# SciEd

SEAQIS Journal of Science Education

SciEd Journal / vol. 1 / no. 1
P-ISSN 2777-0397
E-ISSN 2798-7175
www.journal.qitepinscience.org

# SciEd

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## Director's Message

Alhamdulillah, praise to Allah, God Almighty, that SEAQIS with pleasure presents its inaugural science journal called SEAQIS Journal of Science Education (SciEd). It has been a long wait for the Centre, but finally, it is issued now. This journal is devoted to the science education field from theoretical aspects to practical studies.

This new journal is the authoritative voice in the science education field, covering the science curriculum, instruction, learning, policy, and science teachers' preparation to advance our knowledge of science education theory and practice. The journal's focus is on the teaching and learning of science in a school setting ranging from primary school to secondary education.

This journal also may be a platform for teachers and education personnel to share their ideas and thought about the current issues in the science education worlds. We know that today science education is fundamental for growing our science literacy and nurturing the next generation of scientists. In this fast-paced world where technological and scientific advancements are made at an ever-increasing rate, scientific literacy is crucial to helping us make sense of the knowledge we receive.

We believe that all the papers published in this journal will significantly influence science education, and we thank all of the authors who contributed to this volume.

Dr Indrawati
Director

From the Editor-in-Chief

We know that it is a great challenge to bring a new journal. However, SEAQIS, as a Centre of excellence in science education, desires to publish a scientific journal to cater to the needs of science teachers and education personnel towards the current issues, ideas and thought related to this field. Therefore, we are glad to present to the readers our inaugural volume.

In this opportunity, I would like to extend my gratitude to the authors, the Editorial Board, the designer, the Publishing Office staff, and all who have contributed to the journal's publication. Special thanks are for our future readers. We will not be able to exist without you. We are also inviting you to collaborate by submitting your manuscript for the incoming editions. We believe in the meaningfulness and future of our work together. Enjoy!

Dr Elly Herliani
Editor-in-Chief

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## SEAQIS Journal of Science Education (SciEd)

Volume 1 | No 1 | July 2021

P-ISSN 2777-0397 | E-ISSN 2798-7175





*SEAQIS Journal of Science Education (SciEd), The Southeast Asian Journal of Science Education, is a scientific publication of SEAMEO QITEP in Science published once a year. It contains scientific research articles in Science Education and a review article. A guide for the author can be found on the website.*

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*Cover:*

*Eco-printing is a natural and environmentally friendly fabric dyeing technique. The resulting colours come from plant parts such as leaves, stems and flowers. The motifs resulting from the eco-printing technique are varied and unique because they match the shape of the leaves, stems or flowers used.*

2021

SciEd
SEAQIS Journal of Science Education

SEAQIS Journal of Science Education (SciEd)
P-ISSN: 2777-0397 | E-ISSN: 2798-7175
Vol:1, No:1, PP:1-5
www.journal.qitepinscience.org

Research Paper Open Accsess

# How Students Apply Their Science and Technology Concepts in Developing Blind Stick through STEM Project?

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## Abstract

STEM education plays an important role in developing the 21st-century skills of the students moreover it can also increase students' understanding of science and technology concepts and how to apply their knowledge to solve a real-life problem. The improvement of students' increased understanding of concepts is hypothetically linked to the engineering design process that happened in STEM learning. This study aims to identify how students apply their prior science-technology concept to develop a smart blind stick through the engineering design process (EDP). The descriptive case study method includes direct observations, interviews, and documentation analysis in three STEM lessons of 30 high school students were conducted. During three STEM lessons, students are improving their skills to apply their prior science concepts to solve the challenge, students also introduce to knowledge of coding in order to develop a smart blind stick project. This study shows an example of how the engineering design process facilitates the application of science-technology knowledge in solving given problems. To support the learning process the teacher uses scaffolding techniques and optimizes the engineering design process, especially at the research step.

**Keywords**: Engineering Design Process, Scientific Knowledge, STEM Project Based Learning

## Introduction

In today's world, attention to STEM education is increasing rapidly. STEM is a learning-based approach on the idea of educating students in integrative four specific disciplines — Science, Technology, Engineering, and Mathematics. STEM education aims to prepare students with essential skills to have the adaptability to the constant needs of this fast-growing society. It is strongly believed that competent and creative STEM practitioners will be needed in the future to disentangle the world's problems (National Research Council, 2014). To welcome the challenges in this uncertain future, SEAMEO QITEP in Science abbreviated as SEAQIS also has attention and concern in developing STEM education, especially in Indonesia.

Since 2018, SEAQIS has developed the STEM learning approach that can be integrated into the existing curriculum. Since STEM education has not been specifically defined and integrated into Indonesia's curriculum so far, SEAQIS examines the characteristics of STEM education that can be implemented in science learning in the classroom. From all the complex characteristics of STEM, SEAQIS believes that the Engineering Design Process (EDP) is the main characteristic that can help students improve their knowledge and skills, especially 21st-century skills. EDP facilitates students to apply the knowledge that can be used in solving contextual problems (King & English, 2016; Jolly, 2017).

King & English (2016) also stated that the engineering design process is an iterative process for formulating solutions to problems based on engineering principles by utilizing engineering thinking so that it is not only focused on designing technological solutions. Students not only need skills that are able to connect across disciplines, but they also need prior knowledge and skills to apply them to the design process. Preparing students to be competent in applying and integrating knowledge from multiple sources to solve engineering design problems is at the heart of a successful approach to STEM integration.

The evidence of successful STEM integration in the context of Indonesia's classroom has been collected. Every year SEAQIS organizes training to improve teacher competence in integrating STEM learning into the 2013 Curriculum. This training has successfully produced an output of STEM learning implementation in the classroom and has significant impact on improving the quality of learning. The other product of STEM implementation in the classroom is STEM-based products that have been developed by students through EDP, such as smart watering systems and blind sticks. However, in principle, these sole products developed by students couldn't provide a specific picture of how students apply their prior knowledge in making these products through EDP. Therefore, this study aims to identify how 12th-grade students apply their prior knowledge of the STEM concept to develop a smart blind stick through the EDP.

## Method

This research uses a descriptive case study method. One science teacher and student from grade 12 have stated their consent and actively participated in this study. The participants were 30 students (18 girls and 12 boys) of a Senior High School, Bandung, Indonesia. Data collection techniques include interviews, direct observations, and documentation analysis. The observation was used to collect data on students' learning processes. It is also a tool used regularly to collect data by teacher-researchers in their classrooms (Kawulich, 2012). The observation was used to collect data on the classroom learning scenario, implementation of the engineering design process, and application of the science-technology concepts in STEM learning. Additional data from interviews of a teacher and ten students were obtained to gather an in-depth understanding of the STEM learning process.

## Results and Discussion

### Observation of STEM Learning Process

The observation of the learning process was started from lesson planning. The science teacher developed a STEM learning project which requires students to design and build a smart blind stick to help a visually impaired person to walk easier. Learning is designed by combining Science, Mathematics, and Technology through the engineering design process in a science subject. Students were granted access to learning resources such as personal computers, electrical components, and the Arduino microcontroller.

This learning activities with STEM project was carried out in three consecutive lessons. To optimize the learning process, the first and second lesson were focused on simple hands-on activities that provide students with experiences to understand new concepts and recall their prior science and technology concepts. In term of engineering design process, these first and second lesson consisted of three steps which are define the problem, research, and imagine. For the third lesson, students focused on planning and creating smart blind sticks collaboratively. Then, students created, tested & evaluated the blind stick. At the end of the lesson, students communicated their product.

The first lesson consisted of three simple activities, namely: a blink LED, a flip flop, and a traffic light. These three activities are initial phase for introducing students to coding knowledge and how to apply their prior science concepts in the smart blind stick project. Within this activities students could apply their prior science knowledge on dynamic electricity, closed electrical circuits, series and parallel circuits, and sound waves. These science concepts were given in previous lessons so that students that develop a smart blind stick would use their understanding of the concept to solve the problem. This meeting also led students to develop an understanding of new knowledge, a knowledge of coding.

The first activity was the LED blink activity, in this stage, students were equipped with a guided students' worksheet where students could follow all the direct instructions to make the LED light flash. Due to clear instruction on the worksheet, all the students effortlessly turn on the LED as ordered. The second activity was a flip flop, not significantly similar to the previous one, this activity levelling up the students to follow their instruction that translated as coding block code. Students are asked to re-create the source code that already provided by the teacher to turn on the red and yellow LED alternately. Most of the students were successful, yet two groups failed in this challenge. Based on the observation, there are two alternate reasons why the group couldn't accomplish the task. First, they likely misplaced the LED in the electrical circuit, and second, they presume incorrectly typed the source code. The teacher guides these two groups to evaluate their work and improve it, hence they able to successfully finish the task on the second attempt.

The last activity in the first lesson is a traffic light project where students are expected to make LED traffic lights (red, yellow, green LED to turn on alternately). No direct instruction or source code was provided in this activity. Students develop their own source code from scratch. In this challenge, all the group successfully making traffic lights as instructed. Some students had difficulties at first, fortunately, they were successful in the second or third attempt. Something that worth taking note of is the way students tried to fix the error themself rather than asked their teacher for help.

A similar learning strategy with the first lesson was applied to the second lesson. There \are three simple activities conducted in order to attune the students more with the idea of the engineering design process with Arduino. The activities were to turn on the bell, connect the proximity sensor, and project to find out the maximum distance of the sensor. In this meeting, students are expected to apply the science concept of sound waves. The teacher assumes the students already have a steady understanding of the concept as it has been learned by the students at the previous meeting. Unfortunately, students failed to apply this concept and complete the challenge. Due to a class failure, the teacher decided to give a brief reminder of the science concept to guide the students developed their new solution. Interestingly, even the majority of the student couldn't internalize the concept of the sound waves to the activity, they have no issues implementing source code into the Arduino program. There are still several mistakes in the first attempt, yet students can overcome the problem and fix it themself. It is strongly believed, the coding experience they got from the first lesson contribute to their better performance in the second meeting.

After students complete the activities in the second lesson, as the take-home task students were asked to design and make the smart blind sticks. They are asked to complete all design and construction processes at the third meeting. To get the best design, students are requested to make a sketch individually, present their sketch to their group, and the group will choose the best design to build. During the design process, students are guided to apply all the science concepts and knowledge of coding they got from the previous meeting. Each group was asked to design a blind stick sketch and an Arduino program. All groups work independently as they design, build, and test their project. Teacher interception is limited to the very minimal. In the third meeting, each group presented their project. It is observed that all the students succeeded in making the smart blind stick on their own.

The impressive thing is that each group creates a different solution for the same challenge. Some products use a combination of a bell and an LED, while others use a bell only as an indicator of distance. There are also some groups that make simple ringtones as indicators. This variation is not directly instructed in the student worksheet. Students use their prior science knowledge, knowledge of coding, and creativity to create a differentiator of their products. Regardless of the difference between the design and the actual product, students were satisfied with their product. Their final product resembles a design sketch in distance and coding indicators.

Figure 1 Documentation of students' product of smart blind stick.
a. Students presented their blind stick,
b. Students discussed source codes to run a program
c. Students created a blind stick

**Discussion**

This study shows an example of how students in grade 12 can be involved in STEM learning through the engineering design process and the role of science-technology knowledge in solving given problems. To provide meaningful STEM learning and enhance students' understanding and skills, teachers develop a smart blind stick project. With this project, teachers provide students with plenteous opportunities to explore and apply their prior science knowledge and new technology concepts through engineering design process, especially research step.

The statement was supported with the observation result that shows from two of the three lessons teacher are focused on the application of scientific concepts and understanding new technological concepts. While in the last lesson, the teacher encourages students to plan and create the blind stick solve a real-life problem by using their understanding of science-technology concepts that obtain before. The evidence also comes from student worksheets. Worksheets consist of simple activities and structured instructions related to the engineering design process. In terms of difficulty level, the level was increasing where the first activity is the easiest in every lesson. Through these activities, students are prepared for the skills and knowledge also provide more time to do research and obtain useful information that can be applied to design the smart blind sticks project.

Based on these two findings, the research obtains new insight on how the students can be succeeded in making smart blind sticks by applying the knowledge or science concepts through the engineering design process. The knowledge and skills of coding play a significant role in the smart blind stick project. In coding applications, students first get engaged in coding in a block-based program that works with the drag-and-drop system, and these codes are put into Arduino to make the smart blind stick able to function properly (Cakir & Guven, 2019). The application of the science concept and knowledge of coding cannot be separated from the role of the teacher who uses scaffolding techniques and optimizes the engineering design process, especially at the research step. These findings in line with previous research by King & English (2016) that reported the use of the engineering design process in elementary schools to build optical instruments by applying the STEM concept. The results show that students can apply core STEM concepts through design sketches, experiment through the construction phase, and apply structural changes to their designs through the redesign process. All the mentioned steps are part of EDP.

