimal conditions to foster the growth of herbal medicinal plants. The research method employed an embedded experimental design which is mixed-methods research. This method is expected to provide more comprehensive analysis results to improve critical and creative thinking skills by applying contextual STEM learning to intensify herbal medicine farming using ABS and IoT technology. These two technologies are strategic for enhancing students' competency in science practicums in higher education which can also be studied intensively in the science, engineering and mathematics aspects. The STEM approach empowers students to translate acquired knowledge and skills into direct project activities to address the challenges facing farming communities. Its instructional impact lies in elevating critical and creative thinking skills while its consequential bearing manifests in assisting the community to increase the economic status of the herbal medicinal plant farming sector in Indonesia.

Keywords: Audio bio stimulator, Farmers in Indonesia, Herbal medicinal plants, Internet of things, STEM.

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1. Introduction

1.1. Research Background

The Science, Engineering, Technology and Mathematics (STEM) approach has been used in science learning for quite a long time. The main problem is that the students find it difficult to connect various elements in STEM due to a lack of contextualised learning reinforced by relevant technological applications. Concurrently, the rapid evolution of technology, steering the course towards the Fourth Industrial Revolution underscores the necessity for educational institutions to introduce and implement contemporary advancements such as Artificial Intelligence (AI) and the Internet of Things (IoT) in their curriculum to adequately prepare students for forthcoming challenges. It is crucial to ground education by addressing tangible national issues to foster meaningful learning. Among these pressing issues in the Indonesian context is the preservation and modernization of traditional medicine.

In Indonesia, the traditional medicine industries serve as a vital source for producing and advancing safe, quality and beneficial traditional remedies [1]. Notably, Indonesian traditional medicine exports exhibited an annual growth rate of 6.49% between 2009 and 2013. Most people in many developing countries use traditional medicine [2]. Forecasts indicate a sustained increase in the market share of over-the-counter (OTC) medicines, inclusive of traditional remedies, attributable to their relatively lower prices, widespread availability and challenging financial circumstances prompting self-medication [3]. The preference for traditional medicines is driven by limitations observed in chemical treatments for specific ailments and the associated side effects, rendering traditional alternatives more favourable [4]. Moreover, the high costs associated with modern treatment along with the greater societal acceptance of traditional medicine contribute to its burgeoning use.

Efforts to modernize agricultural technology in herbal medicine cultivation currently face considerable limitations. The introduction of the Audio Bio Stimulator (ABS) device as an innovative technology for intensifying herbal medicinal plant growth emerges as a crucial asset that demands preservation combined with the essential monitoring of field conditions. Furthermore, maintaining optimal growth conditions and ensuring precise automation of electronic devices within designated timeframes becomes pivotal. Mismanagement can lead to plant dehydration under high-temperature conditions, causing leaf scorching and certain audio frequencies may attract undesirable pests. Therefore, the necessity for an IoT-based Smart Audio Bio Stimulator (ABS) device arises. The Audio Bio Stimulator (ABS) device incorporates the WeMos D1 Mini Microcontroller integrated with the ESP8266 module. ESP8266 is an add-on WiFi module for microcontrollers such as Arduino, allowing direct connection to WiFi and the establishment of TCP/IP (Transmission Control Protocol/Internet Protocol) connections. Embracing the Wireless Sensor Network (WSN) concept, the device implementation is segmented into three nodes, each equipped with sensors capturing real-time data transmitted to Firebase. The firebase streamlines application development by handling backend complexities [5]. Sensors monitor the light intensity, humidity, pressure, rainfall and temperature of herbal medicinal plants. Implementing IoT-based ABS devices in herbal medicine has demonstrated efficacy in monitoring growth processes and regulating growth-affecting variables. The control process exhibits an average delay of 2.3 seconds for application-based control and 5.3 seconds for automatic control with a data usage download averaging 1 kb per command. Consequently, it provides real-time monitoring services and intelligent control accessible anywhere. The rapid evolution of digital technology has significantly transformed the operational landscape across various organizational domains [6].

This research embodies the practical implementation of technological literacy within STEM education, specifically contextualised in pharmacy and traditional medicine, leveraging the Internet of Things (IoT). IoT, the interconnectedness enabling communication among objects, encompasses machine-to-machine and person-to-computer interactions [7]. It establishes connectivity between sensors and the internet facilitating communication among intelligent devices and individuals [8]. Integrating technology into the educational framework has revolutionized pedagogy making teaching and learning more interactive and engaging [9]. Notably, STEM education is pivotal in a nation's socio-economic fabric contributing significantly to developing a high-calibre human resource pool essential for economic progress and other critical sectors [10]. STEM education catalyzes a nation's advancements across diverse spheres through its emphasis on fostering scientific and technological literacy alongside innovative skills [11]. It is imperative to note that STEM education transcends mere preparation for careers in science and technology. Rather, it is a foundational framework for nurturing attitudes, skills and knowledge indispensable for developing versatile soft skills applicable across professional landscapes. STEM education aligns competencies with the requisites of 21st-century skills beyond enhancing technical and practical proficiencies. Critical thinking, problem-solving, analytical reasoning and creativity are essential for future careers across multifarious professional domains.

The STEM learning approach, grounded in systematic scientific methodologies surpasses the mere provision of career-centric skills. It serves as a cornerstone in cultivating students' robust knowledge foundations in science, technology, engineering and mathematics (STEM), pivotal competencies bolstering a nation's economic advancement. This proficiency in scientific fundamentals is directly applicable and relevant to future needs, thereby contributing directly to a nation's economic growth trajectory. Students are adeptly trained to engage in critical thinking, systematically strategize solutions for diverse problems and scientific phenomena within their immediate environment, methodically analyse data and adeptly tackle intricate challenges within STEM-based science education. Students acquire the requisite tools and resources to elevate a nation's global competitiveness by honing these competencies through STEM-based pedagogy.

