The Effectiveness of Blended Laboratory Using Virtual Reality and IoT (BLUVRIOT) to Enhance Students' Process Skills and Critical Thinking based on STEM Approach: Case Study Application of Audio Organic Growth System in Science Learning

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Abstract. This research proves that blended laboratory using virtual reality and IoT (BLUVRIOT) based on STEM (Science, Technology, Engineering, and Mathematics) approach can be used to enhance students' process skills and critical thinking in the Natural Sciences Study Program of Universitas Negeri Yogyakarta. The STEM approach in science learning can solve the students' difficulties in connecting the technology elements represented by AOGS, environmental elements related to agriculture that are organic and environmentally friendly, mathematical elements on data analysis and growth charts associated with audio from natural animals modified using the Sound Forge 6.0 program. This research employed a field experiment of AOGS technology assisted IoT application in maize fields and Research & Development (R&D) of the spiral model (Cennamo & Kalk, 2018) with STEM approach to improve students' creative thinking and process skills.

The results of the study can be divided into two categories, i.e. developing the students' skills and partner farmers in using AOGS to increase the growth rate and the maize productivity, and enhancing the students' skills and critical thinking skills in Science Practicum course. Based on the research findings, the maize productivity at AOGS 3500 Hz peak frequency with the area of 1,000 m^2 for experimental plants were 893.04 kg, while for the control plants were 620.73 kg, respectively. There was a significant difference between the treated plants and the control which was about 208.31 kg (133.56%). Moreover, the process of AOGS application using STEM approach was also proven to be able to significantly enhance the process skills and critical thinking among the students participating in Science Practicum course.

Keywords: blended laboratory, virtual reality, IoT, science process skills, critical thinking

Introduction

The industrial revolution 4.0 has the effect of spurring the disruption process in various dimensions of life including education and agriculture. The rise of new digital industrial technology creates a new paradigm and reference in the current order of life. It must be anticipated with the mastery of process skills and critical thinking. Critical thinking refers to an ability to understand and to solve a complex problem as well as to associate information with other data in order to gain various perspectives.

One of the important skills that have been the concern of the 2013 curriculum is science process skills. This skill is not only required in science subjects but also in all subjects related to science. The science process skills are special skills that make students active, simplify learning, emphasize students' responsibility in their own learning progress, enhance long-term memory skills, and facilitate students with research activities (Carey et al., 1989; Korkmaz, 1997; Karamustafaoğlu, 2003). In addition, the science process skills can be used to obtain information, understand problems and formulate results. This skill is also widely popular among scientists in their studies. According to Bredderman (1983), science process skills are cognitive skills that are used to understand and develop information. Similarly, Harlen (1999) mentions that science process skills are one of the main goals that must be achieved in science education to become scientifically literate people. The science process is defined as a procedure that is basically shaped by analytical and critical thinking skills (Ministry of National Education-MoNE, 2013).

It is very crucial for students to learn how to apply science by studying reality, concepts, generalizations, theories and science laws during their learning process. By doing so, process skills can be continuously developed in science learning. These skills are demanded all fields of science, and they reflect the correct behavior of scientists in solving problems and planning experiments. As the core of concepts and research in science, these skills are considered efficient in teaching and learning process that has involved various teaching programs in several countries, such as the 'A-Science Process Approach' (SAPA) developed by the American Association for the Advancement of Science between 1963 and 1974. Within SAPA approach, science process skills are taught specifically in science curriculum on primary and secondary school levels (Brotherton & Preece, 1995).

Meanwhile, critical thinking is also interpreted as the ability to reason, to understand and to make complex choices, to understand the interconnection between systems, to compile disclose, analyze, and to solve problems. It refers to the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, or evaluating information gathered from or by observation, experience, reflection, reasoning, or communication, as a guide to belief and action. In line with this, Benjamin Bloom (1956) divided the way people think into three domains, the Cognitive, Affective and Psychomotor. Analysis, synthesis, and evaluation are regarded as the outcomes associated with critical thinking, while knowledge, comprehension, and application are categorized as the outcomes associated with content competencies (Duke, 2012). Critical thinking skills are needed by students to face the rapid flow of information in this digital era. It involves the ability to distinguish truth from lies, facts from opinions, or fiction from non-fiction, as one of the students' abilities to make wise decisions in their life. In addition, the ability to think critically is also important for students to become good learners.

To improve student process skills and critical thinking in this research, a blended laboratory using virtual reality and IoT (BLUVRIOT) based on STEM (Science, Technology, Engineering, and Mathematics) will be implemented. BLUVARIOT is a new term designed by researchers to explain the concept of an integrated laboratory between realistic laboratory activities using IoT and Case Study Application of Audio Organic Growth System (AOGS) in science learning as a synchronous activity (face to face) and virtual laboratory activities using augmented reality (asynchronous). The STEM approach is believed to be the right solution to develop process skills and critical thinking as efforts to employ science in creating technology and its implications for the environment, both physical and mental. The bond between science and mathematics plays significant role to improve data analysis and interpretation. The STEM application can help to develop knowledge, to answer questions based on inquiry, and to create new knowledge (Harlen, 1999). Moreover, STEM learning approach can develop students' critical thinking skills, i.e. reflective thinking that focuses on decision making about what is believed and what needs to be done (MoNE, 2013). The application of the STEM model is effective to improve students' understanding, logical thinking and mental cycle (Yörük, Morgil, & Seçken, 2010). At present, the application of the STEM approach is so relevant that education world is realizing to facilitate graduates with technology-oriented economy in order to present positive contributions in society (Sofowora & Adekomi, 2012).