In this study, when the teacher directs students to do EDP through instruction on the worksheet, the students simultaneously reinforced the science and coding concepts they had previously learned. Likewise, when students design and manufacture smart blind sticks with EDP stages, students indirectly have applied knowledge of scientific concepts. At this point, understanding and applying initial knowledge is an important key to helping students solve problems successfully.

**Conclusion**

The application of the STEM concept is an important feature in STEM learning to solve a problem. In this case, the problem is making the smart blind sick. The use of the engineering design process, especially the research step gives students the opportunity to apply the science-technology concept and strengthening their engineering and mathematics skills. During the research step, the teacher provides a variety of simple activities that allow students to recall and apply STEM concepts simultaneously. Providing a variety of simple activities is the teacher's way of designing the application of STEM concepts. Through this combination, namely optimizing the engineering design process and scaffolding techniques, students are able to apply the STEM concept in designing and making smart blind sticks. However, students have different endeavors to complete projects successfully.

This study is a case study and only uses one class that implements STEM learning. So it cannot be generalized whether the learning outcomes will be in accordance with other conditions. It is recommended that further research be extended to other classes or schools that have not implemented STEM learning, in order to obtain more information about the application of STEM concepts through the engineering design process.

**Acknowledgements**

We would like to extend our heartfelt gratitude to our institution, SEAMEO QITEP in Science, especially Dr. Indrawati as our director that gave us full support. A sincere thanks also delivered to Ms. Adella Anfidina Putri for her input and contribution for translating and formatting the paper also for the teacher and students who participated in this study.

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2021
SciEd
SEAQIS Journal of Science Education (SciEd)
P-ISSN: 2777-0397 | E-ISSN: 2798-7175
Vol:1, No:1, PP 6-17
www.journal.qitepinscience.org
Research Paper
Open Accsess

# Implementation of STEM Local Context in Indonesia

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## Abstract

This study aims to analyze the ability of teachers in implementing Local Context STEM learning in the classroom. This research used a qualitative design and a multi case study method of the implementation of STEM learning for elementary, junior high and high school teachers in several cities in Indonesia who participated in the STEM Local Context training. Data were collected through learning observations and interviews as triangulation. The results showed 1) the teacher was able to identify local issues for STEM learning; 2) Engineering Design Process (EDP) as one of the characteristics of STEM learning that can integrate concepts to solve local issues has been illustrated in the lesson plans, 3) teachers are relatively able to implement STEM learning according to the lesson plans; 4) the teacher facilitates students so that they are able to carry out EDP relatively independently; 5) generally the products development is done in the form of homework which is monitored via WhatsApp as a solution to time constraints and other technical aspects that are not easy to do at school; 6) products resulting from STEM learning are varied and reflect local issue-based innovations; 7) get a positive response from students and improve their ability to solve problems; 8) teachers receive good support from school principals and peers in the form of permission to adjust learning schedules and technical support during the implementation of STEM learning.

**Keywords**: STEM, Engineering Design Process, Local Context.

## Introduction

In order to prepare the younger generation for mastery of 21st century skills, the Indonesian government responded by setting it as one of the 2013 curriculum targets and encouraging teachers to use inquiry-based learning not only for science but for other subjects. In the scientific context, in the 21st century, each science no longer has to work alone, but various branches of science can work together, not only within scientific groups, technology or social sciences and humanities, but in many cases between several groups. One of the learning concepts that is in accordance with the scientific context of the 21st century is the STEM approach. Although the term STEM is an acronym for Science, Technology, Engineering and Mathematics, STEM is seen as an integrated learning design.

In the context of learning, STEM is a learning approach that integrates science, technology, engineering and mathematics content to solve problems in everyday life (Reeve, 2013). STEM learning becomes meaningless if only strengthening in the STEM field separately, but must develop an approach that integrates science, technology, engineering and mathematics by focusing on solving real problems in everyday life (National STEM Education Center, 2014). As stated by Morrison (2008) and Tsupros (2008) that STEM education is a "meta-discipline" and this means the "creation of a discipline based on the integration of other disciplinary knowledge into a new 'whole' rather than in bits and pieces. It is an interdisciplinary approach to learning by integrating the four disciplines into one cohesive teaching and learning paradigm. This integration that is aimed at the removal of the traditional barriers erected between the four disciplines is now branded as STEM (Morrison, 2008). According to Tsupros (2008), “STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy (Tsupros, 2009).

In order for STEM learning to run well in schools, Anne Jolly (2014) proposes good STEM learning criteria, one of which is by using the engineering design process (EDP) to integrate science, technology and mathematics. Therefore, EDP is one of the characteristics of STEM learning. EDP is a step to make solutions to contextual problems and provide opportunities for students to apply knowledge of the S, T, E, M subjects in solving contextual problems in an integrative manner. Morrison (2006) provides criteria for effective STEM learning to be taught in class, he suggests that in integrating STEM learning, students must have a role as 1) problem solvers, 2) innovators, 3) inventors, 4) logical thinkers and also be able to understand and develop the skills needed for, 5) self-reliance and 6) technology literacy. In the context of primary and secondary education, Bybee (2013) states that STEM education aims to develop STEM literacy students, which are characterized by: 1) knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues; 2) understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design; 3) awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and 4) willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

Science, Technology, Engineering, and Mathematics (STEM) as an innovation in science learning has become the focus of studies in SEAQIS. Since 2015, STEM learning has become one of the leading education and training programs in SEAQIS in increasing the competence of teachers and education personnel. In order to develop STEM education, in 2018, SEAQIS held STEM training for 30 junior high school teachers and 90 high school teachers representing 67 teacher working groups in 29 cities from 9 provinces in Indonesia. In the same year, SEAQIS collaborated with SEAMEO QITEP in Mathematics and the Directorate of Junior High Schools of the Ministry of Education and Culture of the Republic of Indonesia to organize STEM Training for teachers from 256 reference schools from 34 provinces in Indonesia.

The initial program for the development of SEAQIS STEM learning is to integrate STEM into the 2013 Curriculum where the identification of issues for STEM learning begins with the demands of basic competencies that can be used as opportunities to raise relevant issues and fulfill the characteristics of STEM learning. Based on the lessons learned from the implementation of STEM learning through integration into the 2013 curriculum, starting in 2019 the STEM Local Context (STEM LC) was developed, as an effort to optimize STEM learning opportunities to solve life problems around the immediate environment. Thus, STEM learning can be used to develop the potential of students to have a concern for their environment and the local values that accompany it and make a constructive contribution as citizens. In addition, through STEM LC students can identify problems in the utilization / processing of natural resources that are abundant in their area so that they have added value to help improve the welfare of the surrounding community. Through STEM LC, the issues raised are more contextual, varied, and have the opportunity to practice entrepreneurial skills and have a direct impact on society through community empowerment.

In order to gather information about the successful implementation of STEM LC, this research was conducted to: 1) compile a profile of the teacher's ability in developing a STEM learning plan; 2) compile a profile of the teacher's ability to carry out STEM learning; 3) identify supporting factors and challenges in implementing STEM learning; 4) and identify the impact of STEM learning on students.

## Methods

This research used a qualitative design and a multi case study method of STEM learning implementation. The cases analysed in the study were five classes from several cities in Indonesia, consisting of two classes from elementary, two classes from junior high, and one class from high school. All school located in urban area except one junior high school in coastal area which close to religious tourism destination. The teachers are key teachers or representation of their working group and have participated in the STEM Local Context training as preparation or adjustment for introducing STEM learning as new approach in science learning. The training facilitated teachers to discuss and do some activities on STEM learning, experience in developing lesson plans based on each local issues identified, do peer teaching, and develop action plan. After the training, teachers are given post-training services to prepare for the implementation of STEM learning as part of their action plan in the form of mentoring. In this activity the teachers are assisted in improving lesson plans, preparing for the implementation of STEM learning, and discussing things that need to be considered in STEM learning. Data were collected through learning observations and interviews to teachers and students as triangulation. The observation of STEM learning was recorded and conducted two times with the aim that feedback on the 1$^{st}$ learning could help improve the 2$^{nd}$ learning. The interviews to teacher were conducted after each of observation whilst to students were carried out after second observation. The data collected was analyzed by three steps from Miles and Huberman (1994) which are data reduction, data display, also drawing conclusion and verification. The data collected reduced based on research focus which is implementation of STEM LC learning and displayed based on criteria related to each research question and lastly analyzed and verified to draw conclusion.

## Result and Discussion

In order to facilitate the discussion, the findings in the form of a summary of the results of data reduction are presented before the discussion as a source of data to analyze and are carried out in accordance with the sequence of research questions.

### *1. Teacher's ability in developing lesson plans*

The teacher's ability to plan learning plans is a very important factor in the success of learning (Ejiwale, 2013). In the discussion of this research, the focus of the study on the ability of teachers in preparing lesson plans is on lesson plans that have been compiled 1) containing local issues; 2) Conformity of basic competency and knowledge prerequisites; 3) Suitability of EDP indicators; 4) the use of learning models; 5) Contains EDP stages;

The results of the analysis show that each teacher has been able to write down the required components. The problems raised in lesson planning already contain local issues. The basic competencies and prerequisite materials presented are in accordance with the issues raised. Every teacher has been able to write indicators that are in accordance with basic competencies and EDP. STEM learning is carried out not only to gain knowledge, but through STEM learning students are required to be able to apply the concepts that have been obtained to solve problems around them. STEM learning by raising local issues requires students to make a product that can solve these problems. The learning model used by the teacher is project based learning that is in accordance with the needs of students to make products as a solution to the problems raised.

**Table 1.** Teachers's ability to develop lesson plans

| Teacher 1 | Teacher 2 | Teacher 3 | Teacher 4 | Teacher 5 |
|---|---|---|---|---|
| **Local Issue**<br>Shellfish and shrimp, sold raw at tourist sites near schools → cannot be souvenirs → limited sales, standard price.<br>**KD and Prerequisites**<br>KD is relatively adequate, there are other basic competencies that are more supportive. Prerequisite knowledge according to the problem.<br>**EDP Indicator**<br>Indicators according to KD and EDP indicators.<br>**Learning Model**<br>Appropriate: Project based learning (PjBL)<br>**EDP Stages**<br>Define the problem, research, imagine, plan, create, test and evaluate, redesign, and communication. | **Local Issues**<br>Vertical garden which is always broken after the long holiday at the end of the learning year.<br>**KD and Prerequisites**<br>KD - prerequisite knowledge: according to the problem.<br>**EDP indicator**<br>Indicators according to KD and EDP indicators.<br>**Learning model**<br>Appropriate: PjBL based learning<br>**EDP Stages**<br>define the problem, research, imagine, plan, create, test and evaluate, redesign, and communication | **Local Issues**<br>The problem of organic waste in schools.<br>**KD and Prerequisites**<br>KD and pre-requisite knowledge according to the problem.<br>**EDP indicator**<br>Indicators according to KD and EDP indicators.<br>**Learning model**<br>Appropriate: Project based learning<br>**EDP stages**<br>ask, imagine, plan, create, and improve | **Local Issues**<br>Limitations of conventional blind stick assistive devices<br>**KD and Prerequisites**<br>KD and prerequisite knowledge according to the problem.<br>**EDP indicator**<br>Indicator according to KD and EDP indicator.<br>**Learning model**<br>Appropriate: 5 E<br>**EDP stages**<br>Define the problem, research, imagine, plan, create, test and evaluate, redesign, and communication. | **Local Issues**<br>Limited school land for agriculture.<br>**KD and Prerequisites**<br>KD and prerequisite knowledge according to the problem.<br>**EDP indicator**<br>Indicator according to KD and EDP indicator.<br>**Learning model**<br>Appropriate: Project based learning<br>**EDP stages**<br>Ask, imagine, plan, create, and improve. |

In order to solve problems, STEM learning follows the EDP stages. The results of the analysis show that all teachers prepare lesson plans using EDP, although it appears that the EDP used has different stages. Based on this, it is known that teachers who teach at the SMP and SMA levels use the more detailed EDP stages, while those for the SD level use the simpler EDP stages.

The good ability of teachers in preparing STEM learning plans is the result of mentoring carried out by the SEAQIS team during the implementation of the training. During the training, discussions were held about STEM learning and how to plan learning and draft learning plans. Furthermore, the teacher receives assistance before the teacher begins the implementation of learning and during learning. That way, the success of teachers in preparing STEM learning plans can be assumed as a contribution to training and mentoring. This is supported by Nazuhi (2016) that the implementation of effective mentoring can increase teacher competence in preparing good and correct RPP. This is supported by Sriyati, et al (2018) which states that through workshop activities, designing and presenting STEM-based learning designs is able to develop teachers' abilities in designing STEM-based learning.