John Dewey, a prominent figure in educational history introduced the concept of critical thinking in educational settings through his paper published in 1910 [12]. His perspective on critical thinking garnered endorsement from the concurrent development of the progressive education movement [12]. The backing for STEM education in nurturing students' critical thinking abilities has gained substantial reinforcement through extensive research [13-19]. Critical thinking skills cultivated through STEM learning are pivotal in decision-making and addressing multifaceted challenges across diverse spheres aligning closely with present-day requisites. These skills empower students to evaluate information resources effectively, adeptly analyse problems, articulate compelling scientific arguments and engage in clear, logical and systematic thought processes. Students are encouraged to scrutinize various pertinent issues, critically assess viable solutions, deepen their comprehension of subject matter and enhance their critical thinking abilities to foster creativity in problem-solving and the formulation of effective solutions within the framework of STEM learning [20, 21].

Several studies have substantiated that STEM education effectively fosters students' creativity by integrating science, technology, engineering and mathematics within the learning process [22-26]. Creativity stands as a fundamental competency for a nation's sustained leadership across diverse domains driven by the capacity to innovate and devise novel solutions to multidimensional challenges. Creative thinking grounded in the fundamental principles of science, technology, engineering and mathematics denotes the ability to generate fresh and inventive ideas or problem-solving approaches. The ability to think creatively is becoming increasingly vital in the modern economy with the disruptions of the Fourth Industrial Revolution (4IR) and Society 5.0.This skill involves perceiving problems from diverse perspectives, facilitating the exploration of innovative solutions that might otherwise remain concealed within conventional thinking frameworks. Such a mode of thinking demands strong determination and motivation to explore a spectrum of ideas, challenging preconceptions about existing problems. It should be noted that creative thinking transcends mere imagination. It revolves around generating new, original and valuable outcomes driven by individual interests ultimately geared towards enhancing societal welfare. This orientation emphasises the transformative potential of creative thinking skills in addressing contemporary challenges and advancing societal progress.

The advent of the 4IR has disrupted conventional norms reshaping the dynamics of work and education. This transformative landscape necessitates acquiring new skills for optimal innovation and societal contributions. Present-day students are urged to cultivate critical and creative thinking abilities to adapt and thrive amidst this rapid pace of change. Creative thinking involves the generation of fresh and innovative ideas or solutions, demanding an open and flexible mindset to unconventional and original ideation. This often requires thinking outside established parameters, embracing risk-taking, and challenging conventional perspectives [27, 28]. Creative thinking has progressively found application in problem-solving across diverse domains, encompassing realms such as art, design and research within scientific fields. This research specifically delineates the implementation of audio bio stimulators and IoT within STEM learning to bolster the quantity of herbal medicinal plants in Indonesia. The pedagogical impact of STEM learning manifests in enhancing critical and creative thinking proficiencies. Students engage in comprehensive problem-solving, fostering a deeper comprehension of real-world applications, particularly in enhancing both the quality and quantity of herbal medicinal plants through the integration of concepts across diverse STEM disciplines.

1.2. The Influence of Contextual STEM on Critical and Creative Thinking

In the research background, numerous studies have explored the influence of STEM learning on critical thinking and creativity. However, these studies have not explicitly delved into contextual STEM—a pivotal linkage between projects centred on herbal medicinal plants and experiential learning involving the experimental measurement of physical variables to augment the growth of these plants through audio bio stimulators. A significant gap persists in assessing the impact of contextual STEM-based scientific learning in herbal medicinal plants using IoT technology on the critical and creative thinking skills of aspiring teacher candidates despite existing research endeavors. Addressing this void, the present research concentrates on second-semester students enrolled in the science education study program. The primary objective is to elucidate the outcomes derived from testing the efficacy of contextual STEM learning of herbal medicinal plants in enhancing the critical and creative thinking competencies of university-level students preparing for careers in the teaching domain. This research endeavor seeks to bridge the existing gap by meticulously evaluating the impact of this innovative pedagogical approach on the cognitive skill development of prospective teachers.

In STEM, learning effectively focuses on productive, directed and deliberate thinking. Students are encouraged to think critically and creatively to develop a deeper understanding of the concepts they study so that complex cognitive processes take place that involve the use of various skills, behaviours and thought patterns that are not limited to just logic, reason, innovation, imagination and reasoning [29]. The contextual STEM approach to herbal medicinal plants strongly emphasises the inter-and multidisciplinary integration of scientific concepts, technology and engineering studies as downstream scientific fields. It also involves basic mathematical knowledge to encourage innovative and analytical thinking as well as synthesis skills [28]. Students will face real-world problems requiring them to apply knowledge and skills to find effective and efficient solutions using an optimal STEM approach. Students can develop more comprehensive and in-depth thinking processes that go beyond surface-level understanding by engaging them in critical and creative thinking.

1.3. Research Questions

The research questions can be formulated as follows:

a. How is the design of the IoT-assisted contextual STEM Project in science learning to enhance the quantity of herbal medicinal plants in Indonesia?

b. What is the instructional impact of the IoT-assisted contextual STEM Project in science learning to improve students' critical and creative thinking skills?

2. Methodology

2.1. Research Design

This research uses mixed methods with an embedded experimental design [30]. In this design, the quantitative method is the primary method and the qualitative method becomes the secondary one. Thus, the main focus of this research is the analysis with quantitative methods in the form of critical thinking skills and creative thinking skills tests while the qualitative methods play a role as supporting data. The research design can be seen in Figure 1.