The implementation of this approach in science learning has been known for a long time (The NSTA Position Statement, 1990), but the main problem is on students' difficulties to connect various elements in STEM because the learning process has not been supported by relevant technology. Therefore, in this research, BLUVARIOT through the implementation of Audio Organic Growth System (AOGS) technology is applied to optimize the growth and productivity of organic maize plants in Biophysical Practicum course in which STEM is a teaching reform that can fulfill these needs (Driver et al., 2000). The research results conducted by Akcay and Akcay (2015) show that STEM learning has a better impact on students' understanding and learning outcomes compared to traditional learning which is oriented on textbook instructions though both processes performed by the same teacher. It may happen because STEM facilitates students with authentic problem solving and peer collaboration (Fortus et al., 2005).

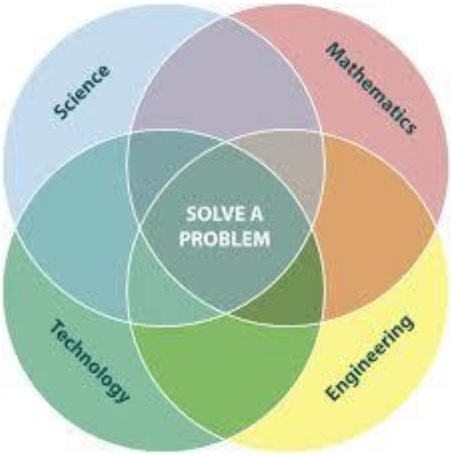

Figure 1. Visualization of problem-solving using STEM
Source: http://secc.sedl.org/resources/

The STEM approach used in this study is about science and technology in the context of realistic learning experiences for students. The developed STEM learning model is not just a concept on paper, but it really learns something realistic that can be understood, sensed, analyzed and is able to solve problems. This learning model also improves the relevance between theory and application in the form of AOGS application to increase maize productivity. It means that students do not only learn about concepts of natural science but they also pay close attention to a real-life related to the theory being studied of which can provide a positive impact students' competency (Pedretti et al., 2008). The learning theories used in STEM approach are constructivism, behaviorism, cognitive development, and social-cognitive. The STEM learning syntax used in this study is shown in Figure 2.

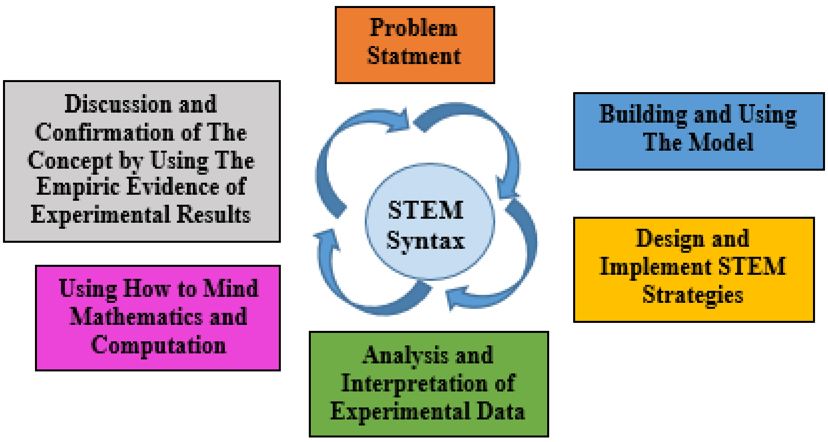

Figure 2. STEM learning syntax

The STEM learning model in this study was done by utilizing AOGS as an effort to intensify agriculture both as a tool and an environmentally friendly process. The AOGS tool designed in this research was made more compatible and comprehensive based on microcontroller technology (embedded systems) and used solar energy as the response to previous problems where there is no electricity in agricultural areas (so it can be used in remote areas). With this technology, the audio intensity variable was optimized on the frequency and optimum intensity to control pests and at the same time to produce plants that are able to absorb optimal nutrients and solar energy to produce "greedy" plants that impact on crop productivity and quality (Rosana et al., 2017). The research results with ABHS (Audio Bio Harmonic System) devices have been able to increase the productivity of potato plants (87%), and onion plants (57%).