***2. Teacher's ability in implementing STEM LC learning***

Sanders (2009) suggests that integrative STEM education should include technology or engineering design as a basis for making connections to concepts and practices from mathematics or science or both. Bryan et al. (2016) stated that one of the core features of an integrated STEM learning experience includes learning where the integrator is engineering practices and engineering design technology as context and / or a deliberate component of the material to be studied. They added that engineering design or engineering practices related to relevant technology requires the use of scientific and mathematical concepts through design justification.

EDP is an important part of STEM learning. English & King, (2015) shows how STEM learning at the basic level through EDP provides opportunities for students to design and redesign their work to be better by applying science and math concepts. STEM learning through problem-based learning also gives students ideas to integrate math and science concepts in learning. Furthermore, teacher scaffolding in introducing new concepts is also a very important factor.

**Table 2.** Teachers's implementation of STEM learning Local Context

| Teacher 1 (Titis) | Teacher 2 (Novi) | Teacher 3 (Dessy) | Teacher 4 (Lia) | Teacher 5 (Gama) |
|---|---|---|---|---|
| ***Define the problem***<br>1) Presentation of the stimulus: video of sea catches sold at tourist sites, data on the number of sales and income of traders<br>2) Question and answer and discussion with material from the video: identification of data / facts, problems, sources of problems<br>3) The teacher helps: students ask questions / the teacher asks guidance questions | ***Define the problem***<br>1) Presentation of the stimulus: a video about a well-maintained and poorly maintained vertical garden<br>2) Question and answer and discussion with material from the video: identification of data / facts, problems, sources of problems<br>3) The teacher helps: students ask questions / the teacher asks guidance questions | ***Ask***<br>1) Presentation of the stimulus: videos of waste in schools and their management<br>2) Question and answer and discussion with material from the video: identification of data / facts, problems, sources of problems<br>3) The teacher helps: students ask questions / the teacher asks guidance questions | **Define the Problem**<br>1) Presentation of stimulus: video a) Challening Obstacle: The Life of Blind People; b) robot wall-E<br>2) Question and answer and discussion with material from the video: identification of data / facts, problems, sources of problems<br>3) The teacher helps: students ask questions / the teacher asks guidance questions | ***Define the problem***<br>1) Presentation of the stimulus: video about aquatic ecosystems<br>2) Question and answer and discussion with material from the video: identification of data / facts, problems, sources of problems<br>3) The teacher helps: students ask questions / the teacher asks guidance questions |
| ***Research***<br>Finding information: basic principles of processing seafood products via literature studies, videos, internet, etc.<br>Students identify several alternative solutions in accordance with the working principles of processing seafood products.<br>The teacher guides via directive questions. | ***Research***<br>Finding information: the principles and methods of making a miniature Smart Watering System via the internet<br>The teacher guides via directive questions. | | ***Research***<br>Search for information via the internet and create simple Arduino-based projects<br>1st meeting: LED blink project, flip flop and traffic light<br>2nd meeting: turn on buzzer, proximity sensor project and measure the maximum distance using the proximity sensor. | ***Research***<br>Looking for information: how to make a simple aquaponic via the internet<br>The teacher guides via directive questions. |
| ***Imagine***<br>Group discussion: determining the product to be made and the reasons for choosing<br>Questions and answers: reasons for choosing marine processed products to be made. | ***Imagine***<br>Group discussion: determining the product to be made and the reasons for choosing<br>Questions and answers: reasons for choosing the product | ***Imagine***<br>Group discussion: discuss in groups to analyze the nutritional content needed by plants by utilizing organic waste.<br>Learners collect information from various sources.<br>The teacher guides via directive questions. | **Imagine**<br>Group discussion: determining the product to be made and the reasons for choosing<br>Questions and answers: reasons for choosing the product | **Imagine**<br>Group discussion: determining the product to be made and the reasons for choosing<br>Questions and answers: the reasons for the conceptual and technical aspects of the aquaponics selection to be made |
| | | | Based on the identification of problems and information that has been obtained, students in groups are asked to discuss possible solutions to solve existing problems. Each student puts forward his idea, then the best idea is chosen in making a smart blind stick. | |

| | | | | |
|---|---|---|---|---|
| ***Plan***<br>Group discussion determines product design: product quality indicators, materials to be used, manufacturing procedures, time allocation<br>Questions and answers: the reasons in terms and technical aspects of the selected design<br>Group work: making designs in the form of recipes for marine processed products. Each group makes a different type of product / recipe.<br>The teacher provides guidance at each stage of the activity via directive questions. | ***Plan***<br>Group discussion determines product design: product indicators, materials to be used, manufacturing procedures<br>Questions and answers: the reasons in terms and technical aspects of the selected design<br>Group work: make a design in the form of a sketch. Each group made a different sketch<br>The teacher provides guidance at each stage of the activity. | ***Plan***<br>Group discussion determines product design: indicators of product quality, materials to be used, manufacturing procedures<br>Questions and answers: reasons for determining the design<br>Group work: design a mole recipe for hydropinics. Each group makes a different recipe.<br>The teacher provides guidance at each stage of the activity via directive questions. | **Plan**<br>Group discussion determines product design: indicators of product quality, materials to be used, manufacturing procedures,<br>Question and answer: the reasons in the conceptual and technical aspects of the selected design<br>Group work: create designs in the form of sketches and Arduino source code. Each group made a different sketch<br>The teacher provides guidance at each stage of the activity | **Plan**<br>Group discussion determines design: product quality indicators, materials to be used, manufacturing procedures, time allocation<br>Question and answer: the reasons in the conceptual and technical aspects of the selected design<br>Group work: make a design in the form of a sketch. Each group made a different sketch.<br>The teacher provides guidance at each stage of the activity |
| ***Create***<br>Students make processed marine products at home according to the design of each group with the guidance of the teacher | ***Create***<br>Students make a Smart Watering System according to the design of each group with teacher guidance | ***Create***<br>Students make hydroponic moles according to the design of each group with teacher guidance | **Create**<br>Students make smart blind sticks according to the design of each group with teacher guidance | **Create**<br>Students make simple aquaponic according to the design of each foreign group with the guidance of the teacher |
| ***Test and Evaluate***<br>Product trials through organoleptic testing by other groups<br>Guidance questions from the teacher: identify things that need to be improved based on the results of the trial<br>Another group made suggestions | ***Test and Evaluate***<br>Product trials<br>Guidance questions from the teacher: identify things that need to be improved based on the results of the trial | ***Improve***<br>Product trials via hydroponic use of moles in plants.<br>Observation of plant growth and identification of advantages and disadvantages of moles<br>Redesigned the mole recipe based on test results | **Test and Evaluate**<br>Product trials<br>The tool indicator functions in the form of a varied sound ("beep" "beep-beep" to ringtone music) even though, the teacher asks only for a "beep" sound.<br>Guidance questions from the teacher: identify things that need to be improved based on the results of the trial | **Test and Evaluate**<br>Simple aquaponic product trial in a school pond.<br>Guidance questions from the teacher: identify things that need to be improved based on the results of the trial<br>Another group asked questions and made suggestions |
| ***Redesign***<br>Discussions in groups to redesign according to input from peers | ***Redesign***<br>The redesign was not done | | ***Redesign***<br>The redesign was not done | ***Redesign***<br>The redesign was not done |
| ***Communication***<br>The design presentation included the advantages and disadvantages of the product as well as a trial demonstration of processed seafood products<br>Another group asked questions and made suggestions | ***Communication***<br>The design presentation included the advantages and disadvantages of the product as well as a demonstration of the Smart Watering System product trial<br>Another group asked questions and made suggestions | | **Communication**<br>The design presentation includes the advantages and disadvantages of the product as well as a demonstration of the Smart Blind Stick product trial<br>Another group asked questions and made suggestions | **Communication**<br>The design presentation includes the advantages and disadvantages of the product as well as a simple aquaponic product trial demonstration<br>Another group asked questions and made suggestions |

The results of the analysis show that most of the engineering design stages can be carried out by the teacher. However, in general, from all the case studies observed, each teacher experienced difficulties in carrying out the redesign stage. In case study 1 (Teacher 1), the EDP stage that was not implemented in the classroom during learning was create and redesign stages. This occurs due to the limited time available to make marine processed products in schools and the difficulty in bringing tools and materials to school. The solution taken is to carry out the create stages at home and outside class hours. As proof that each student did a create activity, they made videos and photos during the activity and then sent them to the teacher. Furthermore, the redesign stage was not carried out because it took time to repair and make more processed seafood. At this stage, students only record input from the results of tests conducted by teachers and peers.

In case study 2 (Teacher 2), the research stage was not optimal. At this stage students are asked to find relevant sources related to the project to be implemented through the internet media. However, at the time of implementation there were network constraints so that the search for relevant sources was hampered. The solution is to provide a hotspot to facilitate the search process from the internet.

Furthermore, in case study 3, the EDP stage that is not fully implemented is create and improve stage. At the create stage, in addition to the participants being asked to make a product according to the design, students are also asked to test their work. This stage is not carried out well because it takes a long time to carry out the testing process until the results are visible. The results of the liquid fertilizer that have been made by students are tested for reliability by looking at the growth of the fertilized plants and this process takes 1-2 weeks so that it cannot be implemented in a series of lessons. The solution given is to do the create stage outside of learning.

In case study 4, the EDP stage that was not implemented was the redesign stage. Students do not get the opportunity to improve their work. This happens because of limited learning time in the classroom. So that students only record input from the results of the trial.

Furthermore, in case study 5, the EDP stage that was not implemented was also at the redesign stage. The re-creation of a student project in the form of a floating aquaponic took a long time. So that students only redesign the aquaponic according to input from teachers and peers.

From the data in the table above, it appears that all the teachers are relatively successful in implementing the lesson according to the lesson plans and following the EDP flow well. Possible explanations for this are as follows. When discussing the characteristics of EDP and STEM learning materials, discussions are carried out in detail regarding the targets, roles of teachers and students at each stage of EDP including discussions about things that need to be considered or anticipated. This helps teachers have an overview of the details of STEM learning. This picture was clarified through peer teaching, reflection, and in-depth discussion which was carried out at the end of the training. This experience coupled with his knowledge, skills, and experience as a teacher who is actively involved in discussing and sharing in the working group, provides provisions for them to carry out learning in class. Relatively intensive discussions during mentoring, reflection, and feedback after the first learning strengthen their understanding and require provision.

In the table it also appears that generally teachers face limited time constraints, especially in learning where all work is done at school so that there is an EDP stage which is likely to be implemented less optimally. Relatively adequate time is needed in activities when students search for literature to identify relevant ideas, study the literature obtained, develop designs, making products, and present designs and trials. Another obstacle in making products is the availability of equipment that is inconvenient when done at school.

For teachers who assign the task of making products at home, the constraints on materials and time for making products can be resolved properly. For the implementation of activities at other EDP stages, especially teachers who decide to carry out all activities in the classroom still face obstacles related to the limited time allocation so that the implementation of the EDP activity stages has a chance to be less than optimal, even if the product is successfully completed. Optimization of activities at each stage of EDP is needed, because when students search for literature to identify relevant ideas, study the literature obtained, develop designs, make products, and present designs and trials, teachers have an excellent opportunity to facilitate skills development. Critical thinking, creativity, working together, and communicating. At the same time students also have the opportunity to strengthen the basic concepts and other supporting concepts used to develop products.

If time is sufficient, the teacher has the opportunity to use it through the use of asking techniques and asking a series of questions both orally and through worksheets so that students can uncover the logical, scientific, and technical reasons behind all group decisions in developing products. The teacher can also organize classroom strategies and management to optimize the development of these skills in advance.

### *3. Supporting Factors and Challenges in STEM LC Implementation*

According to Stohlmann, Moore, Roehrig (2012) the factors that need to be considered in STEM learning consist of 4 factors with the acronym s. t. e. m. These factors are 1) S or support, namely support from various parties such as the principal, teacher colleagues, or universities as well as support in the form of increased competence; 2) T or teaching, which is all aspects related to STEM learning including the ability to plan such as compiling lesson plans and implementing learning including assessment; 3) E or efficacy, which is the teacher's self-confidence in carrying out tasks including having knowledge and skills that contribute to the formation of self-efficacy, commitment, skills in planning and organizing activities; 4) M or material, namely the availability of adequate infrastructure for the implementation of learning

Based on Table 3, all teachers receive support from the principal, peer teachers, and education personnel. A possible explanation is that from the start the principal has supported the teacher by allowing the teacher to attend the STEM LC training and understand the program the teacher is participating in so that this support has an impact on the support of other school members such as teacher peers and education personnel. Meanwhile, the provision of teachers to implement STEM learning was obtained by teachers when they attended training and post-training services in the form of mentoring during the preparation for implementing STEM learning which was carried out relatively intensively both through social media and face-to-face before the first and second observations.

