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THE EFFECT OF LEARNING BIOPHYSICS WITH STEM APPROACH ON SCIENCE PROCESS SKILLS AND CRITICAL THINKING: FIELD STUDY ON APPLICATION OF NA-AOGS FOR INCREASING SOYBEAN PRODUCTIVITY AND GROWTH RATE

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ABSTRACT

Efforts to fulfill food security to anticipate population growth in Indonesia need to be supported by universities through research and community service. The application of the Natural Animal Audio Organic Growth System (NA-AOGS) with a STEM (Science, Technology, Engineering, and Mathematics) approach is an effort to help the community increase crop yields and accelerate the growth of soybeans (*Glycine max (L.) Merill*). The research method used is R&D (Research & Development). This model is a spiral cycle using five main activities as follows: (1) defining the product concept; (2) designing research products; (3) demonstrating the product in a limited trial; (4) developing the product through evaluating the test results; and (5) presenting the product to the public. The direct impact of learning is the improvement of science process skills and critical thinking of students in the Biophysics course at the Natural Sciences Study Program, Universitas Negeri Yogyakarta. This impact is due to the effective application of STEM to link science learning with contextual technology and engineering (NA-AOGS), environmentally friendly technology (only using natural animal sound frequency variables), mathematical elements in data analysis, and analysis of soybeans growth charts. The economic impact of this research is the scientific contribution in the form of adaptation of agricultural technology to increase soybean yields (an increase of 130.38% on an area of 2750 m^2). The novelty and contribution of this research is the integration of science learning with agricultural techniques and technology with a STEM approach to improve the welfare of farmers in educational institutions as a new model in science learning.

Keywords: STEM; NA-AOGS; soybeans; critical thinking; science process skills

INTRODUCTION

Significant changes occur in various fields due to the industrial revolution 4.0. These changes also impact agriculture and education, implying the need for changes in the science learning system at the primary, secondary, and higher education levels. The dominance of digital technology devices in the learning process, driven by the ongoing COVID-19 pandemic, has led to a high intensity of interaction between teachers and students using digital devices. For this reason, specific skills are needed to anticipate global developments that require speed and accuracy of the information and the ability to solve increasingly complex problems.

Mastery of the 4Cs (critical thinking, creative problem solving, communication, and collaboration) is required to meet the demands of mastering 21st-century skills. Therefore, in this research, Science Process-Skills (SP-Skills) and critical thinking (CT) have been developed. SP-

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Skills are related to efforts to build basic skills as a prospective researcher, while CT becomes a valuable asset to find alternative solutions to various problems students face in their future lives. Activities in SP-Skills, if carried out consistently in the learning process, can increase student perceptions in "careers in science" and "careers with science" (Salonen et al., 2017). In addition, SP-Skills can be reviewed from three subskills levels: science specification, scientific thinking, and science metacognition (Kruit et al., 2018). SP-Skills help students learn by doing science, experiencing the science process, linking science objects with their daily lives, and facilitating students to communicate their scientific and technological findings in real life (Setiyawan & Sugiyanto, 2020). The science process is defined as a procedure shaped by analytical and CT skills (Ministry of National Education (MoNE), 2013).

Students need adequate scientific provisions to apply their learning outcomes in scientific theories and concepts, the reality of scientific objects, and generalizations and interrelated natural laws to form a life skill needed for their future. All of those forms must be presented in science learning so that students can realize skills that reflect the correct behavior of scientists in designing an experimental activity and problem-solving in every field of science. SP-Skills are the core of concepts and research in science, so these skills are developed effectively and efficiently in teaching and learning processes in various countries. For example, the American Association for the Advancement of Science developed the 'A-Science Process Approach' (SAPA) between 1963 and 1974. This project taught SP-Skills in a specialized science learning curriculum at primary and secondary school levels (Brotherton & Preece, 1995). Researchers at the university level have also developed the same thing.

CT skills are also essential to be developed in science learning as one of the supports for students' life skills growth. This skill develops the ability to understand the interrelationships between systems, provide reasons, make the right choices from complex choices, and set priorities to express and analyze to solve problems. Furthermore, Glazer (2001) and Karbalaei (2012) reveals that CT skills are related to the intellectual discipline process actively and skillfully creating and applying concepts, analyzing, synthesizing, or evaluating various relevant, meaningful information based on the results of observation, experience, reflection, reasoning, or communication, as a guide to building confidence in choosing the right course of action. Bloom (1956) provides a reference that supports CT skills by dividing the participant's way of thinking into three domains (Cognitive, Affective, and Psychomotor). Analysis, synthesis, and evaluation abilities are related to CT skills based on Bloom's cognitive taxonomy, while those related to basic material mastery competencies are the level of knowledge, understanding, and application (Rahman & Manaf, 2017). Students need CT skills to follow the pace of information flow in this digital era. Students need to be critical of various information that is true or false, useful or useless, legal or illegal, safe or unsafe so that they can distinguish truth from lies, fact from opinion, or fiction from nonfiction. This skill is important for students to make wise decisions in dealing with various problems in their lives.

The application of the STEM approach to equip students to develop problem-solving skills and CT is very appropriate to be implemented in learning at the primary, secondary, and tertiary levels so that they are skilled in the application of science which has an impact on the growth of the ability to create technology with constructive implications for the environment. The improved ability to select and collect big data and interpret and use it results from the strong link between science and mathematics. The increasing awareness in various countries about the importance of STEM education cannot be separated from efforts to meet global demands that have to meet increasingly acute economic challenges (Honey et al., 2012; Marginson et al., 2013; English, 2016).