Methods

The research employed a field experiment of AOGS technology assisted IoT application in maize fields and Research & Development (R&D) with the spiral model (Cennamo & Kalk, 2018) using STEM approach to improve students' critical thinking and process skills. In this spiral model, it was known as 5 (five) development phases namely; (1) define, (2) design, (3) demonstrate, (4) develop, and (5) deliver. Meanwhile, in the experimental application of the device, the source of the Cricket (Gryllidae) sound was manipulated at a peak frequency of 3500 Hz validated with the Octave 4.2.1 program. The plants studied were maize (Zea mays) in the experimental area of 1000 m^2 and the control with a similar width area. The observed data included the growth of maize plants (plant height, number of maize cobs in one tree and number of leaves per maize tree). The important data analyzed was the width of the stomata opening during the AOGS technology assisted IoT application which was observed using a light microscope with its output of NIS Elements Viewer program. To measure the stomatal opening area, Image Raster 3.0 was used to measure the productivity of maize plants in the form of mass which was analyzed using Origin 8.0 and Microsoft Excel 2013. The sound intensity level produced by AOGS during sound exposure was measured with a sound level meter.

The BLUVARIOT based on STEM model application involved the experimental and the control class with the research subjects among the fourth-semester students of Science Practicum course in the Science Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta in the academic year of 2018/2019. For each stage of R&D, data collection was done through product validation instruments in the form of models and engineering results of AOGS, observations, interviews, questionnaires, performance evaluation sheets, attitudes, as well as conceptual and procedural knowledge tests. The observations and interviews were intended to conduct a needs analysis of the developed BLUVARIOT based on STEM model.

The validation sheets had been assessed by experts in the case of the design of learning models, the instructional media, the constructs (content and language). The instrument for validity testing was in the form of expert assessment sheets containing rubrics on the quality of the developed instruments, while the instruments for practicality were in the form of questionnaires for students who participated in the Science practicum. After the BLUVARIOT based on STEM model and AOGS device were theoretically valid, the model was empirically tested using one to one evaluation method. The evaluation results were tested again with small group method and field test evaluation to determine the practicality of the model.

During the implementation of BLUVARIOT based on STEM model and AOGS device both in Science practicum and field activities in the agricultural area of Purwomartani Village, Kalasan District, Sleman Regency, several observations were done using observational sheets to obtain the data on the development of critical thinking and process skills through the of students' cognitive, affective, and performance assessment. The data regarding the measurement results of the students' process skills and critical thinking were obtained using test and non-test instruments as well as performance assessment. The data collected from various instruments were analyzed quantitatively and qualitatively.

Table 1. Syntax of BLUVARIOT based on STEM Approach in AOGS Implementation

Steps	Activities
Define	Conducting an Analysis on the Learning Outcome Program to be achieved by Science practicum, the needs, the formulation of conceptual definitions of STEM approach using AOGS tools to improve process skills and critical thinking among students of pre-service teacher education
Design	Designing the learning tools to apply STEM models, AOGS tools and the instruments to measure process skills and critical thinking as well as validating and testing them in case of its practicality and effectiveness.
	Validate STEM model guides, learning tools, and AOGS devices through expert judgment
Demonstrate	Testing the STEM model empirically with one to one evaluation method
Develop	Implementing STEM models and AOGS devices in Science practicum activities, both in laboratories and in the field (agricultural land) and conducting practicality and effectiveness tests; a. *One to one* b. *Small group* c. *Field group*
Deliver	Taking measurements using instruments of process skills and scientific thinking
	Final Packaging of STEM model with the help of AOGS device
	Describing the diffusion process of STEM model and AOGS devices

This research data consisted of two types, namely the data on (1) the experimental results of AOGS application to increase the productivity of maize plants, and (2) the assessment of students' process skills and critical thinking using STEM model. The obtained data were divided into two, i.e. qualitative and quantitative. The quantitative data were analyzed by Exploratory Factor Analysis (EFA) with the help of the SPSS 20.0 program. The construct validity was tested by checking the expected Kaiser Mayer Olkin (KMO) value of 0.5 (> 0.5). The analysis with EFA was to test the validity of the second trial and to test construct normality before it was analyzed with CFA on the third trial. The reliability of the measurement data can be seen from the alpha value (it was declared not reliable if the alpha value <0.7 and reliable if the alpha value> 0.7). Testing with Cronbach Alpha was used to test the reliability of the instrument during the trial.

The trial results were then analyzed using CFA (Confirmatory Factor Analysis) method to know the validity of each instrument. The validity analysis using CFA can be seen from t-value, and factor load was seen from the alpha value. If the value of alpha> 0.03 (5% significant level) compared to the value of T- table 1.96, so the item was declared valid. Besides, the validity can also be proven by looking at the path diagram shown in black numbers, the bigger the t value, the higher the validity level. If the alpha value was written in red color, it would be stated that the item was invalid so it must be replaced or omitted.

The compatibility test between theoretical and empirical models was based on four categories; (1) Chi-Square, (2) Significant Probability, (3) Root Mean Square of Error Approximation (RMSEA), and Goodness of Fit Index (GFI). To test the appropriateness of the model, it can be seen from RMSEA which must be below 0.08 and Goodness of Fit Index (GFI) must be above 0.90 (Wijanto, 2008). The measurement guidelines can be seen in Table 2 below.