**Table 3**. Supporting Factors and Challenges in STEM LC Implementation

| Teacher 1 | Teacher 2 | Teacher 3 | Teacher 4 | Teacher 5 |
|---|---|---|---|---|
| ***Support and Constraints***<br>General support:<br>Principals and teachers and education personnel (GTK) in schools ◊ adjusting the learning schedule and technical assistance during learning.<br>SEAQIS: competency improvement via STEM LC training from SEAQIS.<br><u>Teaching Support:</u><br>Increased competence in planning and implementing STEM | ***Support and Constraints***<br>General support:<br>Principals and teachers and education personnel (GTK) in schools ◊ adjusting the learning schedule and technical assistance during learning.<br>SEAQIS: competency improvement via STEM LC training from SEAQIS<br><u>Teaching Support:</u><br>Increased competence in planning and implementing STEM | ***Support and Constraints***<br>General support:<br>Principals and teachers and education personnel (GTK) in schools ◊ adjusting the learning schedule and technical assistance during learning.<br>SEAQIS: competency improvement via STEM LC training from SEAQIS.<br><u>Teaching Support:</u><br>Increased competence in planning and implementing STEM | ***Support and Constraints***<br>General support:<br>Principals and teachers and education personnel (GTK) in schools ◊ adjusting the learning schedule and technical assistance during learning.<br>SEAQIS: competency improvement via STEM LC training from SEAQIS.<br><u>Teaching Support:</u><br>Increased competence in planning and implementing STEM learning via STEM LC Training. | ***Support and Constraints***<br>General support:<br>Principals and teachers and education personnel (GTK) in schools ◊ adjusting the learning schedule and technical assistance during learning.<br>SEAQIS: competency improvement via STEM LC training from SEAQIS.<br><u>Teaching Support:</u><br>Increased competence in planning and implementing STEM learning via STEM LC Training. |

| | | | | |
|---|---|---|---|---|
| learning via STEM LC Training. Material support: school infrastructure is adequate to complete the product. Obstacles: internet access is not strong and stable bring equipment for making processed seafood products to school. | learning via STEM LC Training. Material support: school infrastructure is adequate to complete the product. Obstacles: internet access is not strong and stable | learning via STEM LC Training. Material support: school infrastructure is adequate to complete the product. Obstacles: relatively face no significant obstacles | Material support: school infrastructure is adequate to complete the product. Obstacles: relatively face no significant obstacles | Material support: school infrastructure is adequate to complete the product. Obstacles: internet access is not strong and stable bring equipment for making processed seafood products to school Obstacles: relatively face no significant obstacles |

In the Teaching aspect, provisions in planning and implementing STEM learning are obtained through STEM LC Training. Based on the explanation in the implementation of STEM learning in advance, the competencies obtained through training can relatively help teachers to implement STEM. In the material aspect, the infrastructure in schools is adequate in completing the product.

The obstacles faced are the lack of strong and stable internet access and the difficulty of bringing the equipment to make processed seafood products to schools. Another obstacle faced by teachers is the limited learning time. Relatively sufficient time is needed for activities when students search for literature to identify relevant ideas, study the literature obtained, develop designs, making products, and present designs and trials. Another obstacle in making products is the availability of equipment that is inconvenient when done at school. For teachers who assign to make products at home these two obstacles can be resolved well, but for teachers who decide to do all activities in class, they still face obstacles related to the limited time allocation so that the implementation of the stages of EDP activities is not optimal, even though the product is successfully completed.

Why is that, because when students search for literature to identify relevant ideas, study the literature obtained, develop designs, make products, and present designs and trials, teachers have an excellent opportunity to facilitate the development of critical thinking skills, creativity, cooperate, and communicate. At the same time, teachers also have the opportunity to strengthen the basic concepts and other supporting concepts used to develop products. If time is sufficient, the teacher can optimally implement these opportunities in each of these activities in advance through a series of questions for students to reveal the logical, scientific, and technical reasons behind all group decisions in developing products.

Relatively all teachers do not find problems in terms of tools and materials because they are easily obtained at affordable costs. Unfortunately, data regarding how high the self-efficacy of teachers is in implementing STEM learning after participating in debriefing through training and post-training services are not available. This is a note for SEAQIS in preparing teachers in the future so that the provisions needed by teachers are more complete.

### *4. Impact of STEM LC Learning on Students*

As shown in Table 4, students generally gave a positive response to STEM learning by following it enthusiastically. Teacher 4 even measures the impact of learning on student activity. This response shows that students have an interest in participating in STEM learning according to the definition proposed by Walgito (2004) interest is a condition in which a person pays attention to an object accompanied by a feeling of pleasure because it is considered to have benefits. Shahali et al., (2016) stated that STEM learning can increase students' interest in the STEM field and careers in the STEM field. The interest of these students will ultimately improve students' STEM literacy.

As stated by Bybee (2013) knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues.

**Table 4.** The Impact of STEM Learning on Students

| Teacher 1 | Teacher 2 | Teacher 3 | Teacher 4 | Teacher 5 |
| --- | --- | --- | --- | --- |
| Learners:<br>♣ excited about learning.<br>♣ Able to carry out the EDP stage (problem identification up to testing and redesign of the product) as a solution to the problem.<br>♣ increased learning outcomes with N-gain 0.417 (moderate category)<br>♣ increased interest in entrepreneurship | Learners:<br>♣ enthusiastic and actively involved in learning<br>♣ Get satisfying learning outcomes.<br>♣ Able to carry out the EDP stage (problem identification up to testing and redesign of the product) as a solution to the problem. | Learners:<br>♣ enthusiastic and actively involved in learning<br>♣ Get satisfying learning outcomes.<br>♣ Able to carry out the EDP stage (problem identification up to testing and redesign of the product) as a solution to the problem. | Learners:<br>♣ Excited about learning.<br>♣ increased learning outcomes with N-gain 0.6 (medium category)<br>♣ actively participate in teaching (good category)<br>♣ Able to carry out the EDP stage (problem identification up to testing and redesign of the product) as a solution to the problem. | Learners:<br>♣ Excited about learning.<br>♣ increases in thinking skills, creativity, communication, and collaboration (relatively obvious)<br>♣ Able to carry out the EDP stage (problem identification up to testing and redesign of the product) as a solution to the problem. |

Teachers 1, 2, and 4 measure that STEM learning improves learning outcomes even though the N-gain results of teachers 1 and 4 are in the moderate category. The impact on learning outcomes is supported by the results of research by Suwarma and Endah (2015) which state that STEM learning can increase motivation and creation in learning science and increase students' understanding of concepts. Other research shows that students who carry out project-based STEM learning show higher scores on the concepts being taught (geometry, probability, and problem solving) than those who carry out project-based learning alone (Han et al., 2016)

In general, teachers stated that STEM learning facilitates the development of problem-solving skills. In STEM learning the form of assignments is relatively open so that students must be more independent in completing them. Teachers must function themselves as facilitators so that the inquiry process can be carried out by students properly. The success of students in completing assignments shows that STEM learning can facilitate the development of problem-solving skills. Teacher number 5 also found that critical thinking, creative thinking, collaboration, and communication skills improved. This shows that the EDP stage which provides opportunities to develop these four skills in advance has been successfully utilized by the teacher.

Another impact that was measured by teacher number 1 who raised problems related to the economy was the increased entrepreneurial interest of students which became an added value. This shows that there are opportunities for teachers to use STEM learning to provide added value to students according to the issues raised and the local context used.

## Conclusion

Based on the result of this study, we can conclude that: 1) the teacher was able to develop lesson plan which indicated by the ability to identify local issues for STEM learning and to implement EDP as one of the characteristics of STEM learning that can integrate concepts to solve local issues has been illustrated in the lesson plans; 2) teachers are relatively able to implement STEM learning according to the lesson plans and facilitates students so that they are able to carry out EDP relatively independently; 3) teachers receive good support from school principals and peers in the form of permission to adjust learning schedules and technical support during the implementation of STEM learning; 4) get a positive response from students, improve students' achievement and their ability to solve problems; 5) training subjects which cover topics needed for STEM learning and their delivery which very similar to real STEM learning contribute to teachers ability in planning and implementing STEM learning; 6) post training service in forms of intensive mentoring before teachers implement STEM learning, STEM learning observation which conducted two times and discussion right after each observation to give feed back for better STEM learning contribute to teachers be able to deliver STEM learning more effectively and confidently.

Several things need to be considered are: 1) to improve the time constraints faced by the teachers, it is necessary to consider alternatives to implementing STEM learning as a school project or part of the Youth Scientific Group program which can provide more time and a more flexible schedule. If it will be integrated into the intracurricular system, it is necessary to comprehensively organize the time allocation including the layout of the learning schedule on the daily lesson schedule. If additional time needed but do not allow it to be used as homework, teachers need to consider carrying out assignments at school outside of class hours. For elementary school level, it is necessary to consider using a special time allocation for integrated learning or projects that are usually available at the end of each sub-theme; 2) to resolve time constraints and access to information, especially at the basic level, it is necessary to consider teachers providing an excessive amount of information assistance so that students still have the opportunity to have skills in selecting and sorting the information needed. Even though it is assisted by the teacher, it can still facilitate students in developing critical thinking skills, creative thinking, working together, and communicating; 3) based on the importance of self-efficacy as one of the considerations for STEM learning, it is necessary to consider measuring teachers self-efficacy when attending training sessions to provide the necessary support to strengthen content knowledge and pedagogical knowledge; 4) to improve the quality of measurement of improvement in problem-solving skills, there is a need to improve the process by using instrument so that the quality of the improvement can be measured; 5) to be able to implement STEM learning effectively, teachers need sufficient provision in term of knowledge, skills, and assessment in STEM learning; 6) teachers provision needed may be delivered through competency based training with intensive post training services to support teachers comprehension knowledge also develop skills and self esteem in implementing STEM learning effectively.

**Acknowledgements**

We would like to extend our heartfelt gratitude to our institution, SEAMEO QITEP in Science for facilitating this research. A sincere thanks also delivered to the teachers and students who participated in this study.

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2021
SciEd
SEAQIS Journal of Science Education
SEAQIS Journal of Science Education (SciEd)
P-ISSN: 2777-0397 | E-ISSN: 2798-7175
Vol:1, No:1, PP:18-26
www.journal.qitepinscience.org
Research Paper
Open Accsess

# Perception and Motivation of Female and Male Students Toward STEM in Indonesia

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## Abstract

The aim of this research is to find out the differences of male and female lower secondary school students on the aspects of perception, motivation, and interest in the field of STEM. The sample of this study consists of 370 middle school students in various province in Indonesia who had experience in STEM learning with teacher who had participated SEAQIS STEM training. The instrument used in this study was five scales Likert of SEAQIS STEMs Survey (SS-STEMs), which cover perception and motivation toward Science, Technology and Engineering as well as Mathematics. The instrument was validated by Rasch Model approach using Winstep v 3.7 and was found that it compatible with the model. Data analysis was conducted using the IRT Rasch model approach assisted by Winsteps Aplication ver 3.7. It was found that: (1) There is a significant difference between male and female students in the aspects of perception toward mathematics subjects; (2) There is no significance difference between male and female students in the aspects of motivation towards all subjects.

**Keywords**: Gender, Motivation, Perception, STEM

## Introduction

Science, Technology, Engineering, and Mathematics (STEM) has been a SEAQIS concern in developing and improving teachers' competencies since 2015. In its implementation, SEAQIS conducts training annually to improve teachers' competencies in integrating STEM learning in the Current National Curriculum. This gives an impact on improving the quality of classroom learning, based on students' products, such as smart watering systems, palm seeds processor and activated charcoal from candlenut skin waste. In principle, the products that have been developed by students have not provided a specific description of how students are involved and students' interests in STEM learning or even in STEM careers. Because actually, as Aschcraft, McLain, and Eger (2016) stated that student involvement in a group can be associated with a level of collective intelligence.

Although the prospect of the STEM industry is quite promising in the future, there are still challenges in attracting female professional workers to work in the STEM industry. In another study, it is stated that increased participation of women, not only in the field of STEM, had a positive impact on the economy as a whole (Duflo, 2012). Pusat Statistik Nasional (Statistics Indonesia, 2010) data shows that there are around 131.58 million workers available in the domestic labour market. Based on gender comparison, women's participation rates are around 35% while only 30% out of it are female workers in STEM industry. This is in line with the findings of Taylor and Valerie (2016) that shows although students do not have significant differences in mathematical and scientific abilities, they have differences in interests and confidence in the STEM field (computer science). Most female students choose to enter psychology, biology and social sciences majors when entering the tertiary level education. When compared with male students, only 19% of female students majored in engineering, or about 4 times lower than male students (81%) (National Science Board, 2018). Student involvement in learning, not only STEM, is influenced by perception (Syaripah, 2016) and motivation (Saeed & Zyngier, 2012; Hoffman, 2015; Vero 2017).