Science learning using the STEM approach is implemented in this research because it is proven effective in developing Higher-order Thinking Skills (HOTS) such as creative problem-solving skills and CT skills in project design and inference. Moreover, the STEM approach also fosters positive responsibility, perseverance, adaptability, cooperation, and organizational skills (Koehler et al., 2021). Students' CT skills that can also be developed with STEM learning are reflective thinking about what to believe and do (Duran & Sendang, 2012). Nuray & Morgil (2010) explain that applying the STEM learning model improves the mental cycle, logical thinking skills, and students' understanding. Current conditions related to the need for education to apply the STEM approach are relevant to efforts to prepare 21st-century skills. The world of education contributes to facilitating graduates to contribute positively to society through STEM learning based on the development of digital technology engineering as the main supporter of global economic development (Sofowora & Adekomi, 2012).

According to the NSTA Position Statement (1990), many teachers have applied the STEM approach in science learning for a long time, but the lack of technological support in the classroom makes students difficult to connect the five elements in STEM in a real way. Students do not yet understand how mathematics plays a role in developing science so that it plays a role in engineering technology and its environment. To connect the gap between theory and practice of science learning, this study applied Natural Animal Audio Organic Growth System (NA-AOGS) technology to optimize the growth and productivity of soybeans organically in the Biophysics course.

The STEM approach in science learning functions in building connectivity between scientific inquiry activities with the ability to formulate research questions that are sought for answers through scientific investigations where they are involved in the engineering design process to solve problems (Kennedy & Odell, 2014). Akcay & Akcay (2015), in their research, find that the application of the STEM approach has a better impact on improving understanding of concepts and student learning outcomes compared to direct learning with the aid of reference books, even though the same teacher carried out the two learning approaches. Correspondingly, Moore et al. (2014) explain that the STEM approach in learning is an effort to integrate both spatially and as a whole from science, technology, engineering, and mathematics into one learning activity that combines the material in the subject with problems in the real world (p. 38). Equally important, the STEM approach attempts to anticipate concerns related to economic growth in both developed and developing countries (Kennedy & Odell, 2014).

The application of STEM in science learning based on an analysis of related situations has not yet achieved food self-sufficiency in Indonesia. Several leading commodities, including soybeans, are still imported from several producing countries. In comparison, the need for soybeans in Indonesia is very high because it is the raw material for making tempeh and tofu, which are the favorite foods of the Indonesian people. Therefore, this research is significant to provide practical competence for students through science learning using the STEM approach. Increasing the growth and productivity of soybeans is practiced in an appropriate technology in the form of NA-AOGS to solve food scarcity. The STEM approach in science learning is closely related to problem-solving skills in the real world (Hong, 2017). The potential of children to build a strong relevance between learning materials and local potential in their environment can also be developed using the STEM approach (Sochacka et al., 2016). Guyotte et al. (2014) explain that the application of the STEM approach is considered a reform of the learning model because students learn through recognizing patterns and practicing creative thinking skills, observing, playing, and collaboration and communication skills in completing a task. The development of a STEM approach integrated with NA-AOGS technology in science learning encourages students to develop study materials or new scientific products at the end of the Biophysics learning process. This activity is a best practice for the application of sound wave technology in living systems. Process learning is seen as more important than just measuring the success of the final learning product because, in the learning process, there are very constructive exercises for the development of students in creative expression activities, exploration, creative thinking, engineering design, and evaluation (Perignat & Katz-Buonincontro, 2019). Another competency attribute of trained students is problem-solving skills through collaborative activities with teachers and peers (Michaud, 2014). Curiosity and open acceptance of learning experiences can also be developed through the STEAM approach (Perignat & Katz-Buonincontro, 2019). Through STEM learning, students are also trained to investigate things around them, ask questions to build knowledge by exploring, observing, discovering (Munawar, 2019).

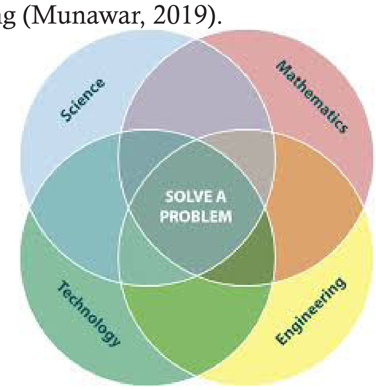


Figure 1. STEM Schemes for the Development of Problem-solving Skills (source: http://secc.sedl.org/resources/)

The STEM approach used in this study is realistic through students' learning experiences in a community service project for farmers. Students gain direct experience applying NA-AOGS technology to help soybean farmers so that scientific concepts can be easily understood, felt, analyzed, and used to solve problems in the field of food crop agriculture. The application of AGHS can also increase the relevance between theory and community needs, especially in increasing soybean productivity. This integrated learning model is very effective for building connectivity or link and match between the world of education and the world of work. An integrated learning assignment provides opportunities for students to learn through experiences that are more relevant to real-world needs to stimulate and encourage the emergence of CT skills, HOTS, problem-solving skills, and increase retention (Stohlmann et al., 2012). The steps for implementing STEM in science learning can be seen in Figure 2.