Table 2. Goodness of Fit Index

Measure	Name	Description	Cut-off for good fit
X^2	Model Chi-Square	Assess overall fit and the discrepancy between the sample and fitted covariance matrices. Sensitive to sample size. H_0: The model fits perfectly.	p-value> 0.05
(A)GFI	(Adjusted) Goodness of Fit	GFI is the proportion of variance accounted for by the estimated population covariance. Analogous to R^2. AGFI favors parsimony.	GFI ≥ 0.95 AGFI ≥0.90
(N)NFI TLI	(Non) Normed-Fit Index Tucker Lewis index	An NFI of .95, indicates the model of interest improves the fit by 95% relative to the null model. NNFI is preferable for smaller samples. Sometimes the NNFI is called the Tucker Lewis index (TLI)	NFI ≥ 0.95 NNFI ≥ 0.95
CFI	Comparative Fit Index	A revised form of NFI. Not very sensitive to sample size. Compares the fit of a target model to the fit of an independent, or null, model.	CFI ≥.90
RMSEA	Root Mean Square Error of Approximation	A parsimony-adjusted index. Values closer to 0 represent a good fit.	RMSEA < 0.08
(S)RMR	(Standardized) Root Mean Square Residual	The square-root of the difference between the residuals of the sample covariance matrix and the hypothesized model. If items vary in range (i.e. some items are 1-5, others 1-7) then RMR is hard to interpret, better to use SRMR.	SRMR <0.08
AVE (CFA only)	Average Value Explained	The average of the R^2s for items within a Factor	AVE >.5

Note: Structural Equation Modelling: Guidelines for Determining Model Fit (Hooper, Coughlan & Mullen, 2008)

The mastery of science process skills and critical thinking were divided into five categories, i.e. “very high”, “high”, “moderate”, “low” and “very low”. This categorization was useful for interpreting the mastery level of students’ science process skills and critical thinking. It used a formula adapted from (Saifuddin, 2003), as presented in Table 3.

Table 3. Formulas of Mastery Level Category

	Score Range	Interpretation
1.	Mi + 1,5 SBi< X	Very high
2.	Mi + 0,5 SBi< X ≤Mi + 1,5SBi	High
3.	Mi– 0,5 SBi< X ≤ Mi + 0,5 SBi	Moderate
4.	Mi– 1,5 SBi< X ≤ Mi– 0,5 SBi	Low
5.	X ≤ Mi– 1,5 SBi	Very low

Explanation:

X = Percentage of respondents obtained by Mi = Mean ideal
Sbi = Ideal standard deviation
Mi = ½ (ideal higest score + ideal lowest score) Sbi
= ⅙ (ideal highest score – ideal lowest score)

The values range to determine the categorization of mastery level of process skills and critical thinking was done by determining the values of Mi and SBi. After the Mi and SBi values were obtained, the next percentage level values can be gathered. The percentage values that had been obtained were used in determining the categories as presented in Table 4.

Table 4. The Category of Science Process Skills Mastery Level

No.	Percentage of Mean score (%)	Category
1.	75,05 < X	Very high
2.	58,35 < X ≤ 75,05	High
3.	41,65 < X ≤ 58,35	Moderate
4.	24,95 < X ≤ 41,65	Low
5.	X ≤ 24,95	Very low

Discussion

AOGS Characteristics

The research on AOGS application is to increase maize productivity by using the sound source of cricket (Gryllidae). The cricket sound stimulator was produced in the range of 5000hz with the peak frequency stimulator at 4747hz. The sound waves were manipulated at 5000 Hz peak frequency with Octave 4.21 software as shown in Figure 3. The x-axis was the frequency and the y-axis was the magnitude. With Octave 4.21, the peak frequency was also analyzed to gain the signal spectrum.

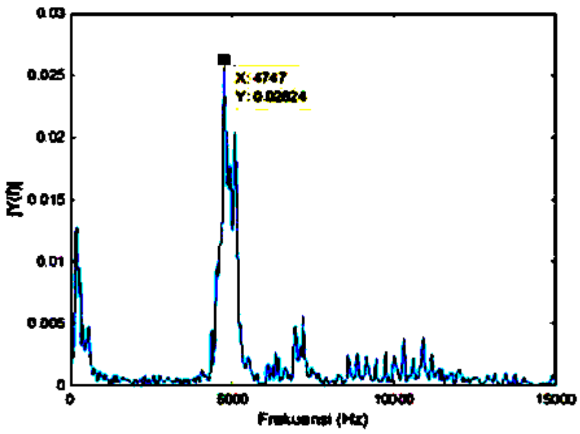

Figure 3. Gryllidae frequency audio spectrum (Alvianty & Kadarisman, 2018)

The cricket sound (Gryllidae) from the field was processed to be the input of AOGS device, so it can be manipulated into several frequencies adjusted to the plant characteristics that will be stimulated. Besides frequency manipulation, AOGS device also modified sound intensity and pattern in order to optimally increase plants growth and productivity. The design of electronic circuits in AOGS devices can be seen in Figure 4 below.