Students' attitudes toward STEM are an important factor influencing student motivation to learn STEM subjects and pursue a STEM career. While there has been considerable research conducted about student attitudes toward science (Osborne, Simon, & Collins, 2003) and mathematics (Elci, 2017), there is less research available about female students' perception and motivation in the STEM field.

Integrated STEM classroom approaches are used in Indonesia, as STEM education is not particularly described and integrated in the curriculum. Yet, less attention has traditionally been paid to study STEM integration in National Curriculum and its effect on students' perception and motivation in the field of STEM including whether there are differences of the two aspects of girls toward STEM education subjects. Therefore, this research aims to find out Indonesian lower secondary school students' perception and motivation in each of STEM education subjects which are Science, Technology and Engineering as well as Mathematics, and to compare male and female in those two dimension.

While conceptions of what STEM entails vary among researchers, educators, and policy makers, there are two commonly accepted approaches to STEM education (Breiner, Johnson, Harkness, & Koehler, 2012; Sanders, 2009). The first approach, traditional STEM education, views STEM as four separate fields taught as traditional disciplinary courses. The second approach, integrated STEM education, "includes approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (Sanders, 2009). Importantly, the National Academies of Engineering views engineering as a critical component of integrated STEM education and encourages K-12 teachers to use engineering as a vehicle to teach science, mathematics, and technology concepts (NRC, 2011).

Much of the available research on student learning and teaching practices comes from both STEM-focused schools (schools were implemented the STEM education) as well as STEM classroom (STEM education was only carried out in specific subject). Those mode of STEM education implementation refer to a country which has not adopted STEM as National Policy in a shape of formal curriculum guidelines, but schools as their own initiatives started to adopt STEM education on a classroom level. This research was conducted in the context of ASEAN countries that adopting and adapting STEM education in their own unique national contexts.

Perception is an impression of an object that is obtained through sensing, organizing, and interpreting the object which is accepted by the individual; thus, it is a meaningful and integrated activity within the individual (Walgito, 2002:100). So stimuli from outside are received or absorbed by the five senses which are then organized and interpreted into something that has meaning for the individual. The perceptual process is an activity that is integrated within the individual, namely a unit of psychophysical activity within the individual. Therefore according to Davidof (1989) and Rogers (1965) in Walgito (2002) that perception is individual. What is in the individual will be actively involved in perception, because feelings, thinking abilities, individual experiences are different, so that in perceiving a stimulus may also be different. According to Asrori (2009) perception is an individual process in interpreting, organizing and giving meaning to stimuli that come from the environment in which the individual is located which is the result of the learning process and experience.

According to Walgito (2002) there are three conditions for perception to happen, namely (1) the object being perceived, namely the object that causes the stimulus; (2) sensory organs as receptors to receive stimuli and sensory nerves as a means to transmit the stimulus to the center of the nervous system (brain); (3) attention which is the main step as a preparation for perception. Robin (2015) declared that factors which influence perception are individual, target or object (stimulus), and situation. These factors need more attention to create more positive students' perception. Learning activities need to accommodate students' characteristic as it effects their perception. In learning context, teacher, as a target, can present clear, interactive, and innovative learning materials which can help students to get adequate learning information. Whereas, situation becomes one of the factors by creating comfortable, pleasant, and conducive condition for student as an individual. It can encourage students to be actively involved in learning activities and to have successful learning experience.

Motivation is an effective factor that led human organism to behave and determines insistence and energy of humans' behaviours' (Sevinc, Ozmen, and Yigit, 2011). The term motivation comes from the word motive which can be interpreted as the strength found in the individual that causes the individual to act (Uno, 2017). Referring to Kast and Rosenzewig (in Pardee, 1990), motives are what drive a person to act in a certain way to at least develop a tendency for certain behaviours. Motivation can be defined as the forces within a person that encourage him to meet basic needs or desires. Motivation ultimately comes from the tension that arises when one or more of our important needs is not satisfied.

Motivation to learn can arise due to intrinsic factors, namely the will and desire to succeed as well as the encouragement of learning needs, expectations of ideals/ambition. Meanwhile, the extrinsic factors are the existence of appreciation, a conducive learning environment, and interesting learning activities. These two factors must be considered because it is certain stimuli which make them want to do more active and enthusiastic learning activities (Uno, 2017: 23).

The brains of women and men are more similar than different. The brain is very plastic and experience can modify its growth. Thus, biological factors do not really determine gender behavior and attitudes. It is the child's socialization experience that has more of an effect. The socialization view, both psychoanalytic theory and social cognitive theory, explains that social experiences affect children's gender development (Santrock, 2010). Gender differences in behavior and attitudes are more due to differences in social expectations and different treatment of boys and girls. According to Martin & Dinela (Santrock, 2010) the gender scheme theory states that individual attention and behavior is guided by intermal motivation to adjust to gender-based socio-cultural standards and gender stereotypes.

## Methods

This study used survey design and questionnaire as mean for collecting data. This research utilizes a 5-points Likert scale to measure students' perceptions and motivations toward STEM subjects. This instrument was developed through standard procedure in developing instrument and the instrument item (24 item) meets the criteria of Rasch model, illustrated by 0,5 < MNSQ < 1,5 and 0,4 < point measure correlation < 0,85 (Boone et al., 2014) and has R value of 0.93 which was categorized as high reliability. The respondent are 370 students (143 males; 227 females) from different cities in Indonesia. The students have participated in STEM learning by the teachers who had participated in SEAQIS STEM training. Data analysis was conducted using the IRT Rasch model approach assisted by Winsteps Aplication ver 3.7 . Data analysis was carried out to classify students' motivation and perception towards STEM subjects into five scale using formula of mean ± deviation standard (Syaifuddin, 2012) and to find out gender bias significance.

**Results and Discussion**

In order to find out the levels of perception and motivation of the students toward STEM subjects (science, technology & engineering, and mathematics), a 5-scales categorization was first made using the formula as shown on table 1 as explained by Syaifuddin (2012). This categorization was made for perception and motivation toward STEM subjects.

Table 1 Categorization of Students Perception and Motivation toward STEM Subjects

| | Formula | Category |
|---|---|---|
| **1.** | $+1.5\ \sigma < \mu$ | Very High |
| **2.** | $+0.5\ \sigma < \mu \leq +1.5\ \sigma$ | High |
| **3.** | $-0.5\ \sigma < \mu \leq +0.5\ \sigma$ | Moderate |
| **4.** | $-1.5\ \sigma < \mu \leq -0.5\ \sigma$ | Low |
| **5.** | $\mu < -1.5\ \sigma$ | Very Low |

Note: $\mu$: Mean; $\sigma$: Deviation Standard

***Perception by Gender***

According to the formulas on Table 1, which regards to the categorization of the responses on the perception and motivation of the respondents toward STEM subjects, these data were collected. It can be seen in Table 2 that both female and male students have high perceptions toward technology and engineering also have moderate perception toward mathematics. While female students have higher perception toward science than male students.

Table 2. Students' Perceptions toward STEM Subjects

| **Gender** | **Perceptions** | | | | | |
|---|---|---|---|---|---|---|
| | **Science** | | **Technology & Engineering** | | **Mathematics** | |
| | **Mean** | **Category** | **Mean** | **Category** | **Mean** | **Category** |
| **Female** | 0.73 | High | 1.71 | High | -0.05 | Moderate |
| **Male** | 0.57 | Moderate | 2.22 | High | 0.04 | Moderate |
| **Significance** | 0.236 | | 0,233 | | 0.047 | |

Further, Table 2 also shows that, based on statistical test, the students' perceptions significance toward Science is 0.236 which can be concluded that there is no significant difference between male and female students in their perceptions toward Science. According to the data, the mean for female students is 0.73 while for male students, it is 0.57. These numbers show that female students have more positive perceptions toward Science in comparison to male students. These results are in accordance with the study of Kaya, Kilic, and Akdeniz (2004) who state that statistical result of the QPSC score undergraduates' perception of their science classes were significantly differ favouring female students in the grades of third year. Another possible explanation, that it is probably that science learning in middle school tend to has more focus on practicum activity as female students tend to have more interest in thorough and tenacious activities as they can be found in practicum activity. This finding is in line with a study by Kaya, Kilic, and Akdeniz, (2004) which states that female students better than male students on the factors of interest in teaching, grades as feedback, and laboratory experiences, while male students were better than female students on only the factor of passive learning.

Further, the students' perceptions toward Technology & Engineering also show no significant difference between the perceptions of female students compared to male students as the significance being 0.233. Just looking at the mean, the perceptions of female students (1.71) is lower than that of male students (2.22), even though both of them were categorized as high. This translates to male students having a more positive perceptions toward Technology & Engineering in comparison to female students. It is caused by assumption which believes that technology and engineering are male stuff which then unconsciously affects teachers, parents, and people assumption (Madara and Namango, 2016). It is also supported by finding that female students have been less-related to information on technology and engineering. Furthermore, female students prefer to choose education, psychology, and health as their majors in university (Castillo, Grazzi, and Tacsir, 2014). Therefore, to attract more female students to technology and engineering are by creating engineer's resources and training opportunities to school counsellors and teachers which can be used to promote engineering education and careers to girls, their parents, and educators. (Madara and Namango, 2016).

As for the students' perceptions toward Mathematics, there is a significance value of 0.047. This value, is lower than 0.05, therefore a significant difference between the perceptions of male and female students toward Mathematics can be concluded. According to the mean, the perception value of male students toward mathematics is slightly higher compared to that of female students. This result is not that different with the findings of Mutodi, Paul and Ngirande, & Hlanganipai (2014), which stated that the results of their study is consistent with another's findings by Hoang (2008), who showed that male consistently reported slightly more positive perceptions than female.

In the context of this study, the explanation for the result is that there is a possibility that STEM learnings which the students enrolled in were science-dominated. During the development of STEM projects, most of the issues dealt with are related to science. There is also the fact that in referencing the National Curriculum, the basic competencies for science were the main references, while basic competencies for mathematics serve only as prerequisites or as secondary references. This is due to the fact that in Indonesia, there are no STEM curricula, so that STEM was integrated into the National Curriculum. However, the National Curriculum itself was not designed for STEM learning, so it is not easy to find a topic that accommodate basic competencies in the courses of Science and Mathematics in relatively same or similar moment. Consequently, an alternative to this is by designating a course to be the leading sector, while the other becomes the prerequisite or as secondary materials.

Consequently, female students rarely get the opportunities to experience learning mathematics material positively. While, positive experiences are necessary toward positive perceptions, because individuals who experience an object or event positively tend to also have positive perceptions toward the object or event, and vice versa (Asrori, 2009). On the other hand, in the case of male students, less intensive material presentations are assumed to be sufficient for their learning, as shown by them scoring slightly higher compared to female students. It is supported by other studies, such as the one by Mutodi, Paul and Ngirande, & Hlanganipai (2014), who showed that the perceptions of male students are a bit higher compared to female students. They also stated that their study is consistent with findings by Hoang (2008), who showed that male students consistently reported slightly more positive perceptions than female students.

Same result of statistics test was shown between female and male students' perception toward science also technology and engineering. This was indicated by significance value higher than 0.05 which mean no gender bias, which can be interpreted as there is contribution of STEM learning to provide balanced positive experience for female and male students which implies to decreasing of gender bias. Even though, both perception must be enhanced, especially for male students toward science and female students toward technology and engineering. In contrary, statistic test for perception of female and male students toward mathematics show significance which indicate there is gender bias to be handle moreover the value of both mean are still categorized as moderate.

Therefore, to increase the perceptions of male students toward science, female students toward technology and engineering, moreover both female and male students toward mathematics, and to make STEM learning more comprehensive, collaborative STEM learning between science, mathematics, and technology teachers need to be considered. Lesson learnt from teachers who conducted on the job learning using STEM Local Context (SEAQIS, 2019) indicate that making use of local issues where the school is situated can also help teachers and students find suitable topics for STEM learning easier. With respect to time allocated for them in the curriculum, it is worth considering the use of the school projects approach, extracurricular activities, or any other activities that the school condition allows for. Robin (2015) declared that factors which influence perception are individual, target or object (stimulus), and situation. These factors need more attention to create more positive students' perception toward science and technology and engineering. Learning activities need to accommodate students' characteristic as it effects their perception. In learning context, teacher can present clear, interactive, and innovative learning materials which can help students to get adequate learning information. Whereas, situation becomes one of the factors by creating comfortable, pleasant, and conducive condition for student as an individual. It can encourage students to be actively involved in learning activities and to have successful learning experience.