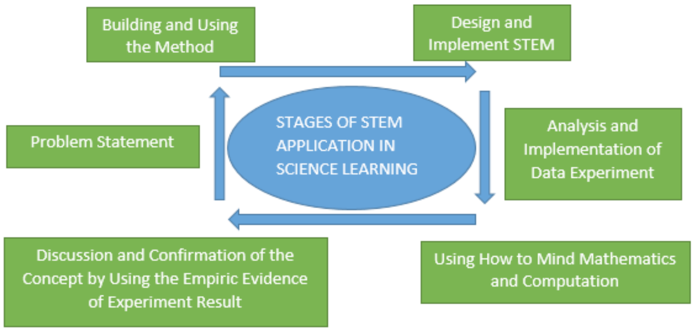


Figure 2. Steps to Apply STEM in Science Learning

Agricultural technology engineering based on animal sound frequency in NA-AOGS was chosen in STEM learning to develop technology application skills and collaboration between students and soybean farmers in Bantul Regency, Yogyakarta, Indonesia. The NA-AOGS model is an effort to intensify agriculture both as a tool and an environmentally friendly process. NA-AOGS was developed into a compatible and comprehensive tool based on microcontroller technology (embedded system). Solar energy is used as an energy source to respond to the problem of the absence of a directly accessible electricity grid in some agricultural lands. NA-AOGS technology optimizes audio intensity and frequency variables by recording the sounds of natural animals commonly found on agricultural land (e.g., crickets, cicadas, and others). It controls pests and increases the rate of growth and productivity of soybean plants because they can optimally absorb nutrients and solar energy due to the opening of leaf stomata when exposed to sound from the Audio Organic Growth System device (Rosana et al., 2017). The research results on potato plants in the Dieng Plateau and shallots in Bantul Regency increased by 87% and 57%, respectively.

In this study, science learning using the STEM approach aims to improve the SP-Skills and CT of students participating in the Biophysics course. Soybean plants were chosen because they are commodities needed by the tofu and tempeh industry, which still depend a lot on exports from other countries. Previous studies showed a significant effect of learning activities on developing SP-Skills on improving students' CT skills (Tanti et al., 2020). The previous statement is supported by other research that explains that students who have high skills will tend to have high CT skills (Ješková et al., 2016; Jatmiko et al., 2018). Diani et al. (2020) also explain that SP-Skills have a strong relationship with CT, wherewith low CT skills, the value of SP-Skills is also low.

METHODS

The research method used is R&D (Research and Development), modified from Cennamo & Kalk (2019). This model is a spiral cycle using five main activities: (1) defining the product concept; (2) designing research products; (3) demonstrating the product in a limited trial; (4) developing the product through evaluating the test results; and (5) presenting the product to the public. During the test, the NA-AOGS device used natural animal sound sources manipulated at a peak frequency of 3500 Hz. The sound was validated with the Octave 4.2.1 program. The plants studied were soybeans on the experimental land (20 m x 50 m). As a comparison, soybean plants without NA-AOGS sound exposure were used as control plants with the same planting area. Observational data recorded was soybean plant growth rate (plant height, width, and several leaves per soybean tree). Using the NIS Elements Viewer program, supporting data measured on a laboratory scale using a light microscope is the width of leaf stomata openings during NA-AOGS sound exposure. The stomata opening area was also measured using Image Raster 3.0. Meanwhile, to determine the productivity of soybeans, the mass of harvested yields was measured using Origin 8.0 and Microsoft Excel 2013.

The stages of demonstrating the product in a limited trial and developing the product through evaluating the test results were carried out using a true experimental design using an experimental group and a control group with random samples. The experimental class is 35 students of Class C, while the control class is 36 students of Class A. The students of both classes are participants in the Biophysics course for the 2019/2020 academic year. Data collection related to SP-Skills and CT skills during the Biophysics learning process was carried out using validation instruments in performance tests. The tests were declared valid and reliable.

An important stage in R&D research is testing the validity by referring to the standard of Biophysics material and its feasibility as a learning medium using the STEM approach. Experienced lecturers in the field of Biophysics carry out the validation process by using the validation of Lawshe (1975) using three rating scales as follows: (1) unnecessary; (2) useful but not necessary; and (3) necessary (Azwar, 2011). The assessment is carried out by expert judgment using the CVI (Content Validity Index) methods or the V Aiken coefficient. The results of the validation of each aspect of the product assessment achieved an Aiken score above 0.75. Therefore, the Biophysics learning device using the STEM approach is declared valid and suitable for further research activities. Learning devices that have met the validity criteria are then included in a sample of students in the Biophysics class to determine the practicality of the model. For the practicality test, a practicum instrument in a questionnaire was used to determine the perception of the science learning carried out.

Agricultural areas in Bantul Regency are used as research locations during the implementation of science learning using the STEM approach and NA-AOGS tools. The learning design using an outdoor learning system in the NA-AOGS implementation project is then evaluated for the success of the learning process and product using a test instrument. Multiple-choice test instruments and essays were developed to measure the achievement of CT skills indicators, and performance appraisal sheets were used to measure learning mastery of SP-Skills indicators.