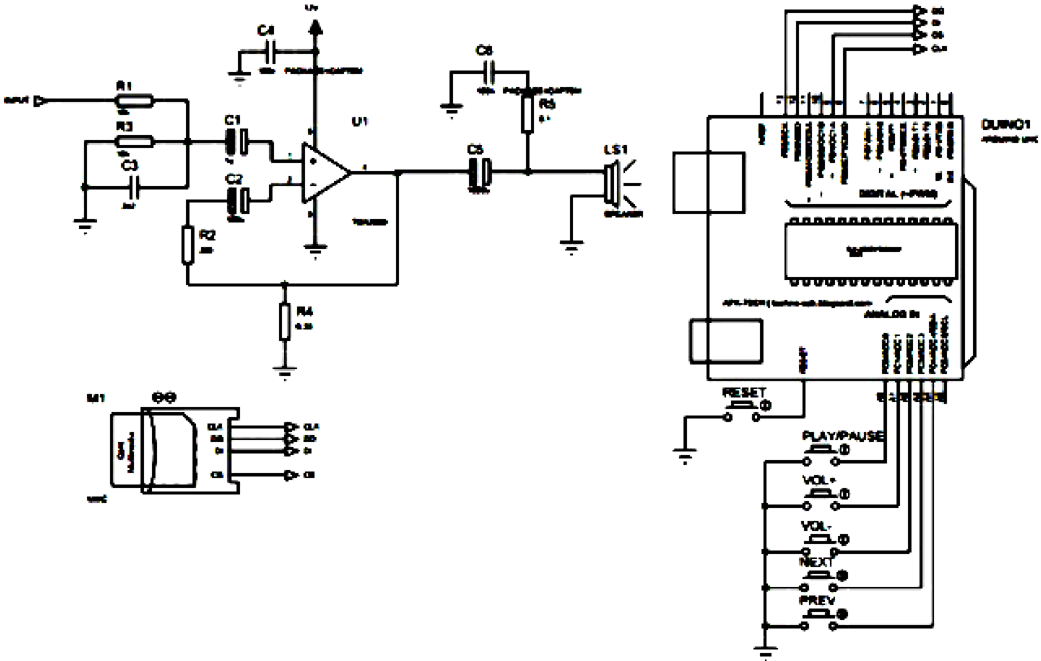

Figure 4. AOGS Device electronic circuit (Dwandaru, Kadarisman &Purwanti, 2015)

AOGS is an electronic device that can produce natural animal sounds that have been manipulated by its frequency and intensity so that it can stimulate the opening of leaf stomata during photosynthesis due to vibration disturbance from natural animal sound waves. In this study, the basic sound was from the sound of crickets (Gryllidae). The vibration from sound will transfer energy to the leaf surface and will stimulate leaf stomata to open wider (Kadarisman, Purwanto & Rosana, 2011). Based on this research, it was found that the manipulation of cricket sound which was manipulated at 4500 Hz peak frequency can influence the stomata opening in maize leaves. The following are the pictures of the stomata opening of the maize leaf that is seen with electron microscope before given sound exposure from AOGS (5a) and when given sound exposure (5b).

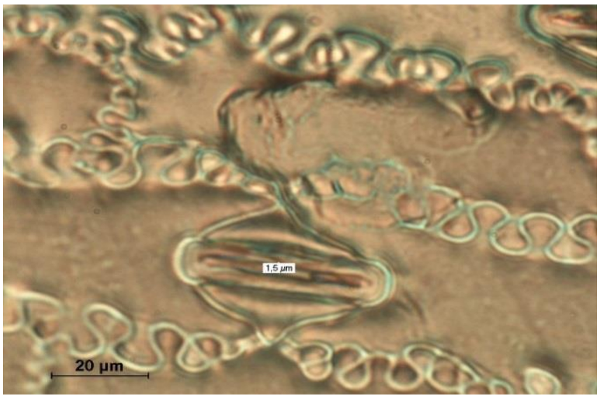

Figure 5a. Before AOGS implementation (Stomata length 15.1 µm)

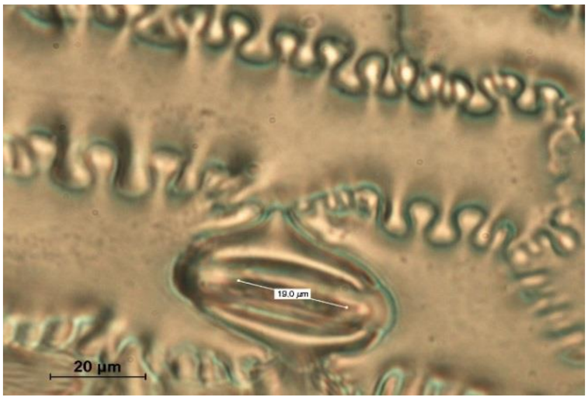

Figure 5b. During AOGS implementation (Stomata length 19.0 µm)

Figure 5. Stomata opening before and during sound exposure of AOGS (there was a significantly different length of stomatal opening)

There were differences in the area of the stomata opening before and after the cricket sounds exposure. The average value of stomata opening when given sound exposure was much bigger than before the sound exposure. The average stomata opening area before the exposure was 35.85 µm2, while during the exposure was 49.18 µm2.