***Motivation by Gender***

Table 3 shows the motivations of male and female students toward Science and Technology & Engineering scoring equally on the High category. Considering the mean value, female has higher score in science but lower score in technology & engineering. This is in line with other studies which claim that female students' motivation in science level is higher than male (Yilmaz and Cavas (2007); Sevinc, Ozmen, and Yigit, 2011; Chan and Norlizah (2017)). On the other side, they have moderate category in motivations toward mathematics. This is also in line with several studies which show the same result (Frenzel, et. al. 2010), and even Nosek, Greenwald, and Banaji (2002) who claim that in university level, women are poorly represented in math and math-intensive field such as the physical science, math/computer science, and engineering. This happened because of stereotype.

Table 3. Students' Motivations toward STEM subjects

| Project Gender | Motivations | | | | | |
|---|---|---|---|---|---|---|
| | Science | | Technology & Engineering | | Mathematics | |
| | Mean | Category | Mean | Category | Mean | Category |
| **Female** | 2.16 | High | 3.88 | High | 0.34 | Moderate |
| **Male** | 1.86 | High | 4.49 | High | 0.42 | Moderate |
| **Significance** | 0.259 | | 0.083 | | 0.543 | |

In the context of this study, the high motivations toward Science and Technology & Engineering along with the ordinary motivations toward mathematics, is possibly due to the fact that STEM learnings which the students enrolled in were Science-dominated; as is the case with the students' perceptions dimension as explained before. Further, the high motivations of students learning in Technology and Engineering can be attributed to the fact that the STEM projects they were involved in were heavily related to Technology & Engineering. It can be said that those projects, being one of the cores in STEM learnings, contrast them with other project-based learnings. For every STEM project, each team is assigned to solve real problems/issues happening around them. From the report of On the Job Learning (OJL) of teachers who participated in SEAQIS STEM Local Context training, it was found that the results of STEM learning observations are in line with the students' interviews after participating in them, in which they mostly said that they enjoy STEM learning and were happy in being able to solve problems/issues in the STEM projects (SEAQIS, 2019). This is further supported by the motivational theory, in which it says that the factors that increase students' motivations include a learning where they were given the opportunities to try, participate, and feel accomplished. This feeling of accomplished will rouse their learning motivations (Sukmadinata, 2011).

Table 3 also shows the significance values, acquired from the comparative test between the motivations of male and female students toward the three STEM subjects, where all the values are higher than 0.05. Therefore, the gender-based differences regarding motivations are not significant. This can be assumed that through STEM learning, teachers are able to increase relatively equal motivations between male and female students which decrease gender bias. Even though the motivations toward Science and Technology & Engineering are high, improvement is needed to work on the students' motivations toward Mathematics.

Another possible explanation is that the brains is very plastic, in which experiences can modify its growth for example socializing experiences of the students which can significantly determine gender behaviours and attitudes (Santrock, 2010). From the context of Santrock's explanations, it can be concluded that teachers need to consider to provide their students with socializing experiences through gender bias free learning so that gender bias can be decreased, as was previously stated in the beginning of this paper.

**Conclusion**

Based on the results of this study, we can conclude that: (1) there is a significant difference in female and male students' perception toward mathematics even though they have slightly different score and both were categorized as moderate. (2) There is no significant difference between female and male students' perception towards science also technology and engineering. Female students have more positive perception toward science and was categorized as high while male perception was categorized as moderate. Although male have more positive than female student toward technology and engineering but both perception were categorized as high. 3) Furthermore, there is no significant difference in female and male students' motivation toward all of STEM subjects. Both have high motivation toward science also ~~in~~ technology and engineering but have moderate motivation toward mathematics. Female have higher motivation toward science while male have more motivation toward technology and engineering also in mathematics.

In order to improve female and male students' perceptions to Mathematics subject, male student perception to science, and to reduce gender bias on male and female students' perception toward mathematics, STEM learning should be able to provide a positive learning experience to build a positive perception. The positive learning experience is a learning that is accommodating students' characteristics, clear, interesting, and innovative so that students can receive sufficient information about the learning. Besides, the teacher need to provide equal opportunities for female and male students in all hands-on activities, particularly in engineering and in using technological devices. Moreover, teachers and school counsellors need to support to make their female students realize that engineering and technology are prospective for female careers.

Despite providing a reduction in gender bias, STEM learning need to be able to increase students' motivation in learning mathematics. STEM learning needs to be more accessible and cohesive, especially if approaches to integrating STEM into curricula are used. Collaborative teaching between science, mathematics, and technology teachers needs to be considered, particularly to expose the role of Mathematics subject. Additionally, it is also essential to create comfortable, exciting, and proper learning environments for students' personal development where students can actively participate and gain successful experience.

**Acknowledgements**

We would like to extend our heartfelt gratitude to our institution, SEAMEO QITEP in Science, especially Dr. Indrawati as our director that gave us full support. A sincere thanks also delivered to Ms. Euis Heryati and Dr. Rina Mutaqinah for their input also for the teacher and students who participated in this study.

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2021
SciEd
SEAQIS Journal of Science Education (SciEd)
P-ISSN: 2777-0397 | E-ISSN: 2798-7175
Vol:1, No:1, PP:27-35
www.journal.qitepinscience.org
Research Paper Open Accsess

# Automatic Trash bin Arduino Project (ATAP): Enhancing Computational Thinking Skills through STEM Learning

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## Abstract

Computational Thinking is nowadays the fifth of twenty-first-century skills for every individual. Two main approaches to enhance Computational Thinking Skills (CTS) are computer-based and unplug activities. In this study, computer programming exercise was embedded in STEM Learning Using Automatic Trash bin Arduino Project (ATAP). Observations of student's activities, products, and students' worksheets were collected and analyzed in accordance with Portfolio assessment rubric consist of some indicator and criteria to get the figuring of student's computational thinking skills. Based on the data, there are enhancement of Computational Thinking Skills (CTS) during the lesson of ATAP STEM Learning. The CTS was getting better enhancement are abstraction, pattern recognition and decomposition but algorithm design were considered need more time to practice. In addition, the results showed that learning cognitive outcomes with normalized gain <g> valued at 0.66 with average category. These indicates that STEM Learning Using ATAP have positive effect to enhance learning effectivity and Computational Thinking Skills. But there are still need many improvement especially in learning material like module, worksheet and implementation.

**Keywords**: ATAP, STEM Learning, Computational Thinking Skill

## Introduction

Our education today was not quite suitable to prepare students have high-skill related to global society. Many teachers still not have various strategies to involve students in future-ready learning. As a teacher who has responsibilities to teach millennial students, we know that it is not easy to make an interesting lesson suitable for global pretension. Our learning still has focused to achieve base competences in the curriculum for cognitive exam. Students are not very often to develop step by step solutions of real-life problem in the learning process. In fact, many students are not used to critical thinking because they are very often learning just for understanding phenomena or concepts without application the concept in order to solve the problem. Meanwhile finding solutions regardless of the problem is a skill to prepare students for challenges and job that possibly do not exist today.

One of the future-ready competences is Computational Thinking Skills (CTS). Computational Thinking is nowadays the fifth of twenty-first century's skills for every individual's needed. Two main approaches to enhance CTS are computerize activities mainly programming exercise and unplug activities which is no use digital device. Each approach has different advantages of implementation. An advantage of computerize activities is improving computer technology literacy. We know that more than hundred thousand new job related to computer has been opening. Just individuals who has good-skills will fill the job vacancy today and in the future.

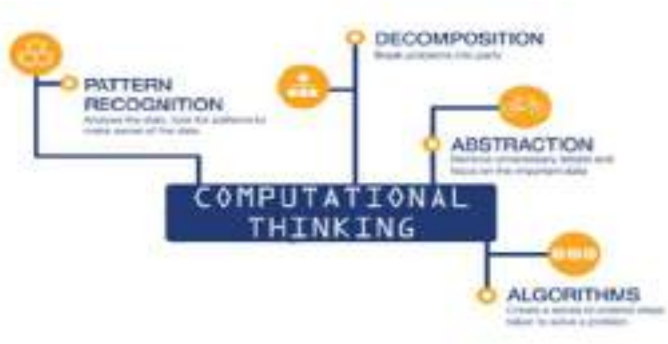
However, based on the results of observations, the students' CTS still need to be developed. When the first time I implemented STEM learning Using Arduino, most students were still depend on teacher's explanation for completing the Arduino project. Students are less trained in making designs and problem solving steps through the project. In order to minimalize this problem, we need an approach to improve student's CTS.

Computational Thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science (Wing, 2006). Computational thinking is not only about programming but how writing a program could solving real life problem, what the best way to solve the problem and breaking down the complex problem to particular problem. Next Generation Science Standards (2013) (Psycharis & Kotzampasaki, 2019) suggest that CT "is a core scientific practice and due to the increased presence of computation in mathematics and scientific contexts, a new urgency has come to the challenge of defining computational thinking and providing a theoretical grounding for what form it should take in Science and Mathematics".

The Australian Curriculum Assessment and Reporting Authority (ACARA, 2020) defines:

> Computational thinking is defined as "a problem-solving method that involves a variety of techniques and strategies which may include organizing data logically, breaking a problem into parts, designing and using algorithms and models"

Adopted from Australian Curriculum Assessment and Reporting Authority (ACARA, 2020), Computational Thinking is divided into several sections as shown in the picture 1.




Picture 1. Computational Thinking

In line with the description of ACARA, Hidayat (2019) state that:

1. Pattern Recognition, ability to see the similarities or differences in patterns, trends and regularities in the data that further is used for predictions and data presentation. The same solution can used to solve the problem, which has similarities in patterns.
2. Abstraction, finding characteristic of problem, determine what details we need and what we can ignore to solve the problem.
3. Decomposition, breaking down a complex problem or system into smaller, more manageable parts. The solution begin for every smaller part toward more complex problem.
4. Algorithm Design, develop the step-by-step solution to the problem.

One alternative of the learning approaches that can be supposed to enhance Computational Thinking Skills (CTS) is STEM learning. The research of Psycharis and Kotzampasaki (2019) concludes that STEM Learning has positive influence on the dimension of Computational Thinking. STEM education is a strategy to improve technology literacy as an important skill in this twenty-first century era. Akgun (2013) describe that technological literacy (TL) is one of the most important qualifications for a 21st-century person to acquire (ETS, 2003), and STEM education is important for the acquisition of this qualification. Technological literacy is, “the ability to responsibly use appropriate technology to: Communicate, solve problems, access, manage, integrate, evaluate, design and create information to improve learning in all subject areas, and acquire lifelong knowledge and skills in the 21st century” (Technology Literacy Assessment Project, 2009, p. 1).

In addition, through STEM learning, students practice to implement engineering design process (EDP) which is an important curriculum in this century. Morgan (2013) mentioned that “The design process is a systematic approach followed when developing a solution for a problem with a well-defined outcome”. There are many variations in practice today, but most of them include the same basic steps. Following a well-structured design process is important because it provides the structure needed to formulate the best solution possible, and the act of following a design process builds problem-solving skills and logic”.

Morgan in Akgun (2013) represented utilizing a seven-step process of Engineering Design process (EDP). First step is identify problem and constraint. This process aim to capture student’s interest in the design problem, motivate and involve students to identify problem related to the human element. The important process in the first step is to find out what the students already know to kick off a project and constraints. The second step is research. This process is a vital activities in the lesson. The students do their research related to find out solution for the problem. Based on the result of the research, next step students generate ideas and analyse ideas about the product in order to solve the problem. They can use math, science and technology concept that are used in their ideas to make a design. After they have ideas of the design, they build the project or product. Students learn better when they have opportunities to apply the concept in a context of real world. The next step is test and refine. Students compare the result of the test and their prediction, they analyse the results based on the problem criteria and objective. They refine their design solution, and used critically thinking to rebuild the project. The last step of EDP is communicate. Students communicate their product or project and also have to describe the weakness and strengths of their project.

There are some benefits of using engineering design in the classroom. Engineering requires high order thinking skills, build 21st century skills, such as problem solving and creativity, cultivates skills required for successful collaboration and teamwork and develops a stronger interest in science, technology, and mathematics concepts, provides an environment where metacognition and journaling are of great importance and the purpose of these activities are better understood and appreciated (Akgun, 2013). One research about the impact of implementation STEM has been conducted by Psycharis and Kotzampasaki (2019). They were designed and implemented STEM Inquiry using computational tools such as Arduino and RGB LED in Greek public school 5th - 6th grade. The findings indicate a positive influence of integrated STEM in the teaching sequence in order to enhance students’ confidence with computational experiments.

**Method**

The brief line of STEM components in this learning as shown as Picture 2. Science mastery in this learning had been have by students before the implementation.