Table 1. Stages of Biophysics Learning Activities with STEM Approach using NA-AOGS

Research Activity Syntax	Types of Research Activities
Defining the product concept	Analyzing biophysics content characteristics and student characteristics to formulate learning outcomes, learning needs, and operational definitions of SP-Skills indicators and CT indicators as dependent variables developed in STEM-based NA-AOGS learning
Designing the research product	Designing a learning model and subject-specific pedagogy (SSP) to develop Biophysics learning with a STEM approach using the NA-AOGS tools The stages of developing learning device products are carried out by validating the suitability of Biophysics material and testing SSP in terms of practicality and effectiveness in developing indicators of SP-Skills and indicators of CT.
	Validating the SSP and Biophysics learning model using the STEM approach through an assessment by a team of experts in science and a team of learning media experts
Demonstrating the product in a limited trial	Testing the application of the Biophysics learning model with the STEM approach using NA-AOGS empirically in the control class and experimental class
Developing the product through the process of evaluating the test results	Field practicum on soybean farms for implementing the STEM approach using NA-AOGS and testing the practicality and effectiveness of the Biophysics learning model.
Deliver (presenting the product to the public)	Research data collection through measurement of SP-Skills and CT using research instruments that have been validated.
	Producing the final product of the STEM Biophysics learning model using the NA-AOGS device to improve SP-Skills and CT
	Describing the results of delivering the STEM Biophysics learning model using the NA-AOGS device

There are two types of data generated from the process and results of the application of the Biophysics learning model: (1) the data on the results of measuring the growth rate and productivity of soybeans stimulated by the NA-AOGS device; and (2) data on the results of the assessment of the process and learning outcomes using the STEM approach in the form of SP-Skills and students' CT. Data consists of two types of data; qualitative and quantitative data. The results in content validation for the written test assessment tool were analyzed using Lawshe's content validity. The standard of validity of the CVR (Content Validity Ratio) depends on the number of SMEs (Subject Matter Experts). CVR value must meet 0.99 so that the item can be declared valid. From the results of the product trial, it was found that the CVR value exceeded 0.99. Thus all items on the process skills and CT instrument were declared valid (Lawshe, 1975) to be used in further research. The expert judgment shows the results of the validity of the assessment 0.3, which means that all items on the two instruments are valid.

Field testing of the SP-Skills and CT instrument was analyzed using the construct validity of Exploratory Factor Analysis (EFA) using Cronbach's Alpha reliability coefficient. The reliability of the empirical test in the Biophysics learning class shows no significant difference between the raters' assessment results. The calculation of KMO is 0.712, and the average MSA is 0.749 in the first trial. In the second trial, the KMO is 0.828, and the average MSA is 0.854. Based on the factor load, all items on the two instruments have a value of 0.3, so the overall test items for SP-Skills and CT are valid and reliable.

Quantitative data is categorized based on the results of descriptive data analysis determined based on the data mean and standard deviation. Table 2 is used to interpret the results of the measurement of SP-Skills and CT based on criteria that are arranged based on the mean and standard deviation.

Table 2. Categories of Assessment of CT Skills and SP-Skills (Modification of Syarifudin, 2011)

No.	Categories	Data Range
1.	Low	$X \leq M - 1\ SD$
2.	Moderate	$M - 1\ SD < X \leq M + 1\ SD$
3.	High	$X > M + 1\ SD$

X = Acquisition scores from CT indicators or SP-Skills indicators
M = Mean
SD = Standard Deviation

In the application of NA-AOGS in Biophysics learning using the STEM approach, a Randomized Block Design was used to examine the effect of three treatment factors arranged in a factorial manner, namely, variation of treatment time (t), variation of audio intensity (I), and variation of audio frequency.

Table 3. Grouping of Variables in a Randomized Block Design to Test the Effect of Three Treatment Factors

Control Variable	Sound treatment characteristics of NA-AOGS	Dependent Variable
NA-AOGS exposure time, sound frequency level, and foliar fertilizer mass	Sound intensity level	Growth rate and productivity of soybeans plant
Sound intensity level, frequency level, and foliar fertilizer mass	NA-AOGS exposure time	Growth rate and productivity of soybeans plant
NA-AOGS exposure time, sound intensity level, and foliar fertilizer mass	Sound frequency level	Growth rate and productivity of soybeans plant

RESULTS AND DISCUSSION

In the application of NA-AOGS to increase soybean productivity, the sound source of crickets (Gryllidae) is used. Audio frequency of crickets was recorded, then modified using Soundforge, and produced output with a frequency range of 5000 Hz with a peak frequency of 4747 Hz. Sound waves were manipulated at a peak frequency of 5000 Hz with Octave 4.21 software, as shown in Figure 3. The x-axis is the frequency, and the y-axis is the magnitude. By using Octave 4.21, the peak frequency is also analyzed to obtain the signal spectrum. The result of recording the sound of crickets (Gryllidae) is processed using Soundforge to become the input for the NA-AOGS device. The Soundforge analysis is then manipulated into several frequencies that are adjusted to the characteristics of the test plants, which will increase their growth rate and productivity.

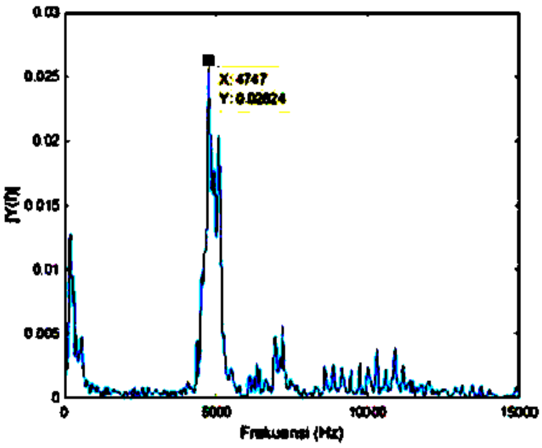


Figure 3. The Results of the Optimal Frequency Analysis to be Applied in NA-AOGS from the Sound of Crickets

In the implementation of the application of NA-AOGS, the frequency, sound intensity, and sound patterns are modified so that they can be adapted to the characteristics of the type of plant that will be tested to increase plant growth and productivity (Dwandaru et al., 2015; Alvianty & Kadarisman, 2018). The block diagram of the electronic circuit of the NA-AOGS is in Figure 4.

