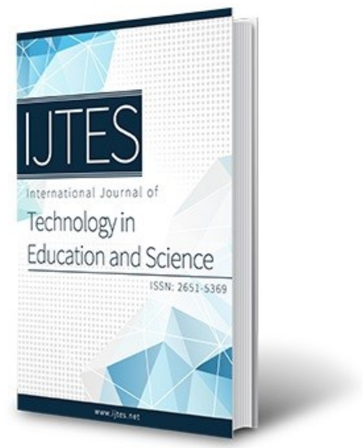

www.ijtes.net

STEM Literacy of Students in Vocational Education

Panita Wannapiroon
King Mongkut's University of Technology North Bangkok, Thailand

Prachyanun Nilsook
King Mongkut's University of Technology North Bangkok, Thailand

Somsak Techakosit
Kasetsart University, Thailand

Sayam Kamkhuntod
King Mongkut's University of Technology North Bangkok, Thailand

To cite this article:

Wannapiroon, P., Nilsook, P., Techakosit, S., & Kamkhuntod, S. (2021). STEM literacy of students in vocational education. *International Journal of Technology in Education and Science (IJTES), 5*(4), 527-549. https://doi.org/10.46328/ijtes.253

istes
International Society for Technology, Education and Science

International Journal of Technology in Education and Science (IJTES) is affiliated with
International Society for Technology, Education, and Science (ISTES): www.istes.org

International Journal of Technology in Education and Science
2021, Vol. 5, No. 4, 527-549 https://doi.org/10.46328/ijtes.253

STEM Literacy of Students in Vocational Education

Panita Wannapiroon, Prachyanun Nilsook, Somsak Techakosit, Sayam Kamkhuntod

Article Info

Article History

Received:
30 March 2021
Accepted:
12 September 2021

Keywords

STEM literacy
Vocational education
Education 4.0
Thailand 4.0

Abstract

Knowledge of all disciplines is more or less equally important and crucial but, in education management, it is important to integrate disciplines so that the knowledge is useful and can be applied to create new things, solve problems and prevent future threats. STEM education for vocational student is not only a trend in education, but also an instructional approach that focuses on students and will lead to sustainable knowledge and learning. This research studied documents that explored the importance of STEM literacy for vocational school students in Thailand. Vocational education must be aligned with Thailand 4.0 and Industrial 4.0 models, and thus vocational schools must adjust their learning approach to be aligned with the Education 4.0 model. As vocational school students will be valuable to the development of the country, STEM literacy must be integrated into a project-based learning model which is a teaching approach for creating invention and innovation. The result of the study shows that STEM literacy for Thai vocational education consists of six components: identifying a STEM problem, exploring and acquiring new knowledge, applying STEM concepts, solving the STEM problem, communicating STEM information and making a STEM decision. The aforementioned components can be used to create a STEM literacy evaluation form for vocational school students.

Introduction

Developed countries with world-renowned education take an interdisciplinary approach based on core subjects taught in all educational institutions, namely Science and Mathematics, and use technologies, together with engineering methodology, as learning tools. This pedagogy is called “STEM education”. STEM pedagogy is an interdisciplinary as opposed to a single subject approach (Batdi, Talan, & Semerci, 2019). In other words, STEM is not learning only science, only mathematics, only technologies or only engineering. When the four subject areas, S-Science, T-Technology, E-Engineering and M-Mathematics, are integrated, it is called STEM education. Many studies have concurred with the idea to foster an interest in the STEM field (Çetin, 2021; Vu, Harshbarger, Crow, & Henderson, 2019). STEM education has benefits for students, such as increasing achievement and improving attitudes, motivation, creating interest toward STEM disciplines, and increasing higher order thinking skills. Teachers' characteristics, perceptions, and attitudes related to STEM influence teachers' implementation of integrative STEM approaches and, as a result, these shape the learning environment (Bicer, 2021; Kartal & Taşdemir, 2021). The results of meta-analytical and meta-thematic findings indicated that STEM had a positive impact on academic achievement and development of different skills (Batdi et al., 2019).