Picture 2. ATAP STEM Learning Briefline

Students were put into four-member teams. Every group were given some electronic components including some sensors and Arduino UNO. Students could use all of the components or just use some components and ignore some others. They had to complete a Trash Bin Project to solve the rubbish problem around School.

In the previous lesson (before the implementation of ATAP), students had been learnt how to use Arduino UNO in the classroom. The teacher gave worksheets to each group with step by step instruction. Students in a group worked together in completing the worksheet and finally they make a product.

In the first lesson of ATAP implementation, students got some modules about basic circuit to use Arduino UNO and some sensors. But not all of source code in the module is true source code to program Arduino UNO. There are some mistake of source code, which students have to find and fix. Students in a group made a discussion about problems around the school, which is important to be solved. In the classroom, students had to break down the problem into some smaller problems and think about the solution for each smaller problem. They also make a design, choose the components, and write the idea of product that could solve the problem.

The second lesson of implementation was conducted outside the classroom but students could discuss with teachers and make a research in order to complete the product (Automatic Trash Bin) still. In this lesson, students got 3 weeks to complete their project. They can learn about basic programming Arduino electric component circuit and sensor by themselves using a module. After students build the product, students tested, analysed and refine product before the class meeting. In the class meeting as third lesson, students communicate and present their product in front of other students and five teachers as observer and evaluator.

The design of STEM Learning Using Arduino to enhance Computational Thinking Skills (CTS) as shown in Table 1.

Table 1. Design of STEM Learning Using ATAP with CTS Indicator

| STEM Learning | The Implementation of Automatic Trash Bin Arduino Project (ATAP) | CTS | CTS Indicator |
|---|---|---|---|
| **Identify Problem and Constraint** | Students have to identify what are the problem around them and what is the product that they can made in order to solve the problem. | Decomposition | - Identify the problem<br>- Break down the problem into smaller problem)<br>- Break down the big project into smaller project |
| **Research** | Students explore about the problem and solution in STEM perspective. Students also explore about using Arduino through module (including various tutorials) independently and determine which tutorials were needed to design and build a product. | Abstraction | - Identifying the objects characteristics through direct observation<br>- Generalizing to determine some objects in completing the project and ignoring irrelevant object (keep the other object in the box)<br>- Making Connection between process or concept to form a new understanding. For example about pin number concept in Arduino. |
| | | Pattern Recognition | - look for similarities among and within problem, fix the wrong source code based |

| | | | |
|---|---|---|---|
| | | | on the patterns and write their own source code. |
| **Ideate and Analyse Ideate** | Students ideate and analyse ideate in order to make a design of the product and explain how is the functionality, what the components, the advantages and limitation. And students explain how the product can solve the problem in STEM perspective | Algorithm Design | - explain a step by step procedure to make a project<br>- design the Automatic Trash Bin Arduino Project |
| **Build** | Students make a product based on their design using Arduino and appropriate components (sensor) | Algorithm Design | - build their own program (source code) to complete the project<br>- build their product (Automatic Trash Bin) by their step by step procedure |
| **Test and Refine** | Students do some test, redesign and revise the product | 4 Skills | - identify the wrong function of product (bug)<br>- redesign and revise the product by fixing the bug |
| **Communicate and Reflect** | Students did the presentation and communicate to the teacher and other students in front of classroom | | |

To figure out the enhancement of students' Computational Thinking Skills (CTS), students' writing answers in a worksheet was analysed based on portfolio assessment rubric. How quality of students answer, how they finished the worksheet and their product were analysed in order to record their CTS performance. This portfolio assessment is a grading rubric to indicate different levels of achievement for each dimension of CT performance or a checklist to indicate whether a certain criteria is met. Rubric of portfolio assessment and its criteria as shown as Table 2.

Table 2. CTS Indicator and Rubric of ATAP Portfolio Assessment

| **CTS** | **CTS Indicator** | **Rubric of ATAP Portfolio Assessment (Score)** | | |
|---|---|---|---|---|
| | | **1** | **2** | **3** |
| **Decomposition** | - Identify the problem<br>- Break down the problem into smaller problem)<br>- Break down the big project into smaller project | - Just write 1 problem as a big problem | - Write 1 big problem<br>- Write 1 smaller problem as part of manageable problem | - Write 1 big problem<br>- Write 2 or more smaller problems as part of manageable problem |
| **Abstraction** | - Identifying the objects characteristics through direct observation<br>- Generalizing to determine some objects in completing the project and ignoring irrelevant object (keep the other object in the box)<br>- Making Connection between process or concept to form a new understanding. For example about pin number concept in Arduino. | - Determine objects but not all object related to feature in their project<br>- Ignore (Keep in the box) other object which is not used in their product | - Determine objects /components related to feature in their project<br>- Ignore (Keep in the box) other object which is not used in their product<br>- Explain the functionality of all object that they had been Chosen | - Determine objects / components related to feature in their project<br>- Ignore (Keep in the box) other object which is not used in their product<br>- Explain the functionality of all object that they had been Chosen<br>- Make a correct picture of circuit consist of Arduino, component and connection the component into pin number |

| | | | | |
|---|---|---|---|---|
| **Pattern Recognition** | - Look for similarities among and within problem, fix the wrong source code based on the patterns and write their own source code. | Fix 1 wrong source code and write the true source codes | Fix 2 or more wrong source code and write the true source codes | - Fix 2 or more wrong source code and write the true source codes<br>- Write some new source code related to the feature of the project |
| **Algorithm Design** | - Explain a step by step procedure to make a project<br>- Make a design / diagram the product (Automatic Trash Bin Arduino Project)<br>- build their product (Automatic Trash Bin) by their step by step procedur | - Make the design diagram / flowchart how to make the product (Automatic Trash Bin Arduino Project) based on the design from internet, etc<br>- Build their product (Automatic Trash Bin) refers to their design | - Make the design / diagram / flowchart how to make the product (Automatic Trash Bin Arduino Project)<br>- Build their product (Automatic Trash Bin) refers to their design. | - Make their original design / diagram / flowchart how to make the product (Automatic Trash Bin Arduino Project)<br>- Write step by step procedure to make a project/product including its features<br>- Build their product (Automatic Trash Bin) refers to their design |

During the lessons students were also observed by five teachers (as observer). Some teachers (math, biology, physics, chemistry and IT) did a collaboration in this research to be observer. They used portfolio assessment of product to give the students feedback and evaluation. The teachers as observer was involved in the first lesson when students identify the problem, research, ideate and analyse ideate and in third lesson when students communicate the product.

To find out the effectivity of learning process, before and after implementation, students were given pre-test and post-test about the concept mastery with the same instrument. Based on the score of pre-test post-test, the effectivity of learning determine by normalized gain score Hake (2008). Students who involved in this study are grade 12th of SMA Labschool UPI 2019/2020 school year.

## Results and Discussion

The implementation of the lesson was conducted by blended learning. In carrying out independent assignments, students and teachers continue to discuss project completion through WhatsApp groups. Students have a longer time to finish the project, doing their own research, learn how to use Arduino by themselves, and also collect all of the resources to complete the project. In this implementation, students got various kind of Automatic Trash Bin that they want to complete. They found several problems around the school and had to solve one problem with the product using Arduino. They can determine what components, designs, and functions to solve the problems they have chosen.

Based on portfolio assessment of worksheets, students' CTS can be seen in Table 4.

Table 3.Students' CTS Profile

| CTS | Finding | Total Score | Percentage (score/max score) |
|---|---|---|---|
| **Decomposition** | All groups demonstrated Decomposition Skill based on their report of the project. Students describe about the | 15 | 83% |

| | | | |
|---|---|---|---|
| | problem which was solved by the product. They described each function of the product in order to solve the problem | | |
| **Abstraction** | - All groups demonstrated abstraction skill based on their report and their component to build the product. Students determined component/object in completing their product, assemble the component based on the picture of fritzing (circuit). | - 16 | - 89% |
| **Pattern Recognition** | All groups demonstrated pattern recognition based on their code. Students were able to write their own code after recognize the similarities or pattern. They wrote code for their program specification and limitation. | 16 | 89% |
| **Algorithm Design** | There were 6 group draw the design of Automatic Trash Bin. Only 3 groups could write the procedure how to make the product, the design and the procedure. 2 groups wrote the design and procedure which was taken from the internet, One group was not able to make a design of product. | 10 | 59% |

Based on the description in the table above, this study indicate positive influence to enhance students' Computational Thinking Skills especially on abstraction, pattern recognition and decomposition. During the implementation, students show their CT skills. Students did some discussion about the components and determine what components to complete the product, they make their own decisions. They did some creations by changing the code for basic circuits and completing products according to their designs and knowledge. Here are some various product as applications of their knowledge and skills in order to solve the problem.

From 6 groups of students, 4 groups have creativity to build a product which has more than 1 feature. Every group could complete the project by themselves. Only 2 groups did not yet show creativity in completing the project. This 2 groups (Group 3th and Group 6th from table 6) also wrote the step by step solution which taken from internet without modification or added some creation. They did not show the algorithm design process in their report. We could conclude that algorithm design skill were considered need more time to practice. The picture below are some example products and activities when students communicate their product.

Picture 3. Some Products and Activities

The learning effectivity as students' cognitive outcomes based on normalized gain score could be seen in Table 6. The normalized gain score is 0,66 in average category. This indicates that STEM Learning Using ATAP is worthy to implement. Even though the teacher was not teach directly to students, students can learn more knowledge and skills by themselves using module, worksheet and task to complete the project.

Table 4. Normalised gain Score

| | Average Score | Deviation Standard (S) |
|---|---|---|
| Pretest | 4,20 | 1,45 |
| Postest | 21,23 | 3,16 |
| Normalized Gain | 0,66 | 0,11 |
| Criteria | Average | |

Furthermore, the finding of this study conclude that STEM learning using Automatic Trash Bin Arduino Project (ATAP) has good impact to enhance students' Computational Thinking Skills especially on abstraction, pattern recognition and decomposition but on algorithm design still need more time to practise. In the other hand, the learning effectivity STEM learning using Automatic Trash Bin Arduino Project (ATAP) in average category.

## Conclusion

Based on the students' observation results, products, and worksheets, STEM Learning using Automatic Trash Bin Arduino Project (ATAP) has good impact to enhance students' Computational Thinking Skills (CTS) especially on abstraction, pattern recognition and decomposition. Students demonstrated abstraction and pattern recognition skills as the high enhancement. On the other hand, students need more time to enhance algorithm design skills as the lowest enhancement. Students demonstrated decomposition and algorithm design when they have their free learning to complete the project. In addition, students show creativity in their product and have new knowledge as result of their own research. Furthermore, the results showed that learning effectivity as students' cognitive outcomes with normalized gain <g> valued at 0.66 with average category. These findings indicated that STEM Learning using ATAP is worth considering in learning physics. Although there are many things need to be improved such as learning material (worksheet and module) and teacher instruction.

## Acknowledgements

I would like to acknowledge and express thanks for the support and participation of SEAMEO QITEP in Science (SEAQIS) as well as all individuals and groups who involved in this study. Funding form SEAQIS Research Grant Program in 2019 gave me some equipment and spirit to conduct following research in 2020 and another next years.

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2021
SciEd
SEAQIS Journal of Science Education
SEAQIS Journal of Science Education (SciEd)
P-ISSN: 2777-0397 | E-ISSN: 2798-7175
Vol:1, No:1, PP: 36-43
www.journal.qitepinscience.org
Research Paper
Open Accsess

# Developing Sustainability Literacy Through STEM Learning: A Review

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## Abstract

The future of human life is not only full of potential and development but also of challenges. Global challenges that will be faced start from the environmental crisis, poverty and social problems. The UN has formulated bold goals through 17 targets in the Sustainable Development Goals to deal with this sustainability problem. The education sector is a milestone in achieving these goals. Through education, sustainability can be achieved among other things by integrating design thinking into STEM learning which can promote sustainability literacy. This opportunity need to be follow up to develop Sustainability Model of Design Thinking as one innovation to enhance sustainability literacy.

**Keywords**: Climate Change, Design Thinking, STEM Education, Sustainable Development, Sustainability Literacy

## Introduction

The Global Risk Report stated that there are threats risking the development in the future. Out of five risks, four are related to environment (World Economic Forum, 2019). While there is an emerging awareness of the current environmental issue on education provision and learning, it is also clear that education has an important role to play in addressing this change. This includes work carried out using various terms and definitions, including ‘education for sustainable development’ or ESD (Sterling, 2001).

In 2015, the United Nations Development Programme (UNDP) identified a series of seventeen important worldwide goals referred to as the Sustainable Development Goals (SDGs). These goals make up a blueprint for the future well-being of the globe oriented around the themes of people, planet, prosperity, peace, and partnership (United Nations, 2019). Education is a crucial part of the SDGs, not only due to its role as a specific goal (Goal 4: Quality Education) but also because it is essential to the possibility of progress on all goals, including environmental-related goals (UNESCO, 2014).