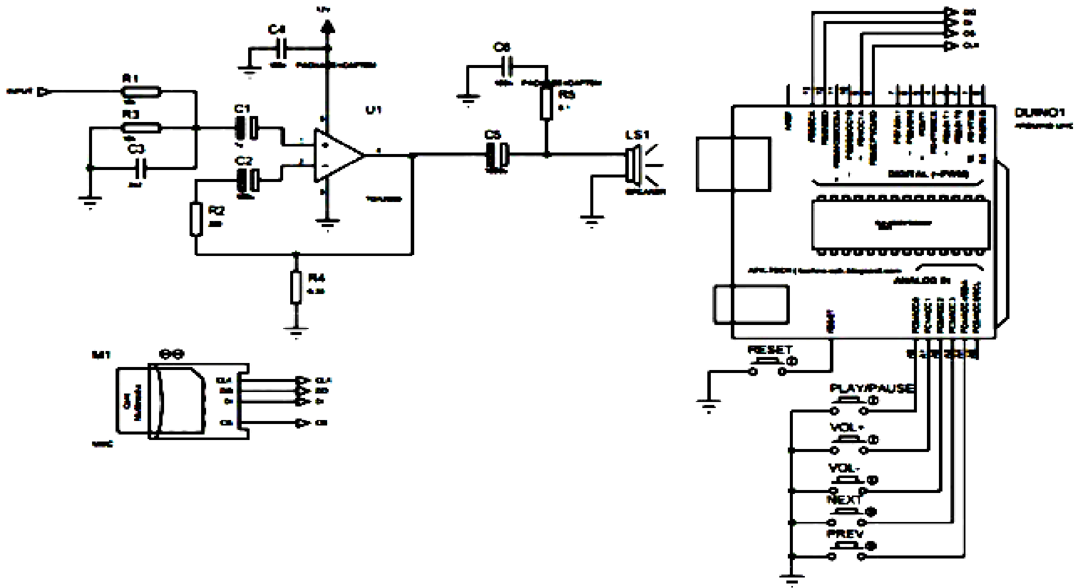
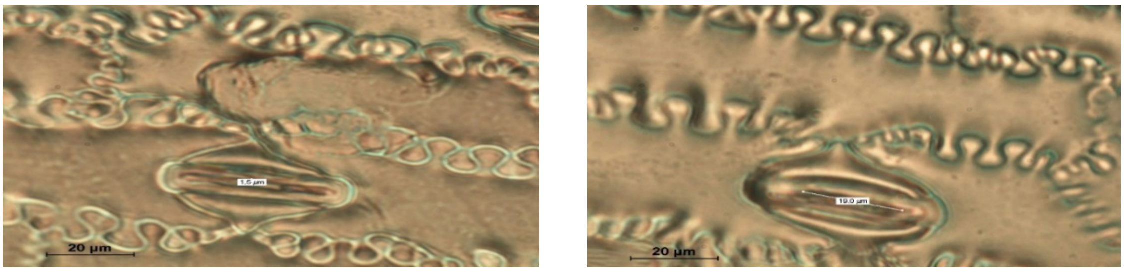


Figure 4. The Block Diagram of the Electronic Circuit of the NA-AOGS

The way NA-AOGS works in this study is to modify the sound of crickets (Gryllidae) by manipulating their frequency and intensity to stimulate the opening of leaf stomata during photosynthesis. Stomata open due to vibration disturbances that transfer energy to the leaf surface and stimulate leaf stomata to open wider (Kadarisman et al., 2011). This research activity found that manipulation of the sound of crickets with a peak frequency of 3500 Hz most optimally affected the opening of stomata on soybean leaves. The following figure shows the stomata opening of soybean leaves viewed with a light microscope before exposure to sound from NA-AOGS (5a) and when exposed to sound (5b).



(a) (b)

Figure 5. Stomata Opening (a) before NA-AOGS Implementation (stomata Length 15.1 µm) and (b) during NA-AOGS Implementation (Stomata Length 19.0 µm)

From Figure 5 (a) and 5 (b), there is a difference in the stomata openings before and after using NA-AOGS. The mean value of stomata opening, when exposed to sound, was much larger than the measurement when NA-AOGS was not applied. Before exposure, the average stomata opening area was 35.85 m2 and increased significantly at the time of exposure to 49.18 m2. The increase happens because stomata have their working system due to their cell walls' special properties in the sub-microscopic anatomy.

Stomata function as a regulator of various gases exchange between the inside of the plant and its environment. Stomata open because guard cells take in water and bulge, then the bulging guard cells push the inner walls of the stomata closer together. Guard cells can expand to the outside, especially the outer wall. The increase in the cross-sectional area due to exposure to sound at the stomata opening causes soybean plants through their leaves to absorb nutrients more optimally, especially during the photosynthesis process. The stomata opening is due to changes in the shape of the guard cells due to their elastic walls (Sarjani et al, 2017). The inner wall is then attracted by microfibrils causing the stomata to open (Franks et al., 1995).