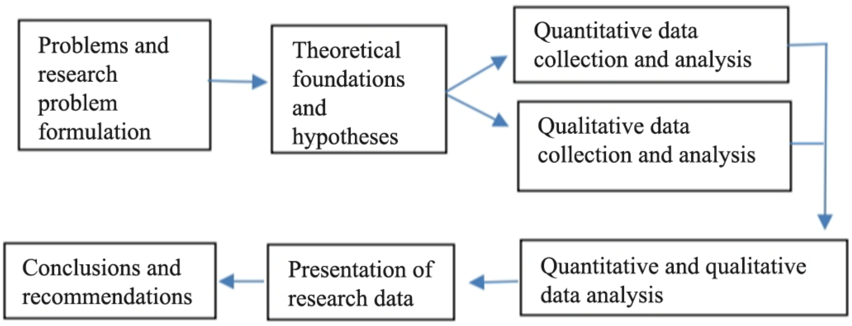

Figure 1.
Embedded experimental design with a mixed method.

The research methodology for this study is an embedded experimental design, incorporating a mixed methods approach. This methodological choice aims to facilitate a more comprehensive analysis specifically targeting enhancing critical and creative thinking skills through applying contextual STEM learning to intensify herbal medicine farming with ABS and IoT technology. The embedded experimental design incorporates quantitative and qualitative data collection methods fostering a balanced integration of these diverse data types. Researchers use a combination of research instruments such as tests, questionnaires and interviews throughout the learning process involving contextual STEM in herbal medicinal plant cultivation. These instruments gather qualitative and quantitative data ensuring a holistic understanding of the learning impact. Implementing this mixed methods approach ensures a deliberate balance between qualitative and quantitative data collection while maintaining the independence of data analysis for each type. The integration of results during the overall interpretation phase allows for a comprehensive examination, seeking convergence, divergence, contradictions or relationships between the qualitative and quantitative data [31, 32].

A quasi-experimental research approach is used to determine the impact of IoT-assisted contextual STEM learning on students' critical and creative thinking skills. The reason for using an experimental design is that first, this approach is commonly used in the field of education and second, it is very useful to overcome the limited time required to establish cause-and-effect relationships using other research methods [33]. Experimental research design is a scientific method that involves changing one or more independent variables to determine whether these changes cause changes in the dependent variable [34]. This approach allows researchers to investigate cause-and-effect relationships between variables, referring to a systematic approach to conduct research in an unbiased and organised manner with the aim of increasing accuracy and obtaining definite conclusions regarding the hypothesis. Observations and measurements of the influence between these variables were carried out to study the rational relationship between the application of contextual STEM in herbal medicinal plants as the independent variable and critical and creative thinking skills as the dependent variable [35]. In a quasi-experimental design, researchers intentionally manipulate independent variables and observe their impact on the dependent variable during the learning period. The primary objective is to facilitate the deduction of logical conclusions regarding the significance of potential causal relationships between the studied variables.

2.2. Data Collection

The data collection process involved evaluating the IoT-assisted contextual STEM implementation's effectiveness in enhancing critical and creative thinking skills through a multifaceted approach. Quantitative data were gathered by assessing the learning tools' feasibility, practicality and efficacy in enhancing critical and creative thinking skills using standardized tests. Qualitative data were obtained through questionnaires, interviews conducted through focus group discussions (FGDs) and an analysis of learning tool documents. These qualitative methods aimed to delve deeper into participants' perspectives and experiences regarding implementing IoT-assisted contextual STEM learning. The respondent selection followed a convenience sampling technique whereby 81 students enrolled in the science education study program undertaking basic physics courses were included based on their accessibility rather than random selection [36]. The research duration spanned from August to October 2023 capturing insights and assessments during this timeframe to comprehensively evaluate the impact of the implemented approach on students' critical and creative thinking skills within the given learning context.

2.3. Research Instruments

The instruments used to collect research data were questionnaires, open interview guides in Focus Group Discussion (FGD) activities regarding the practicality of the IoT-assisted contextual STEM learning tool and its implementation in the learning and assessment process. It also analysed the document study sheets for basic physics learning tools and critical and creative thinking skills tests. The quality of the quantitative data collection instrument from the results of the feasibility validation sheet was analysed using Aiken's V involving three educational science experts. The Aiken validity coefficient was determined on a rating scale of 1 to 5. It contains 1 = very irrelevant, 2 = irrelevant, 3 = quite relevant, 4 = relevant and 5 = very relevant. The Aiken validity coefficient is obtained by calculating the raw scores from experts with the following equation:

$$V = \frac{\sum(r_i - l_o)}{[n(c-1)]}$$

Description
r = Assessment results by expert judgment.
lo = The lowest expert judgment result.
c = The highest expert judgment result.
n = The number of expert judgments that provide scores.
i = Month from 1, 2, 3 up to *n*.
n = The number of expert judgments.

The criteria for determining validity based on the Aiken table involve a minimum value of 0.80 equating to 5% or a p-value of less than 0.05 for three expert validators [37]. The researchers directly analysed qualitative data from open interviews during FGDs and review sheets of learning tool documents in addition to quantitative validation measures. These qualitative analyses necessitate a robust theoretical foundation and broad insight to formulate pertinent questions, analyse gathered information, contextualise findings and construct meaningful learning situations for clearer understanding and relevance. Researchers serve as integral instruments in comprehensively exploring phenomena, facing challenges in navigating unfamiliar territories and employing their theoretical knowledge of STEM concepts in science learning. The expertise required involves implementing STEM concepts effectively within the learning context under investigation. An empirical approach was undertaken using a trial class comprising 20 students from the science education study program at Yogyakarta State University regarding the validation and reliability analysis of the instrument for testing critical and creative thinking skills. The analysis method employed the Item Response Theory (IRT) model of Rasch to assess the appropriateness of items within the model. This analysis aims to determine which items align appropriately with the model used enhancing the reliability and validity of the testing instrument.