The stomata have its own working system because of the special nature that lied in the sub-microscopic anatomy within its cell wall. The stomata functioned as a regulator of various gases exchange on a regular basis, i.e. on the inside parts of plants with outside air. The stomata opened because the guard cell takes water and bulges, then the bulging guard cell pushed the inner wall of the stomata until it was docked. The guard cells can expand outwards, especially the outer wall. The increase of the cross-section on the stomata opening during sound exposure makes the plant able to absorb nutrients more optimally, especially during the photosynthesis process. These movements actually came from guard cells that able to change its shape due to the "elastic" cell walls (Sutrian, 2011). The inner wall was then attracted by the microfibrils which impact the stomata opening (Franks et al., 1995).

STEM Implementation using AOGS to Increase Maize Productivity

The development of STEM model began with an analysis of conceptual definitions of variables that need to be developed in the context of science, technology, engineering, and mathematics. The research was started by need analysis and empirical findings from the learning process that had been carried out. The results of this conceptual analysis were then upgraded to an operational definition in the form of STEM draft model using AOGS to increase the growth rate and productivity of maize. The initial draft that was compiled was then criticized by the research team and experts in the field of evaluation through Delphi technique. The Delphi results impacted the initial draft experiencing many changes, especially the contents of the model components, the form of learning activities, the type of learning evaluation, the accuracy of the model related to the learning and student characteristics, and language construction problems.

The STEM development in this study was prepared by referring to the component mapping as shown in Table 5 below.

Table 5. Mapping STEM Components in Critical Thinking and Science Process Skills

No	STEM	Critical Thinking	Science Process Skills
(1)	(2)	(3)	(4)
1	*Science* a. Observing the functions and uses of sound in life, specifically the function of sound to increase the rate of plant growth and productivity. b. Observing the functions and uses of sound in agriculture to collect information on whether there is an effect on plant growth and productivity. c. Conducting experiments using AOGS to determine the effect of sound towards leaf stomata openings with frequency	Providing basic clarification related to the problem. a. Focusing problems, analyzing arguments, asking and answering questions. b. Identifying sound wave material in everyday life. c. Estimating possible answers to sound wave characteristics related to the application of sound waves in agriculture. d. Determining the relationship between sound frequency and intensity of physical variables in plants (in this study, the	Observing Grouping Formulating Hypothesis Planning Trial

	variations.	opening of leaf stomata).	
2	*Technology* Technology as the application of science. a. Observing science technology, namely AOGS, and discovering phenomena related to the application of physical concepts in the biological field, i.e. the opening of leaf stomata. b. Analyzing how sound can cause stomata to open, and how it impacts the variations of frequency and intensity.	Giving opinions, making initial clarifications and further clarifications. a. Analyzing the application of sound waves in agriculture. b. Giving his opinion after observing the AOGS demonstration. c. Analyzing the application of AOGS in agriculture.	Observing Grouping Interpreting Predicting Formulating Hypothesis Planning Trial
3	*Engineering* Science of Engineering a. Solving problems by providing solutions regarding AOGS technology assisted IoT b. Installing AOGS which serves to increase the rate of growth and productivity of plants by including it as teaching materials for Science Practicum.	Making initial clarifications and further clarifications. a. Identifying various AOGS frequencies applied to maize growth and productivity stimulators. b. Analyzing the effect of AOGS sound intensity applied to the growth of stimulator and maize productivity.	Grouping Predicting Formulating Hypothesis Planning Trial
4	*Mathematics* Mathematics as a Tool a. Observing the function and use of AOGS as a stimulator of growth and productivity of maize plants, so that it can be analyzed the characteristics of maize plants and their stomata b. Measuring stomatal openings, describing data and making interpretation. c. Conducting an experiment on the application of AOGSl, so that it can analyze how it relates to an increase in plant growth rate and productivity.	Making initial clarifications and further clarifications, expressing opinions, and making conclusions. a. Analyzing AOGS characteristics and sound characteristics. b. Applying AOGS to increase growth rate and productivity by analyzing the bond between frequency and intensity. c. Analyzing growth and productivity chart of maize.	Interpreting Predicting Formulating Hypothesis Planning Trial Communicatin g

The STEM model in AOGS application to increase the productivity of maize plants had been empirically tested and it had met the Goodness of Fit Index criteria using Confirmatory Factor Analysis (CFA). The instruments supported the model development had also been tested and the validity of> 0.30, and the reliability of> 0.70. Thus, the developed STEM model can be used in the research.

The results of this study are consistent with research conducted by Rosana, Kadarisman and Suryadarma (1995), which explains that the activities of outdoor learning systems with the use of growth stimulator technology using natural animal sounds succeed in improving students' learning outcomes. The integrated science learning models of the Audio Bio-harmonic System has also succeeded in enhancing students' learning results (Rosana et al., 2017). The application of STEM model in the form of field practicum has successfully involved students in community services which is integrated into the curriculum (Koliba, Campbell & Shapiro, 2006). It can be a solution to promote the link and match between lecture material and community service (Butin, 2003; Gelmon, 2000; Holland, 2001). This kind of lecture requires an integrated approach in case of a comprehensive assessment and evaluation as well as a report that is able to describe its complexity (Karayan & Gathercoal, 2005; Mabry, 1998; Moore, 1999; Steinke & Buresh, 2002).