The development of the STEM Biophysics learning model using NA-AOGS begins with defining the product concept: a study of relevant theories, analysis of learning needs, and community needs (soybean farmers). The second stage is designing research products: designing SSP for STEM-based Biophysics learning, engineering NA-AOGS to be applied in outdoor learning systems, designing research instruments to measure SP-Skills and CT. The third stage is demonstrating the product in a limited trial: testing the SSP, research instruments, and practical learning using NA-AOGS on ten students in the Biophysics course. The fourth stage is developing the product through evaluating the test results: evaluating the application of the CNS and NA-AOGS products in Biophysics learning, making revisions based on the evaluation results, and compiling the final product to be applied in the actual learning classroom. The last stage is presenting the product to the public: presentations and publications in international seminars, publications in reputable international journals, and training on the application of NA-AOGS for soybean farmers in the form of community service activities.

In Table 4, a logbook of research results is presented after revising the SSP for Biophysics learning based on the mapping of STEM components. The research results in empirical trials of the application of the science learning model with the STEM approach using NA-AOGS have been carried out and can increase the growth rate and productivity of soybean plants. The empirical test results have met the Goodness of Fit Index criteria using Confirmatory Factor Analysis (CFA). The research instruments, both test and non-test, were used in the development of the Biophysics learning model have also met the aspects of validity > 0.30 and reliability > 0.70. Thus, the science learning model with the STEM approach using the NA-AOGS developed can be implemented in research. Research by Rosana et al. (2019) is relevant to the results of this study which explains that science learning with the outdoor learning system method using the application of growth stimulator technology using animal sounds has succeeded in improving SP-Skills.

The integrated science learning model of the Audio Bio Harmonic System has succeeded in increasing the ability to apply concepts and combine the knowledge of Physics and Biology of students (Rosana et al., 2017). The application of the STEM model in field practice can increase student participation in solving problems that exist in a society that is integrated into the curriculum (Koliba et al., 2006).

Table 4. Results of Mapping SP-Skills and CT Based on STEM components in Biophysics Learning

No	STEM	CT	SP-Skills
(1)	(2)	(3)	(4)
1	Science The theory of sound waves and their application in living systems Sound analysis practicum using Soundforge and determining the most suitable frequency according to the characteristics of soybean plants. Practical implementation of NA-AOGS to determine the effect of sound on leaf stomata opening with variations in sound frequency and intensity	Clarifying the basic problems in learning Biophysics; Determine the focus of the problem, analyze the rationalization of the argument, ask or answer questions. Identify sound wave concepts that are applied to everyday life. Develop ideas to find solutions related to problems in the agricultural sector and relate them to the theory and concept of sound waves. Identify the effect of variations in sound frequency and intensity on plant growth and productivity variables (the results of the theoretical study lead to leaf stomata opening).	Observation of Science Objects, Classification of research objects, Formulating hypothesis, Project planning and NA-AOGS product testing
2	Technology Technology as an embodiment of the concept of science Observe the application of scientific concepts into NA-AOGS technology to increase soybean growth rate and productivity and discover leaf stomata phenomena related to the application of physics concepts in biology. Connect scientific concepts with how sound can cause stomata to open and affect the audio frequency and intensity variations.	Describing ideas, clarifying initial concepts, and clarifying further concepts Describe the effect of sound waves in application in agriculture. Explore ideas and opinions based on observations on the application of NA-AOGS to soybean plants. Analyze the appropriate characteristics of NA-AOGS to be implemented in agriculture.	Observation of Science Objects, Classification of research objects, Interpreting Predicting Formulating hypothesis, Project planning and NA-AOGS product testing
3	Engineering Engineering serves as a bridge between science and technology applications: Solve the application of science in agriculture with solutions in the form of engineering NA-AOGS Apply NA-AOGS, which functions to increase plant growth rate and productivity as teaching material for Biophysics Practicum.	Identify scientific concepts as a starting point for product engineering and identifying the resulting outputs. Identify various natural animal frequencies as input to the NA-AOGS system applied to the stimulator of soybean growth and productivity. Identify the most optimal sound intensity of NA-AOGS to be applied as a stimulator of soybean growth and productivity.	Classification of research objects, Interpreting Predicting Formulating hypothesis, Project planning, and NA-AOGS product testing
4	Mathematics Mathematics serves as a tool to support the translation of scientific concepts Utilize the graphs and equations that underlie the use of NA-AOGS as a stimulator of soybean growth and productivity. Mathematics is also used to characterize the physical variables of soybean plants and their stomata. Analyze stomatal opening variables, describe data, and make interpretations. Measure environmental variables that affect the application of NA-AOGS (intensity and frequency of sunlight, pressure, temperature, and humidity)	Identify initial needs and further clarification, express opinions, and conclude. Identify the characteristics of the NA-AOGS that are relevant to their learning needs. Analyze the relationship between light frequency and intensity in the application of NA-AOGS to increase growth rate and productivity. Use mathematical equations and analyzing the growth and productivity graph of soybeans.	Interpreting Predicting Formulating Hypothesis Planning Trial Communicating

*(The results of the researcher's thoughts are based on abstractions from theoretical studies)

The application of the STEM approach in learning can be a solution to develop a link and match between lecture materials and community service programs (Gelmon, 2000; Holland, 2001; Butin, 2003). A comprehensive evaluation is needed to describe the complexity of the relationship between its components (Mabry, 1998; Moore, 1999; Steinke & Buresh, 2002; Karayan & Gathercoal, 2005).