Access to quality education in STEM is linked to reduced poverty, economic growth, and more resilient democracies; these disciplines play an essential role in addressing many of the Sustainable Development Goals (SDGs). International organizations, such as USAID and UNESCO have moved STEM education to the forefront of their institutional goals as careers in STEM fields are projected to see exponential growth in the twenty-first century (UNESCO, 2017).

The integrative capability of engineering design is evident in the engineering design process, which is a problem-solving method that engineers use—along with knowledge from science and mathematics—to solve technological challenges (NRC, 2009). Beside that, the literacy should be delivered through empathy. Empathy is a stimulus that connects students with a party or condition, this is a feature of the design thought process that is different from the engineering design process (Cook & Bush, 2018).

**Review**

**Sustainability Literacy (SL): Four Ways Thinking**

Experts have broadened the understanding related to sustainability to more specific environmental issues by pointing out the ecological relationships that exist between human-nonhuman interactions and flora and fauna with land (Kates et al., 2001; Orr, 1992). To deal with this problem, education must be a central component to improving the human condition. The main focus is on preparing the next generation to make decisions, identify problems, and solve them.

Literacy is a collection of skills that can create a certain level of competence that can be measured in the future after being achieved and formed. The term literacy is defined as, "a collection of skills that enable effective participation and influence in various areas of social life" (Stibbe & Luna, 2009).

Nolet (2009) defines sustainability literacy as various advanced abilities and actions such as problem solving and information-based decision making. Likewise, the concept of sustainability literacy stated by Tilbury (2011) not only states new knowledge but also learns to: (a) ask critical questions; portray a more positive future; think systematically; and to explore the relationship between tradition and innovation". Teachers who have acquired sustainability literacy need to be empowered to end society with a critical lens; (b) teach students sustainability topics and ways of thinking; (c) make the right decisions; (d) contribute to cultivating intrapersonal, interpersonal, intergroup and intergroup concepts of society and the environment (Bertschy et al., 2013; Nolet, 2009; Stibbe & Luna, 2009). Together with other literacy, teachers must be able to inculcate sustainability literacy into everyday learning in every curriculum (Santone et al., 2014).

Four ways of thinking (future thinking, value thinking, systems thinking, and strategic thinking) that are more steps or collections of knowledge that must be acquired. Rather, it is a conceptual framework for analyzing sustainability problems and solutions through an interconnected approach. These four specific ways of thinking were identified by a review of the existing literature. Somehow this way of thinking is discussed in many literatures, but still stands respectively (Wiek et al., 2011; Stibbe & Luna, 2009; Bollmann- Zuberbuhler et al., 2014).

Future Thinking is also known as anticipatory thinking, foresight, or trans-creating thinking. Sustainability requires future thinking. This includes, "the ability to analyze, analyze, and create a comprehensive picture of the future related to sustainability issues" (Wiek, et al., 2011). Future thinking allows an anticipatory approach to understanding, reducing, and/or adaptively preparing for future changes, problems, and solutions (Gibson, 2006).

Value thinking is also considered as thinking based on values, knowledge orientation, and/or ethical thinking. Since sustainability is a problem-oriented field and shopping by solutions, potential solutions are value thinking. This includes, "the ability to collectively map, define, apply and negotiate sustainability values, principles, goals and targets" (Wiek et al., 2011, p. 209). Thinking values in the concepts of justice, equality, socio-ecological integrity, and ethics. It also means understanding how these concepts vary across cultures, and how integrating these concepts contributes to solving sustainability problems.

Systems thinking is also known as interconnected thinking or holistic thinking. According to Wiek et al. (2011) System thinking, "is the ability to collectively analyze complex systems across multiple domains (society, environment, and economy) and at multiple scales (local to global), thereby considering systemic effects. Systems thinking does not necessarily require knowledge. In fact, systems thinking is about assessing the level of complexity of a system and analyzing system dynamics to make informed decisions that reduce risks with negative outcomes.

Strategic thinking means being able to develop a strategy or plan to achieve a certain vision. Strategic thinking shapes every decision in order to be able to contribute to achieving a vision. Strategic thinking is, "the ability to collectively design and implement, intervene, transition, and transformative governance strategies towards sustainability" (Wiek et al., 2011, p. 210). It involves considering possible solutions through a specific set of assumptions, suggesting potential alternative solutions, and proposing existing assumptions and alternatives, which can potentially lead to new solutions that may be more appropriate (Lawrence, 1999). Strategic thinking involves using analogies and qualitative equations to create new ideas in addition to developing new learning-dependent actions (Lawrence, 1999).

Teachers must be able to take a global perspective to encourage students to see that problems, people, cultures and places of life are interconnected and that complex systems operate at multiple levels. Likewise, teachers need to provide critical thinking skills, which are directly related to decision-making abilities (Church & Skelton, 2009).

**Education for Sustainable Development through STEM Learning**

Students, teachers and parents need to be helped to possess environmental and scientific literacy by improving a powerful and sustained implementation of future-oriented science, technology, engineering, and math (STEM) learning focused on the issues of critical importance as those outlined in the UN SDGs against societal and health problems such as climate change that can adversely affect their lives (O'Donnell, 2018). STEM learning can be identified as one of the new approaches to be used in the education system, which also aims for students to be able to solve problems in their daily lives.

Technology used in STEM learning is increasingly accessible, intuitive, reliable, and diverse in its application, and it is becoming possible for each student to be educated in a way and at a pace that suits his or her abilities, interests, and needs (Barak, 2014). STEM Learning can enhance conceptual understanding, and promote higher-order thinking skills among students (Barak, 2014).

STEM learning is also called upon to participate in the social process of searching, learning, and shaping to solve global sustainability issues and to critically reflect on their contribution to sustainable developments. STEM knowledge and the process of science can help understand global problems and support actions in society that address them in a meaningful and knowledge-based way (Pahnke et al., 2019).

Inquiry in STEM learning allows students to explore 'hands-on', to experiment, to ask questions, and to develop responses based on the reasoning in addition to solving problems, and understanding the phenomena of the real world around them ('minds on'), just as scientists and engineers do. Exploration and exploration-based and inquiry-based learning are paths to knowledge for students, on which they can build up knowledge and skills. (O'Connell, 2014). Besides conceptual knowledge, an essential part of basic education in the STEM learning is the ability to acquire, expand, critically reflect on, and apply knowledge using suitable methods of thinking and acting. This includes the ability to work out fundamental relationships for oneself, to evaluate these relationships, and to make decisions based on them, and also, to develop skills in using the ICTs (Haus der kleinen Forscher Foundation, 2016).

From all the above, it can be understood that STEM learning can encourage changes in knowledge, skills, values, and attitudes to enable a more sustainable and just society for all. It aims to empower and equip current and future generations to meet their needs using recent effective tools and a balanced and integrated approach to sustainable development

**Empathy as the Main Gate**

STEM learning is essential for developing globally connected innovators in the 21st century (Garner et al., 2017). However, the STEM field generally focuses on developing students' science, engineering, and technology competencies without discussing the emotional relationship students have with STEM learning processes and products (Garner et al., 2017; Gunkel & Tolbert, 2018).

There are several factors that influence student interest in STEM, but the main factor is the relationship between empathy and STEM problem-based learning activities in the classroom (Gunkel & Tolbert, 2018; Wirkala & Kuhn, 2011). Providing opportunities for students to improve learning by involving empathy and a global perspective can increase interest in science learning (Garner et al., 2017).

Problem-based learning (PBL) and design thinking (DT) activities can provide opportunities for students to determine what they want to solve and how they will combine critical thinking and problem-solving skills to develop designs or products as solutions (Barton & Tan, 2018; Bush & Cook, 2019; Bybee, 2010; von Solms & Nel, 2017; Wirkala & Kuhn, 2011). This activity also provides a way for students to develop and practice creative thinking skills such as asking questions, making relationships, showing empathy, collaborating with peers, and experimenting (Akcay, 2017; Cook & Bush, 2018; Wagner, 2012).

Experts describe empathy as an important impact factor of Design Thinking (Brown, 2008; Kouprie and Visser, 2009; Kolko, 2011). They argue that empathy is a very important form of insight that comes from interactions with other people. Therefore, these insights are not the result of mere analytical processes (Grotz and Creuznacher, 2012).

As a basic form of social cognition, empathy is the capacity to share and experience the feelings of others (Greenson, 1960). Empathy is a skill that enables us to understand other people's situations and perspectives, both imaginatively and affectively (Rogers, 1975). The process of passive speech empathy or feelings towards others (Bialystok & Kukar, 2018; Nelems, 2018). Empathy has a definition, but traditionally, empathy is defined as putting oneself in the other party's position (Bialystok and Kukar, 2018; Nelems, 2018).

Empathy is a stimulus that connects students with a party or condition, this is a feature of the design thought process that is different from the engineering design process (Cook & Bush, 2018). Through design thinking, students get the feeling of confidence in their ability to make changes that have a positive and sustainable impact globally (Carroll, 2014). Design thinking is able to encourage students to take advantage of their unlimited imagination (Carroll et al., 2010). Mehalik et al (2008) and Scheer, Noweski, and Meinel (2012) show a study in which design thinking activities based on science learning can be useful in increasing higher learning outcomes, encouraging class interaction, motivating, and expressing oneself in class, design thinking develops creativity for students to be able to connect and contribute in finding solutions to sustainability problems.

**Sustainability Model of Design Thinking: A Way Foward**

Design thinking which consists of five stages, namely Empathize, Define, Ideate, Prototype, and Test, is one of the fastest ways to increase creativity (Plattner, 2018). This model is designed to improve critical thinking skills and creative problem solving needed to translate ideas from sketches to prototypes. During the "empathize" and "define" phases, students engage directly with their peers to understand local community needs regarding challenges directly related to sustainability. Alternatively, this model could draw on students' specific knowledge about their local community to involve them in STEM activities. In the "ideate" and "prototype" phases, students work in teams to find solutions and use feedback to organize their designs. Students then present the design matrix, describe resource constraints, and receive feedback from peers.

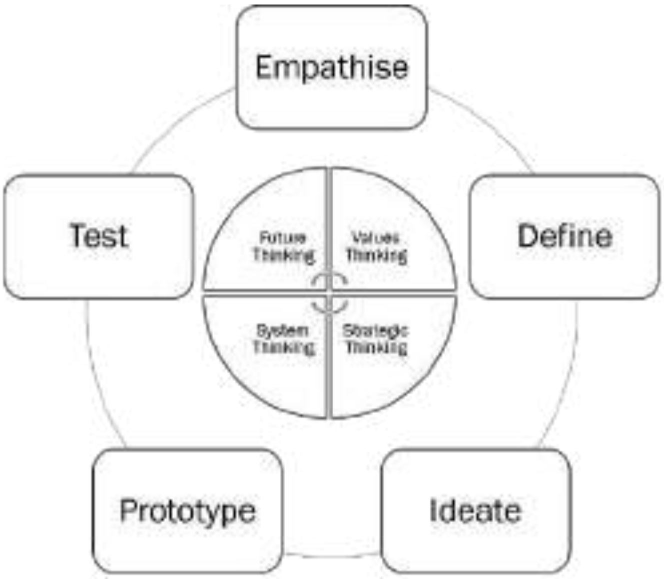


**Figure 1.** Connection between Design Thinking and Sustainable Literacy in STEM Learning

Integrating design thinking into STEM learning to develop sustainability literacy (Figure 1) can help overcome many of the current challenges limiting SDG progress. While these types of difficult challenges are relatively new to science (Bojo´rquez-Tapia et al. 2017). This integration is a great opportunity to achieve the SDGs efficiently and effectively in the midst of the complexities of the real world. It also can produce sustainability initiatives that are effective, transformational, and well-integrated into unique socio-ecological contexts.

**Conclusion**

The diagram of sustainability model of design thinking provides a space where new knowledge about sustainability can be placed. This conceptual model articulates concrete abilities and teaching strategies to link pedagogy and learning with sustainability literacy goals. This model can provide rich insights into the key elements that should be incorporated into STEM learning for sustainability. It can also serve as a guide for meaningful assessment and evaluation of sustainability units, lesson plans, and activities. This model embodies the knowledge, skills and attitudes required for problem solving with respect to complex sustainability challenges.

Based on the importance of sustainability literacy to achieve the SDGs target through STEM Learning, integration of design thinking into STEM learning to acquire sustainability literacy need to further develop. Other opportunities to support teachers in using STEM learning to develop sustainability literacy are by providing teaching materials with various context issues, guidelines for developing learning tools so that teachers are more independent, and policies that motivate teachers to improve sustainability literacy.

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