2.4. Data Analysis

Qualitative data analysis was carried out with the assistance of the QDA Miner Lite application. QDA Miner Lite is a free and easy-to-use qualitative data analysis software package for encoding textual and graphical data, annotating, retrieving and examining encoded data, documents and images. We can understand what happened and what needs to be done by looking at the presentation of the data. The conclusions drawn from data analysis often unveil new insights in the form of detailed descriptions, visual representations or discernible patterns that were previously ambiguous or obscured. Several earlier imprecise aspects become more apparent and simpler to understand through extensive research and evaluation contributing to a greater comprehension of the topic matter. Additionally, ensuring the validity of the data involves employing alternative triangulation techniques. This methodology entails comparing and cross-referencing data obtained from multiple and diverse sources as depicted in Figure 2.

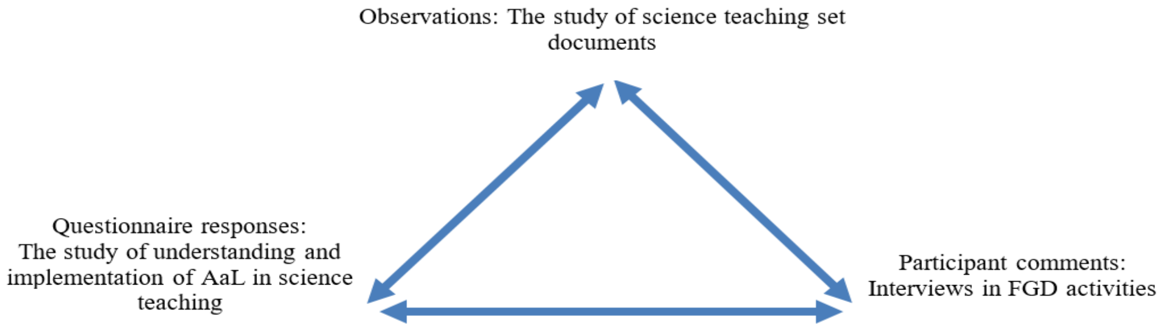

Figure 2.
Triangulation method.

An analysis of the validity and reliability of critical and creative thinking skills tests used Item Response Theory (IRT) with a one-parameter Rasch model. The QUEST program application was to prove the level of validity of the critical and creative thinking test instrument items. QUEST is one of the software program that can be used to analyse items or tests. The central element of the Quest programme is the one-parameter Rasch model (1-PL). The main objectives of the Quest program application are participant parameters (participant ability = θ) and item parameters (mainly item difficulty) (b). This analysis was used not only for creative thinking skills test instruments but also to analyse measurement items from observations and questionnaires. The determination of model fit and item suitability in the one-parameter Rasch model is declared valid if the INFIT MNSQ value is between 0.77 and 1.33 [38]. One of the main item fit statistics of Rasch model analysis is the infit mean square (INFIT MNSQ) which measures the consistency of learners' fit to the item characteristic curve for each item with consideration given to a person close to the 0.5 probability level.

Table 1
Results of the IRT analysis of critical and creative thinking skills test instruments.

Item indicator	**Instrument analysis results**	
	Critical thinking skills	**Creative thinking skills**
MNSQ INFIT range	0.88 – 1.12	0.86 – 1.13
Outfit t range	-0.44 – 0.52	-0.57 – 0.93
Item reliability	0.89	0.87
The number of items in the range -2.0 to 2.0.	23	22
The number of items fit.	23	22
The number of items does not fit.	2	3

Table 1 explains the results of the IRT analysis of the critical thinking test instrument as a whole. It is known that the INFIT MNSQ value range is between 0.88 and 1.12 and the outfit t value range is -0.44 to 0.52, so that overall items can be declared fit with the model used or fit with the Rasch model. However, suppose the analysis of the items is based on the criteria for the validity and difficulty level of each item based on the INFIT MNSQ value, outfit t, and threshold value. In that case, 24 fit items and 2 unfit items are produced, namely number 9 (threshold value of -3.43) and number 21 (threshold value of 4.21). Meanwhile, the results of the IRT analysis of the creative thinking skills test instrument show that the INFIT MNSQ value is in the range of 0.86 to 1.13 and the outfit t value range is -0.57 to 0.93 so overall, the test instrument items are declared fit with the Rasch model. However, the analysis of the items is based on the level of validity and difficulty of the items. In that case, it produces 22 fit items and the remaining 3 items are not fit, number 6 (outfit t value of 2.4), number 17 (threshold value of -2.31) and number 21 (threshold value of -2.33).

Some of the test items were declared to fit and others were declared unfit with the Rasch model based on the analysis of the two critical and creative thinking skills test instruments. The results of the IRT analysis of the critical and creative thinking skills test instrument show that the total number of items in the 25 questions tested each produced 23 and 22 fit items. Therefore, the total number of items declared to fit with the Rasch model is 45 which can then be packaged into the final product of a critical thinking skills instrument. Item reliability for the critical thinking skills test is 0.86 (very high reliability), and the personal reliability value is 0.65 (medium reliability). Meanwhile, the creative thinking skills test instrument was 0.86 (very high reliability) and the personal reliability value was 0.61 (high reliability). This shows that the reliability of the test instrument based on the reliability of the items and the reliability of the test subjects fall in the very high and medium categories, respectively, so that both the items and the test subjects are declared reliable.