Almost all developed countries use the STEM education approach. The U.S.A emphasized the importance of STEM education by setting up the Committee of STEM Education of the National Science & Technology Council and devising a 5-year strategic plan for STEM education development. The plan prescribes goals and pathways to teachers and students adopting a full-scale STEM education approach. (Holdren, 2013) As the U.S. was not ranked high in world education ranking by country, STEM education was introduced to develop the quality of U.S. education (Gonzalez & Kuenzi, 2012). As for Thailand, STEM Education is part of the country's education policy (Promboon & Kaweekijmanee, 2018) . The policy relevancy of STEM Education is in line with Thailand's Industry 4.0 and Education 4.0 models, which are the pathways to becoming a developed country.

Thailand 4.0

The concept of Thailand 4.0 is not entirely new. In fact, it has existed for a long time. A few decades ago, Thailand was considered a newly industrialized country (NICs) and one of the Five Asian Tigers that was expected to become a developed country in the near future. The Four Asian Tigers have all become developed countries while Thailand was caught in the middle-income trap (Chan-o-cha, 2017). Its industry still relies on leading product owners from all over the world hiring contract manufacturers in Thailand. Thus, Thailand does not have its own original products, nor innovation under its own name (Jones & Pimdee, 2017). Thailand 4.0 refers to Thailand as an incubator of innovation and creativity. Its goal is to export goods and products developed within the country and ultimately, overcome the middle-income trap and become a developed country. In the past, Thailand relied heavily on agriculture. Farmers produced agricultural products for domestic consumption and export. Despite high production volume and the large number of workers, the margin was low. After that, the rise in population led to cheap labor and enabled Thailand to manufacture a high volume of products and goods to export at a low cost (Maesincee, 2016). Later on, lots of investment was made for heavy industries, enabling Thailand to manufacture high value, high cost and high-quality industrial goods. Thailand then became known for its quality goods and attracted investment for mass production. Unfortunately, Thailand was consequently vulnerable to economic crises because it depended heavily on export and foreign investment. Moreover, Thailand imported technology and manufacturing knowledge without having its own knowledge base to produce its own goods. Therefore, the development was not sustainable.

Thailand 1.0 was Thailand in the agricultural era. Many decades ago, farmers were the backbone of the Thai economy and the country was very fertile. Most of the country's income came from agricultural products and most of its workforce worked in the agricultural sector, e.g. growing rice, rubber trees, sugar cane, corn, cassava, etc. The country's forests were abundant and trees were harvested for sale. Most products were agricultural products. At present, Thailand is oversupplied with agricultural products, which are cheap and require lots of labor to produce. Although they continue to be one of the country's main sources of income, the country has lost its competitive edge in the global market.

Thailand 2.0 was defined by the rise in population, leading to the booming of factories producing cheap goods at low cost due to cheap labor. The goods were of good quality and were exported all over the world. The labor of the Thailand 2.0 era used light machines to manufacture garments, equipment, processed food and agricultural products. Many of the businesses are still operating today but with higher manufacturing costs and higher wages. As other countries can produce similar products at a relatively lower cost, Thailand can no longer compete against other countries.

Thailand 3.0 was the era when there was a lot of foreign investment supported by the government. As a result, Thailand became a manufacturing exporter with skilled labor, low manufacturing costs and tax incentives to attract investment. Products were exported all over the world, including cars, machinery, electronic appliances, computer parts, etc. Thailand became a big contract manufacturer without any technology of its own. However, when investors withdrew investment or moved their manufacturing bases, Thailand lost income and could not manufacture the products because the technology and know-how required for manufacturing belonged to foreign investors. Thus, Thailand could no longer earn income by manufacturing and exporting such products.

Therefore, *Thailand 4.0* is the model in which Thailand must be independent of foreign investors and rely on local wisdom to create innovation and invention. The model includes creative economy where technology is used in manufacturing to produce high value but low-cost products which are patented in Thailand (Chan-o-cha, 2017). It also enables the Thai people to use information and communication technology to communicate and invent new high value products that require a small number of proficient workers. Thailand 4.0 is the innovation-driven Thailand.