The results of this study are consistent with research conducted by Rosana et al. (2019), which implements STEM model in Biophysical Practicum activities with 32 operational test subjects. The operational field trial aims to find out the practicality and effectiveness of STEM model through AOGS implementation in the field located in Sidorejo Hamlet, Selomartani Village, Kalasan, Yogyakarta. The growth rate of maize is measured every week as presented in the following graph.

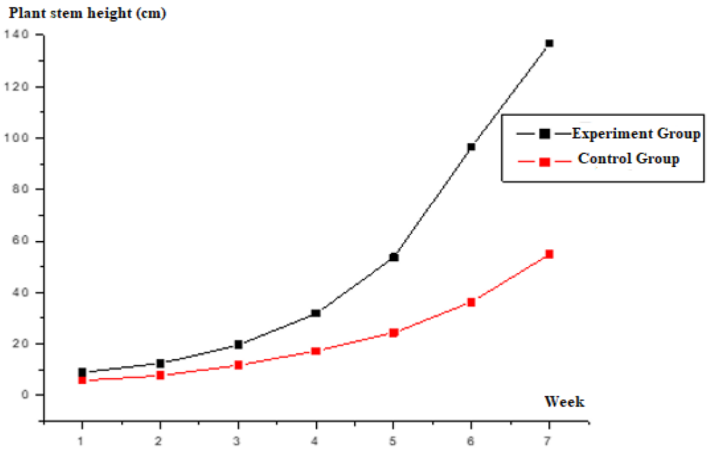

Figure 6. Maize growth rate (per week)

Based on the graph, it can be seen that the height of the maize plant which was given treatment (AOGS with the frequency of 3500 Hz) was bigger than the control plant (without sound exposure of AOGS). These results prove that AOGS devices are effective to increase the growth rate of maize plants.

Besides the growth rate, maize productivity was also measured when the maize had been around 10-11 weeks. The yield measurements were taken for treatment plants at peak frequencies of 3500 Hz. The measurements were made based on the total mass of maize treatment and control. The relationship graph between the productivity of maize treatment and control is presented below.

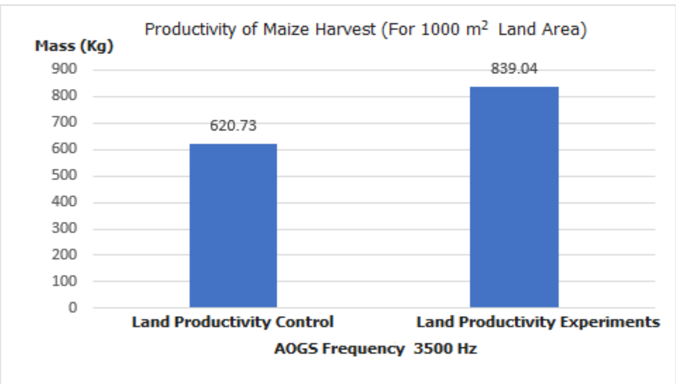

Figure 7. The productivity of maize yields on agricultural land using AOGS 3500 Hz frequency

Based on the graph above, there is a difference of the maize productivity between experimental and control plants. The maize productivity on experimental plants with a peak frequency of 3500 Hz was 893.04 kg, while the control was 620.73 kg, respectively. There is a difference of 208.31 kg in mass of maize yields between experimental and control land. This shows that there are significant differences in the maize productivity between experimental and control plants at peak frequency of 3500 Hz. The role of animal sounds has been proven to be able to increase plant productivity. This finding is similar to related previous studies which explain that the number of insects in agricultural land areas can increase yields (Lewis & Stephenson, 1966; Lewis, & Dibley, 1970; Verboom & Spoelstra, 1999).

STEM Models Implementation to Improve Process Skills and Critical Thinking

SAPA (Science A Process Approach) categorizes as science process skills into two main groups, basic science process skills and integrated science process skills (Padilla, 1990). The range of basic skills developed in this study included observing, classifying, numbers use (counting, summing, measuring), linking, communicating, generalizing, predicting, and identifying. The model of integrated skills involved formulating hypotheses, conducting experiments, controlling variables, interpreting data, and manipulating variables.

The measurement results of the process skills were done when the students had Science practicum including AOGS application, growth rate measurement, the maize harvest measurement, and discussion and classroom presentations. The measurement results of the process skills can be seen in the following Table 6.