Hypothesis testing regarding whether there is an influence from the application of IoT-assisted contextual STEM learning on critical and creative thinking skills uses the MANOVA test. The hypothesis that can be made to answer this problem is:

H_0*: The IoT-assisted* contextual *STEM learning model has no influence on students' critical and creative thinking skills.*

H_1*: The IoT-assisted* contextual *STEM learning model significantly influences students' critical and creative thinking skills.*

Based on the hypothesis, the criteria used to determine assumptions are that if Sig. is in Table 0.05, then H_0 is accepted. Hypothesis testing is carried out after testing data assumptions are met, namely, normality, homogeneity, box test and variance homogeneity tests.

3. Result and Discussion

3.1. Product Resulting from the Development of Audio Bio Stimulator for Desmodium Herbal Plants

The Audio BioStimulator (ABS) in this study employs the original sound frequency emitted by cicadas set at 3256 Hz [39]. This frequency is intentionally adjusted within a range akin to the sonic bloom which typically spans between 3000 Hz and 5000 Hz. Within the ABH (Audio Bio Harmony) technology, peak frequencies encompass 3000 Hz, 3500 Hz, 4000 Hz, 4500 Hz and 5000 Hz. However, for the purposes of this study, only three specific frequency peaks—3500 Hz, 4000 Hz and 5000 Hz were employed and consequently validated. The validation process of this ABS tool involved analysis through Matlab R2008a yielding results represented in Figure 3a. Figure 3b showcases a sample image captured from Desmodium plant stomata subjected to the ABS treatment set at a peak frequency of 3500 Hz.

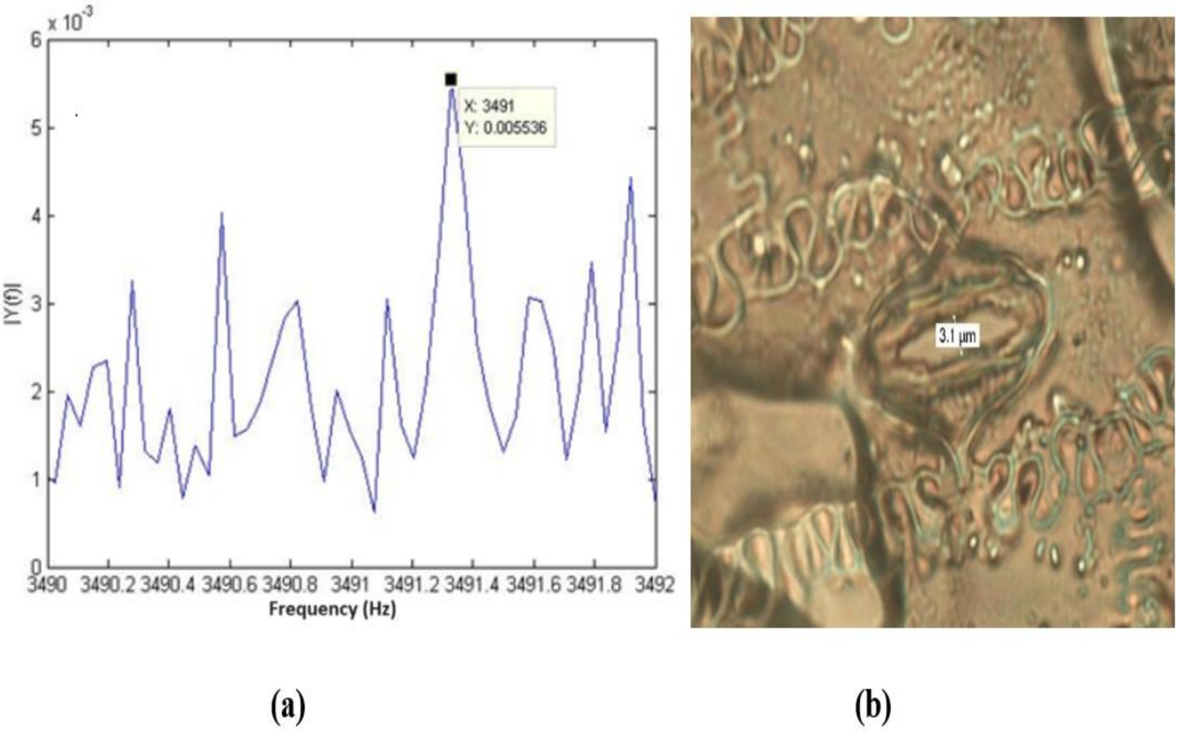

Figure 3.
a. Spectrum of the Cicada sound wave signal with a peak frequency of 3491 Hz ~ 3500 Hz.
b. Stomata samples of Desmodium plants treated using ABS at a peak frequency of 3500 Hz

3.2. IoT-Based Multi Sensors for Measuring Environmental Physical Variables around Desmodium Herbal Plants

In the IoT (Internet of Things) concept, the NodeMCU ESP8266 is a smart things device based on a microcontroller unit. Devices or "things" are generally related to capturing data sourced from the environment in real-time. This task is generally carried out by the MCU (Microcontroller Unit) device which acts as a controller and data processor. Sensors assist the MCU in obtaining data from the external environment. A sensor itself is a device that functions to convert physical quantities into electrical quantities. Physical quantities are obtained from environmental phenomena such as heat, sound, light intensity, pressure, slope, magnetism, humidity, soil capacitive and PH (a measure of how acidic or basic water). The physical quantities obtained by the sensor are processed and produce electrical signals in the form of digital or analog signals.

Figure 4 describes the IoT design developed in this research which includes several physical sensors that can be measured. The measurement results from the sensors will be connected to an internet connection so that the data can be controlled by researchers outside the research location. The design includes input, processing and output. Input comes from various sensors including a CO2 gas sensor, an infrared sensor, a sound frequency sensor, a light intensity sensor, a water turbidity sensor, a PH sensor, a temperature sensor, an air humidity sensor, a soil mouture sensor and a touch sensor. NodeMCU ESP8266 allows the readings from the sensors to be converted into digital data connected to the internet. The output of the measurement results can be sent from the IoT application to a computer connected to the internet.