Consequently, Thai vocational educators must shift their mindset from aiming to groom skilled workers to encouraging students to become innovative, as well as being inventors and entrepreneurs. This is a huge challenge for the management of modern vocational education (Prihantoro, 2020).

Table 1. Comparison of Thailand 1.0 - 4.0

Thailand 1.0	**Thailand 2.0**	**Thailand 3.0**	**Thailand 4.0**
Agriculture was the backbone of the country’s economy. Agricultural products were produced mainly for export.	Cheap labor and export of industrial goods manufactured with cheap labor costs	Era of contract manufacturing of exported goods	Era when the country has its own products with its own innovation and creativity

Industry 4.0

As Thailand is developing the Thailand 4.0 model, its industrial sector must align and shift towards the Industry 4.0 model to support the country’s move to being one that does not depend on any one industry but, on the other hand, being the country whose industries use creativity and technology to replace people in the manufacturing process (Puriwat & Tripopsakul, 2020) . The levels of development are as follows:

Industry 1.0 was the era in which Thailand focused mainly on producing and manufacturing agricultural products and they were the market leaders for exporting goods and processed goods. Human labor was used to produce agricultural products. Farmers were the backbone of the Thai economy. While agriculture is still one of Thailand's main industries, it is faced with oversupply, low prices and it is still labor intensive.

Industry 2.0 was the era of light industry using a large number of workers with low wages doing mainly handiwork. Goods such as, garments, textiles, weaving and handicrafts were manufactured in small factories by many workers and skilled craftsmen. Their wages were low and the products were manufactured mainly for export. The capacity was limited. There were many categories of industries and most of the workers were unskilled or semi-skilled.

Industry 3.0 was the era which focused on manufacturing for export and required many skilled workers. Investments were promoted using tax and expense incentives. Investments were made in heavy industries including chemical, petroleum, automotive and electronics industries, making Thailand one of the biggest manufacturing bases in the world due to its low wages but high-quality workers and low production costs. However, Thailand became the country of contract manufacturers without having its own innovation or products.

Industry 4.0 is the model that will shift towards technological adoption. Machines are used in manufacturing with people as controllers of the machines. The model focuses on the design industry with high value but low production costs, using a small number of workers manufacturing high-technology and innovative products of a high quality and high economic value, generating far more income than investing in older models of industry. Therefore, workers must be prepared for modern technology (Chou, Shen, Hsiao, & Shen, 2018).

Education 4.0

Thailand has a clear policy that aims to become a developed country in order to overcome the middle-income trap and cease being a production hub without its own technology. The goal of this policy is to achieve what is called "Thailand 4.0" or "Digital Thailand". The development will be stimulated by innovation and information technology that drives the economy and society, in order to ensure that Thailand can compete on the international scene in terms of creativity in working and developing products. National human resource development must be adjusted to align with the present era, hence the Education 4.0 model (Hussin, 2018). The model focuses on enabling Thai people to create new products using innovation and become self-made entrepreneurs, instead of climbing the corporate ladder. Therefore, teachers in vocational schools must change how students learn, and how they teach. They must also adjust their assessment to align with the change. Teachers must focus on 21st century skills and encourage students to use their creativity to invent and grow their start-up mindset, rather than wanting to become employees. Therefore, teachers are the key to education reform that could lead to the sustainable development of the country. Thailand has been trying to implement the Education 4.0 model for many decades. It was stated in the education reform of 1999, which attempted to implement child-centered classroom management. The order of educational development is as follows:

In the past, *Education 1.0* model focused on content and knowledge. Teachers were the center of learning as teachers managed classrooms and students followed the teachers. Learning required memorizing as much knowledge as possible. The curricula were designed in a way that students must memorize content in order to pass tests. The goal was to create workers to work in the public sector or be hired by companies.

Education 2.0 was the era when technology was adopted to facilitate learning. Electronic and modern instructional media were provided, allowing students to learn by themselves. Students were the center of learning and teachers acted as facilitators who created and provided appropriate media and technologies to help students learn. Media and technology were used to promote learning so that students could learn anywhere and anytime. It was the era of the information society. Students were taught to support technology.