Table 6. The percentages and categories per Indicators of Students Process Skills when Science Practicum of AOGS

Skills Type Process	No.	Indicators	Percentage (%)	Category
Basic skill	1.	Observing	73,28	Tinggi
	2.	Grouping	71,46	Tinggi
	3.	Using numbers	68,82	Tinggi
	4.	Connecting	54,64	Sedang
	5.	Making generalization	52,24	Sedang
	6.	Making prediction	54,62	Sedang
	7.	Communicating	51,26	Sedang
	8.	Making identification		
Integrated skill	1.	Formulating hypothesis	44,28	Tinggi
	2.	Conducting experiments	72,16	Tinggi
	3.	Controlling variables	69,34	Sedang
	4.	Interpreting data	52,72	Sedang
	5.	Skill of variables manipulation	51,16	Sedang

The indicator of science process skills that had the highest percentage is the observing indicator with 73.28%. The high achievement of science process skills in observing indicators since the students were trained to conduct field activities to observe and directly measure the growth rate and productivity of maize plants which was given AOGS treatment. One external factor that influenced learning outcomes was the students' opportunity to be directly involved in the learning process, for example, the opportunity to conduct experiments. Moreover, investigation or experiment can train students to acquire science process skills (Riess, 2000).

The indicator of science process skills with the lowest percentage was the indicator of hypothesis formulation with 44.28%. In the instrument with the indicator of formulating a hypothesis, the exercises done by the students were in the material of Science Learning Evaluation. Another factor that caused the low indicators of hypothesis formulation because the students were not accustomed to formulate research questions properly. It is in line with several studies (Kartimi, Gloria & Aryani, 2013). When lecturers ask students to express their opinions on certain problems, students cannot give proper answers. The results of this study are also in accordance with the studies (Ratnasari, Sukarmin & Suparmi, 2017), which states that indicators of science process skills with the low percentage were the indicator of hypotheses formulation.

The results of this study are relevant to the opinion from Radford et al. (1992) which revealed that there are three conditions that must be fulfilled within the learning process to make sure the students can experience the learning process of the science process skills. These conditions include a) the understanding of science process skills and their importance in learning by teachers; b) the opportunity for students to practice their scientific process skills; c) the existence of evaluation activities regarding the development of science process skills possessed by students. The application of AOGS to increase the rate of growth and productivity of plants has succeeded in providing meaningful experiences for students so that they can improve their process skills.

Another developed ability when practicing Science with AOGS implementation is students’ critical thinking. Pikket and Foster (1996) state that critical thinking is a type of higher thinking that not only memorizes material but also uses and manipulates materials in new situations. Critical thinking involves the type of reflective thinking about the activities that have been done (Dantas-Whitney, 2002). According to Scrivan (Fisher, 2011) critical thinking as an 'expertise' activity to interpret and evaluate the results of observation, communication, information, and arguments. Fisher (2011) defines critical thinking as the ability to interpret, analyze, and evaluate ideas and arguments. The ability to think critically is now considered as basic ability that is very important to be mastered like reading and writing ability. Critical thinking involves goal-directed thinking in the process of decision making based on evidence which is not just guessing in the process of scientific problem solving (Nugent & Vitale, 2008) According to Glazer (2021), mathematical critical thinking includes abilities and dispositions combined with preliminary knowledge, mathematical reasoning abilities, and cognitive strategies to generalize, prove, access unusual mathematical situations reflectively.

Referring to these definitions, the concept of critical thinking used in this study is the ability to interpret, arrange clarify, analyze, evaluate (an idea, observations, information, or argument), and make decisions based on the existed evidence. The results are shown in Table 7 below.

Table 7. Percentages and Categories per Indicator of Students' Critical Thinking in Science Practicum with AOGS application

No.	Indicators	Percentage (%)	Category
1.	Ability to make interpretation	71,26	High
2.	Ability to arrange clarification	56,88	Moderate
3.	Ability to make analysis	70,92	High
4.	Ability to make evaluation (an idea, observations, information or argument)	60,74	Moderate
5.	Ability to make decisions based on evidence	56,28	Moderate

Indicators of critical thinking from students have not optimally developed. Only indicators of ability to make interpretation (71.26%) and analysis (70.92%) were included in the high category, while other indicators are in the moderate category because it takes a long time to develop maximum critical thinking skills. It is not easy to develop critical thinking since it involves logical reasoning, determination between facts and opinions, fact investigation and self-questioning strategies (Wood, 2002). In addition, Ennis (1981) and Langrehr (1999) highlight that critical thinking is evaluative thinking that involves the use of relevant criteria in assessing information in case of its accuracy, relevance, reliability, consistency, and bias.

Conclusion

The application of the BLUVARIOT based on STEM approach through the application of AOGS technology assisted IoT in the Science Practicum has proven to be the right solution to develop students' critical thinking and process skills in the Natural Sciences Study Program, Universitas Negeri Yogyakarta. The application of this approach in science learning can solve the students' difficulties in connecting STEM elements with the theories learned in Science learning by using the integrated technology in accordance with basic competencies and learning indicators. The AOGS engineering realistic model to increase the growth rate and productivity of maize in Science learning directly involves students in realistic learning through technology application to help farmer communities. The results of this independent study resulted in three aspects, (1) the production of STEM models combined with the use of AOGS technology assisted IoT, (2) the development of the students and farmers skills in using AOGS technology assisted IoT, to increase the growth rate and productivity of maize plants, and (3) the significant development of process skills and critical thinking among the students who participated in Science Practicum courses.

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