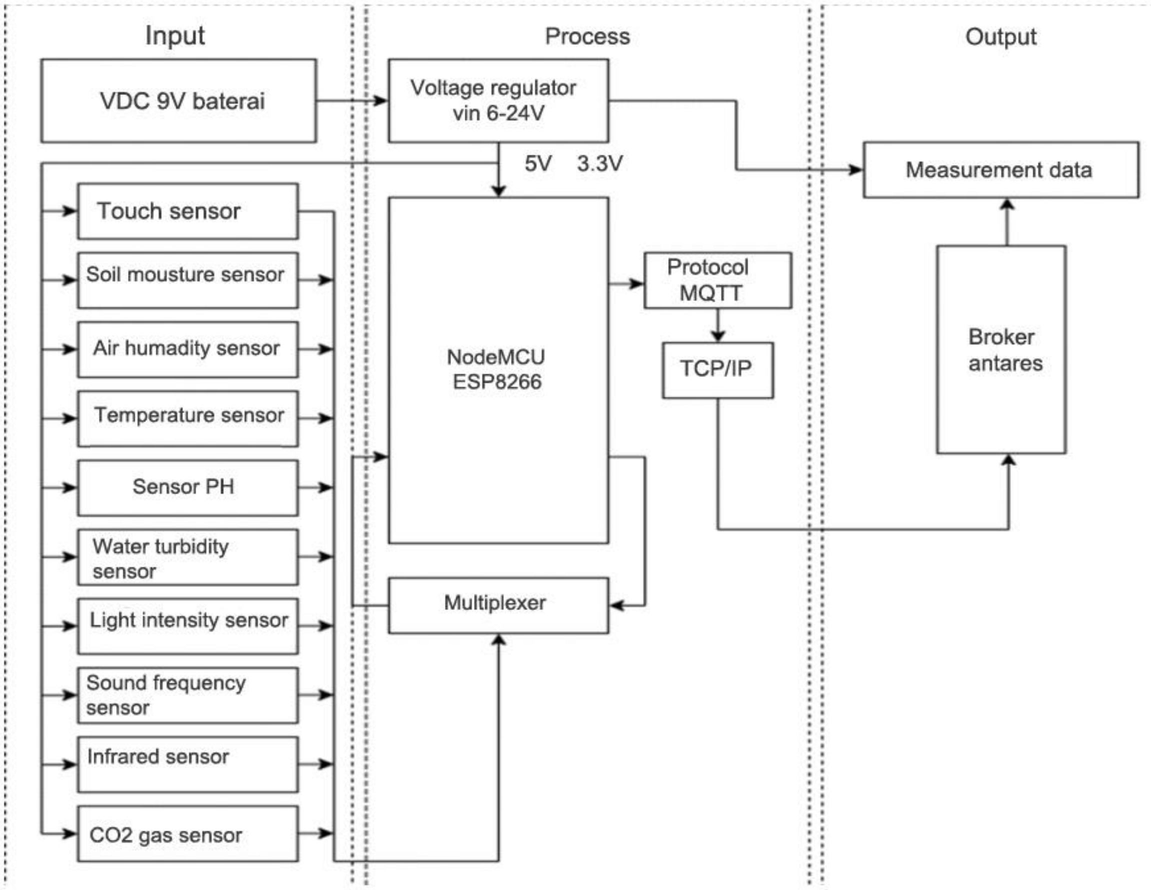

Figure 4.
IoT conceptual design.

In this research, IoT is used simultaneously with ABS. IoT is used to control environmental physical variables and ABS stimulates the growth rate of the Desmodium plant as a traditional plant which is believed to be an alternative medicine for fever and inflammation and tecomaria for blood sugar levels. The following image shows the process of cultivating the traditional herbal medicinal plant Desmodium in this research.

Figure 5.
Cultivation process of the traditional medicinal plant Desmodium with ABS and IoT treatment.

Figure 5 illustrates how the design of the IoT and ABS devices is implemented on the farm owned by the Science Laboratory of Yogyakarta State University. The experimental design with two locations includes desmodium plants in the field treated with ABS and IoT and desmodium plants in the field without being treated with ABS and IoT. The measuring results of the growth rate between Desmodium plants that were exposed to ABS sound and IoT-conditioned environmental conditions can be seen in the graph below. We can see a graph of the results for Desmodium plants that were not exposed to ABS sound and without IoT physical modification.

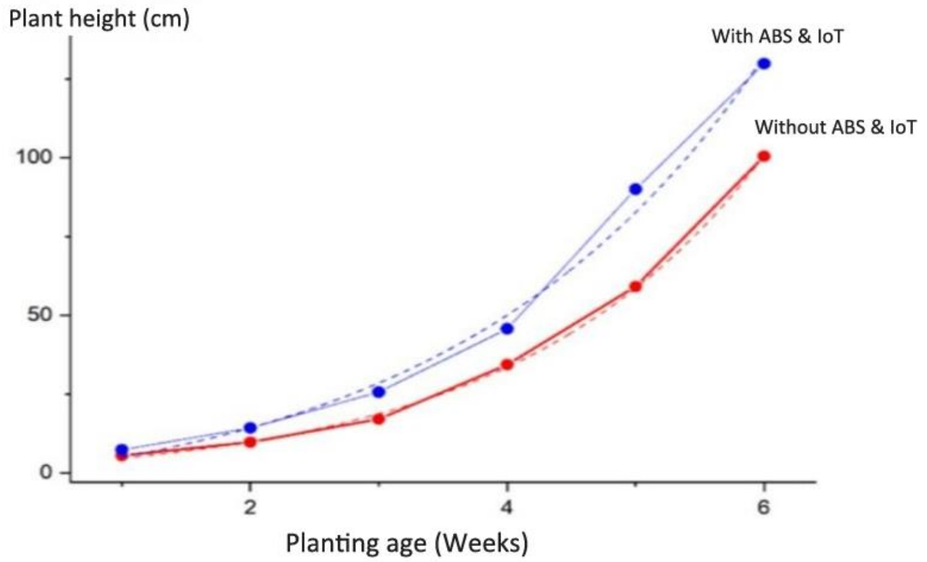

Figure 6.
Comparison of the growth rate of Desmodium plants with the application of ABS and IoT modifications.