The research results are the development of the research topic conducted by Rosana et al. (2019) to implement the STEM model in Biophysics Practicum activities. In this study, the results of operational trials can increase the practicality and effectiveness of the STEM model through the implementation of Audio Stimulator - Multi-Sensor - Pest Control (IASMUSPEC) in increasing the productivity of corn in Sidorejo Hamlet, Selomartani Village, Kalasan, Yogyakarta. The growth rate is measured every week, as shown in the Figure 6.

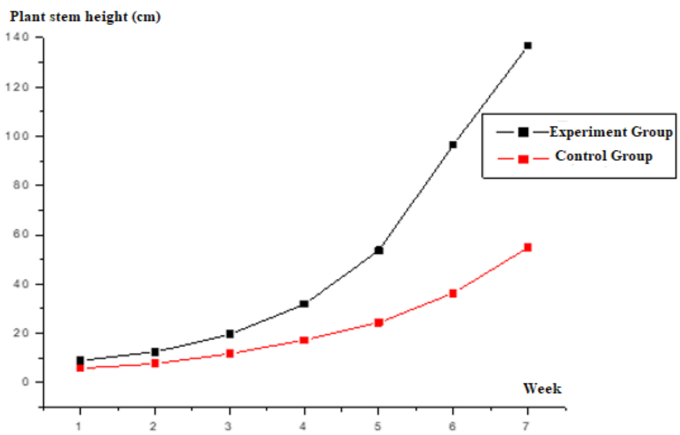


Figure 6. Soybeans Growth Rate (per week)

The graph of the research data processing results above shows that the morphological aspects of soybean plants treated (NA-AOGS with a frequency of 3500 Hz) are higher than the control plants (without NA-AOGS). This result explains that the NA-AOGS technology device is effective in increasing the growth rate of soybean plants. Measurement of soybean crop productivity also showed a significant difference in soybean planting age of 10-11 weeks. With the peak frequency of NA-AOGS 3500 Hz, there is a difference of 130.38%. The total mass of the yields of the control group is 632.03 kg, and the experimental group is 824.06 kg. Soybean yield productivity graphs on experimental and control plants are presented below.

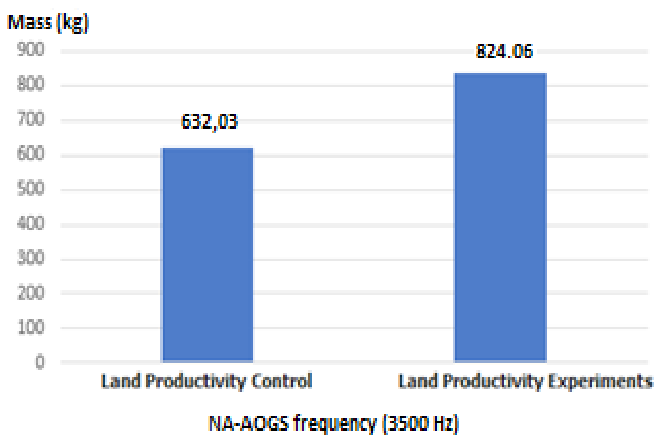


Figure 7. Soybean Mass Harvested on Experimental Land Using NA-AOGS at a Modified Frequency of 3500 Hz

The illustration of the difference in soybean productivity between experimental and control plants in the graph above shows that animal sound frequencies are proven to increase crop productivity. The research results are supported by data from previous studies, which explain a relationship between the number of insects on agricultural land and increased yields (Lewis & Stephenson, 1966; Lewis & Dibley, 1970; Verboom & Spoelstra, 1999).

In addition to the results of technical research in increasing and growing soybean plants, this research also succeeded in developing the academic and pedagogic aspects of Biophysics learning. The relevant student competencies developed through the application of NA-AOGS with this STEM approach are SP-Skills and CT. The developed SP-Skills are divided into two main groups, basic SP-Skills and integrated SP-Skills. The types of basic SP-Skills developed in this study consisted of making an "educated guess" about an object or event based on previously gathered data or information (Inferring), using both standard and nonstandard measures or estimates to describe the dimensions of an object or event (Measuring), using words or graphic symbols to describe an action, object or event (Communicating), grouping or ordering objects or events into categories based on properties or criteria (Classifying), and stating the outcome of a future event based on a pattern of evidence (Predicting). The following are The integrated SP-Skills model: identifying variables that can affect an experimental outcome, keeping most constant while manipulating only the independent variable (Controlling variables), stating how to measure a variable in an experiment (Defining operationally), stating the expected outcome of an experiment (Formulating hypotheses), organizing data and drawing conclusions from it (Interpreting data), experimenting and interpreting the results of the experiment (Experimenting), and creating a mental or physical model of a process or event (Formulating models).

The results of the measurement of SP-Skills are carried out when students carry out Biophysics project activities through the application of NA-AOGS on agricultural land in Bantul Regency. The variables measured were process skills when measuring soybean growth rate and the mass of soybean yields, performance, and participation in class discussions and presentations. The data on the measurement of SP-Skills are presented in Table 5.

Table 5. Data on the Results of Measurement of Basic and Integrated Process Skills in Outdoor Activities Learning System Biophysics using the NA-AOGS tool

Skills Type Process	No.	Indicators	Percentage (%)	Category
Basic SP-skill	1.	Inferring	78.33	High
	2.	Measuring	52,45	Moderate
	3.	Communicating	81,26	High
	4.	Classifying	54.64	Moderate
	5.	Predicting	52.24	Moderate
Integrated SP-skill	1.	Controlling variables	50.76	Moderate
	2.	Defining operationally	76.33	High
	3.	Formulating hypotheses	50.76	Moderate
	4.	Interpreting data	51.03	Moderate
	5.	Experimenting	52.21	Moderate
	6.	Formulating models	54.32	Moderate

The measurement results using the SP-Skills instrument found that the indicator with the highest percentage of achievement is the communication indicator (81.26%). The high achievement of SP-Skills in communication indicators is due to students having complete information because they are directly involved in field activities to directly observe and measure the growth rate and productivity of soybean plants that are part of the experimental group using NA-AOGS. The involvement of students' various senses (hands-on) indirect observation of an experimental science will affect their memory (minds-on) in studying a scientific phenomenon. The previous statement follows the opinion of Reiss (2000), which states that investigations or experiments can train students to acquire SP-Skills. The indicator for achieving the value of SP-Skills with the lowest percentage is formulating a hypothesis (50.76%, moderate category). The low indicator of formulating this hypothesis is caused by the ability to analyze concepts and CT of students who have not been optimally trained in learning. Students are not accustomed to being trained to formulate research questions properly. The research result is supported by Alkan (2016), showing that the formulation of hypotheses in experiential learning is effective for improving academic achievement and scientific process skills. This result is also relevant to Ratnasari et al. (2017) research, which states that the lowest percentage value on the measurement of SP-Skills indicators is the formulation of hypotheses.

This study is also following the opinion of Radford (1992), which revealed that three conditions must be met in the learning process so that students can improve SP-Skills in their learning: (a) understanding of SP-Skills and the importance of these skills in teacher learning; (b) opportunities for students to practice their scientific process skills; (c) evaluation activities regarding the development of students' SP-Skills. In support of this, the application of NA-AOGS has effectively provided a meaningful experience for students to improve their process skills through their involvement in efforts to increase soybean growth rate and productivity. In addition to SP-Skills, Biophysics learning with the STEM approach using NA-AOGS is also effective for improving students' CT skills. CT is a type of higher-order thinking that uses and manipulates material in new situations so that it does not only memorize subject matter (Pikket & Foster, 1996). Following the cognitive level, critical thinking skills are very important for education at all levels (Hudha & Batlolona, 2017). Scrivan in Fisher (2011) argues that CT is a 'skill' activity to interpret and evaluate the results of observations, communication, information, and arguments. Fisher (2011) also defines CT as the ability to interpret, analyze, and evaluate ideas and arguments.

Associated with the era of disruption due to the Industrial Revolution 4.0, CT skills are considered basic skills that are very important to master and basic reading and writing skills. Because CT involves goal-directed thinking in the decision-making process based on evidence, it is not just guesswork but through a scientific problem-solving process (Boroushaki & Lee-Luan, 2016). According to Ennis (1981), CT indicators are Elementary clarification, Basis for the decision or basic support, Inference, Advanced clarification, and Strategies and tactics.

The results of the synthesis of CT concepts used in this study are shown in Table 6.

Table 6. Percentages and Categories per Indicator of Students' CT in Biophysics Practicum with NA-AOGS application

No.	Indicators	Percentage (%)	Category
1	Elementary clarification	59.27	Moderate
2.	Basis for the decision or basic support	58.64	Moderate
3.	Inference	76.32	High
4.	Advanced clarification	55.16	Moderate
5.	Strategies and tactics	77.43	High

The measurement of CT variables in this study indicates that not all CT indicators of students can develop optimally in Biophysics learning with the STEM approach using NA-AOGS. The indicators of elementary clarification, basis for the decision or basic support, and advanced clarification, are still in the moderate category (less than 60% of their competency achievement). Only indicators of inference (76.32%) and Strategies and tactics (77.43%) are included in the high category. Scientifically this is logical because it takes a long time to develop all CT indicators to the fullest. The process of CT is quite complex because it involves logical reasoning, determination between facts and opinions, investigation of facts, and self-questioning strategies (Fahim & Eslamdoost, 2014). The CT process also involves evaluative thinking, which requires relevant criteria in assessing information in terms of accuracy, relevance, reliability, consistency, and unbiasedness (Ennis, 1981; Shek, 2018).

CONCLUSION

Two main objectives in this research are as follows: first, increasing SP-Skills and CT; and second, has succeeded in increasing soybeans' growth rate and productivity as contextual learning in helping farmers. Biophysics learning using the STEM approach through the application of NA-AOGS technology has proven to be effective for developing students' CT and SP-Skills because it can overcome students' difficulties in connecting STEM elements with the theories learned in Biophysics learning. The application of NA-AOGS using the STEM learning syntax has involved students directly in practical learning through technology to help farming communities. The economic impact of this research is the scientific contribution in the adaptation of agricultural technology to increase soybean yields (an increase of 130.38% on an area of 2750 m^2). The novelty and contribution of this research is the integration of science learning with agricultural techniques and technology with a STEM approach to improve the welfare of farmers in educational institutions as a new model in science learning.

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