Figure 6 illustrates the variable heights of desmodium plants between those with ABS and those without ABS whose data was collected using IoT. The graph shows the significant difference in plant height between those treated with ABS and those without ABS after several weeks of treatment.

3.3. Data and Results of Analysis of Critical and Creative Thinking Skills Measurement

The analysis conducted for the data encompassed both descriptive methods [40] and inferential statistical analysis [41]. Descriptive analysis was utilised to depict the average measurements of critical and creative thinking skills along with their standard deviations. Meanwhile, inferential statistical analysis aimed to assess the impact of implementing IoT-assisted contextual STEM learning on these dependent variables through a one-way MANOVA test. Prerequisite analysis tests were executed before conducting hypothesis testing on critical and creative thinking skills data. These tests included assessments for data homogeneity and normality. The data normality test was performed using the Kolmogorov-Smirnov analysis technique considering the data as normally distributed if the significance level obtained exceeded 0.05. Simultaneously, the homogeneity test for data variance among groups was conducted using Levene's equality of error variances technique assuming homogeneous data distribution if the significance level exceeded 0.05.

The Kolmogorov-Smirnov and Shapiro-Wilk analysis results showed significance levels greater than 0.05. This suggests that the data gathered from measuring critical and creative thinking skills in both the experimental and control groups follow a normal distribution (see Table 2). Additionally, the outcomes from Levene's test of equality of error variances displayed significance levels greater than 0.05 implying that the data obtained from measuring critical and creative thinking skills in both groups exhibit a homogeneous variance distribution (see Table 3).

Table 2.
The result of the normality test.

Dependent variables		Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistics	df	Sig.	Statistics	df	Sig.
Critical thinking	1	0.139	33	0.113	0.931	32	0.069
	2	0.138	33	0.122	0.945	32	0.332
Creative thinking	1	0.142	33	0.442	0.942	32	0.268
	2	0.141	33	0.571	0.952	32	0.434

Table 3.
The result of the homogeneity test.

Variables	Parameter values	Levene statistics	df1	df2	Sig.
Critical thinking	Average	0.129	1	63	0.709
	Median	0.091	1	63	0.766
	Median and with adjusted df	0.092	1	59.344	0.769
	Trimmed mean	0.131	1	63	0.731
Creative thinking	Average	0.569	1	63	0.453
	Median	0.434	1	63	0.521
	Median and with adjusted df	0.429	1	59.392	0.522
	Trimmed mean	0.528	1	63	0.480

Descriptive data analysis for critical thinking skills shows that the critical thinking skills of the experimental group have an average value of 81.95 and a standard deviation of 5.98; the critical thinking skills of the non-experimental group have an average value of 68.97 and a standard deviation of 6.71. This confirms that using contextual STEM learning assisted by ABS and IoT is more effective in improving critical thinking skills than the STEM approach alone. Descriptive data analysis for creative thinking skills shows that (1) the mean value for creative thinking skills in the experimental group is 81.93 and the deviation is 6.1. (2) The creative thinking skills of the non-experimental group had an average value of 69.40 and a standard deviation of 5.20. These findings also indicate that contextual STEM learning works better when it is assisted by ABS and IoT in improving creative thinking skills.

The outcomes derived from the one-way multivariate analysis of variance (MANOVA) as presented in Table 4 reveal compelling insights. The interpretation of this data suggests a statistically significant impact attributed to the application of ABS and IoT within contextual STEM learning resulting in a simultaneous increase in students' critical and creative thinking abilities. Specifically, the F coefficient values indicate noteworthy findings. The F coefficient value for critical thinking ability stands at 48.394 while the F coefficient value for creative thinking ability is 81.769. Both coefficients exhibit a significance coefficient value of 0.000. These F coefficient values compare variability between groups against internal variability within groups.

Theoretically, the magnitude of the F coefficient denotes the extent of the difference between the compared groups. A higher F coefficient value signifies a more significant difference. In this context, the research indicates that the notably high F coefficient values signify a substantial disparity in critical and creative thinking abilities between students exposed to contextual STEM learning assisted by ABS and IoT compared to those who did not receive such assistance.

Table 4.
Summary of the results of the one-way MANOVA test.

Source	**Dependent variable**	**Type III sum of squares**	**DF**	**Mean square**	**F**	**Sig.**
Corrected model	Critical thinking	2701.603[b]	1	2702.622	50.194	0.000
	Creative thinking	2578.735[a]	1	2628.713	80.977	0.000
Intercept	Critical thinking	370566.563	1	371332.571	6.928E3	0.000
	Creative thinking	367318.431	1	367342.501	1.201E4	0.000
Application of ABS and IoT in STEM-M learning	Critical thinking	2599.498	1	2731.602	49.274	0.000
	Creative thinking	2581.695	1	2498.698	81.769	0.000
Error	Critical thinking	3286.874	64	54.203		
	Creative thinking	1965.288	64	32.233		
Total	Critical thinking	375900.000	66			
	Creative thinking	372772.437	66			
Corrected total	Critical thinking	5933.440	65			
	Creative thinking	4541.113	65			

Note: a. R Squared = 0.831 (Adjusted R squared = 0.802).
b. Computed using alpha = 0.05.

According to the table, it can be seen that sig. coefficient value of 0.000 is smaller than the threshold of 0.05, thus indicating that the impact of contextual STEM learning assisted by ABS and IoT on students' critical and creative thinking abilities is statistically significant. The results of the Manova test in Table 4 indicate strong evidence to reject the null hypothesis (there is no significant difference between the critical and creative thinking skills of the experimental class and the control class). Experimental classes are classes where students learn using the STEM-C medicine approach by experimenting using ABS and IoT devices. Meanwhile, the control class is where students learn using a contextual STEM approach but do not experiment using ABS and IoT devices. The results of testing this hypothesis indicate potential benefits from implementing STEM-based scientific learning programs in educational environments oriented towards developing students' critical and creative thinking skills. The test results also indicate that using ABS and IoT devices in contextual STEM learning significantly influences students' critical thinking abilities, as indicated by the F coefficient value of 49.274 with a sig. coefficient value of 0.000. Contextual STEM learning gives students empirical experience using the tools they need to succeed in a rapidly changing world. The results of this study are in line with research studies conducted in Sujanem and Suwindra [42], Bulu and Tanggur [43], Hebebci and Ertuğrul [41], Mabrurah, et al. [44], Putra, et al. [45], Sastra, et al. [46] and Topsakal, et al. [47]. According to the results of this study, incorporating STEM education in the classroom substantially enhances the ability of learners to engage in critical thinking.

Applying contextual STEM learning assisted by ABS and IoT also significantly influences students' creative thinking abilities as indicated by the F coefficient value of 81.769 and the Sig. coefficient value of 0.000. These two skills must be taught in the learning process to respond to 21st-century global demands. This research indicates that students who took part in contextual STEM learning activities assisted by ABS and IoT had higher creative thinking scores than students who did not take part in contextual STEM learning activities assisted by ABS and IoT. This is in line with Martawijaya, et al. [48], Suradika, et al. [49], Ichsan, et al. [50], Ilma, et al. [15] and Yerimadesi, et al.'s [51] research findings that the use of contextual STEM learning assisted by ABS and IoT has a significant effect on students' higher-order thinking abilities. Applying contextual STEM learning assisted by ABS and IoT significantly increases students' creative thinking abilities. This finding is in line with research by Kencana, et al. [52], Iskandar, et al. [53], Izzah and Wardani [54], Kencana, et al.

[52], Aguilera and Ortiz-Revilla [55], Amiruddin, et al. [56] and Eroğlu and Bektaş [57]. Research findings incorporating STEM learning in basic physics learning classes also significantly improve students' creative thinking skills. It is also consistent with the opinions of Preca, et al. [58], Sastra, et al. [46] and Sutaphan and Yuenyong [59].

Further interpretation of this research data analysis results produces substantial theoretical implications for enriching knowledge based on empirical experience regarding the application of IoT-based multisensor contextual STEM combined with agricultural technology to be implemented in learning to develop critical and creative thinking skills for prospective science teachers. In the modern era, the Internet of Things (IoT) is an optimal solution for preventing such types of challenges. IoT can connect with neoteric agriculture technology. Farmers can directly connect themselves and control their fields and monitor their field environmental conditions from anywhere around the world by using this technique [60]. Notably, this research represents a pioneering endeavour, unprecedented in its scope and implementation within educational institutions catering to educational staff in Indonesia. The findings derived from this study possess significant potential to make substantive scientific contributions particularly in bridging the gap between theoretical concepts and practical applications of STEM learning. It is poised to offer a comprehensive understanding of the intricate dynamics underlying contextualised STEM-based scientific learning and its direct impact on the cultivation of critical and creative thinking skills within the specific context of herbal medicinal plants.

The research has acknowledged certain limitations primarily concerning the restricted scope of the participant pool, which was confined to the context of basic physics learning within the science education study program at Yogyakarta State University. Nevertheless, considering the contextual relevance and substantive content applicability, contextual STEM with ABS and IoT devices demonstrates significant potential for extensive deployment notably within science and agriculture study programs across diverse and pertinent subjects. The research outcomes extend beyond the confines of a singular subject reflecting adaptability and relevance across varied educational domains. This adaptability positions the findings as transferable to diverse subject areas expanding the learning context's scope and relevance beyond its initial constraints. In terms of future research recommendations, there exists an opportunity for broader replication and expansion. This initiative entails augmenting and replicating a comprehensive spectrum of innovations applicable across various pedagogical materials within diverse educational settings. This broader scope offers the prospect of implementation across a more expansive and heterogeneous participant base, yielding more comprehensive and representative findings. Such endeavours will authenticate and enhance the understanding of the efficacy and implications of contextual STEM, ABS and IoT within diverse educational landscapes.

4. Conclusion

It can be conclusively affirmed that the application of contextual STEM learning supported by ABS and IoT technologies significantly enhances students' critical and creative thinking proficiencies within the basic physics domain at the Natural Science Education Department, FMIPA, Yogyakarta State University based on the findings derived from the research. This underscores the transformative potential inherent in contextual STEM-based scientific learning, redefining pedagogical paradigms in teaching and learning methodologies. The study underscores the imperative of incorporating contextual STEM-based scientific learning within the curriculum framework to elevate students' higher-order cognitive capacities. These enhanced cognitive skills are paramount for students' future pursuits in science, technology, engineering and mathematics equipping them with indispensable skill sets for their prospective careers. Moreover, the research accentuates the pivotal role of teachers in this transformative process. It underscores teachers' need to receive comprehensive training and adeptness in effectively employing contextual STEM models within their teaching methodologies. It also emphasises the significance of judiciously amalgamating technology to empower communities, especially those engaged in agricultural practices.

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