Education 3.0 was the era when students could learn independently. Knowledge was abundant and could be acquired from any type of media. Students were the center of learning and teachers only gave suggestions, advice and recommendations, as well as providing students with sources of knowledge. Students could gain knowledge without only relying on classroom learning. Workers were able to compete because of this knowledge.

The *Education 4.0* model focuses on teaching students how to learn. It emphasizes analytical thinking skills, problem-solving skills, creativity and collaboration. Students must do hands-on practice and apply knowledge to foster innovation while teachers encourage students to use their creativity to create output (Almeida & Simoes, 2019). Teachers create learning processes which allow students to create products and develop students to become entrepreneurs. Thus, students are taught to become part of the digital society.

The key to Thai Vocational Education 4.0 is the teacher who drives changes in education. The teacher must be loved and trusted by students so that they are willing to learn and follow the teacher (Salmon, 2019). The teacher is the parent-like role model for students. Therefore, changes in education and educational reform must be encouraged and driven by the teachers who are the enablers of education (Chalapati & Chalapati, 2020).

Table 2. Comparison of Thailand 4.0, Industry 4.0 and Education 4.0 Models

Level of Development	Thailand 4.0	Industry 4.0	Education 4.0
1.0	Era of agriculture	Agricultural industry	Teaching content and knowledge
2.0	Era of low-wage workers	Light industry	Teaching via electronic media
3.0	Era of contract manufacturing	Heavy industry	Knowledge-based education
4.0	Era of innovation and creativity	Industrial robotics	Education for technology-based innovation

STEM Education Standards

Thailand's Ministry of Education emphasizes the importance of STEM Education and has prescribed it as part of the education policy. Within five years (2016-2021), STEM Education should be taught in every school (Office of the Education Council, 2017). The Ministry of Education formed a committee for developing a STEM curriculum in schools. The committee defined STEM as an educational management approach that encouraged students to learn and allowed them to integrate knowledge from the sphere of science, technology, engineering design processes and mathematics (Chomphuphra, Chaipidech, & Yuenyong, 2019). Learners then use the integrated knowledge to connect the dots and solve real-life problems, as well as developing new processes, products and learning skills for the 21st century (Partnership for 21st Century Skills, 2008). The committee also defined the six steps of learning activities in the STEM approach as follows:

Step 1: Identify a real-life problem to be solved/innovation to be developed
Step 2: Gather relevant data and ideas
Step 3: Design problem solving method) Science + Math & Technology)
Step 4: Plan and implement the problem-solving method (Engineering)
Step 5: Test, evaluate and improve) Engineering)
Step 6: Present how to solve the problem, results of problem solving or innovation development

Table 3. STEM Standard indicators (The Institute for the Promotion of Teaching Science and Technology, 2013)

STEM standards indicators	**In the aspect of vocational education**	
	Stage	**Output, evidence, trace, expression**
First indicator – identifying the problem	Able to identify problems found while gathering data and thinking critically	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map Research record form
	Able to identify the scope of the problem	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form

STEM standards indicators	In the aspect of vocational education	
	Stage	**Output, evidence, trace, expression**
		Worksheet Activity record form Report assignment Mind map Project's topic and objectives
Second indicator – gather relevant data and ideas	Able to gather data and ideas that are related to the problem	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics
	Able to analyze and select appropriate data to solve the problem	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics Making oral presentation
	Able to assess the feasibility of the solution	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics Accepting opinions and summarizing them

STEM standards indicators	In the aspect of vocational education	
	Stage	**Output, evidence, trace, expression**
Third indicator – design solution by integrating knowledge and scientific, technological, engineering and mathematical processes	Able to design a solution by integrating knowledge and scientific, technological, engineering and mathematical processes	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics
	Able to select appropriate solution under specified conditions	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics
	Able to explain the ideas behind the solution design	Answering questions Expressing opinions Giving explanations Group discussion Observation record form Interview record form Worksheet Activity record form Report assignment Mind map, graph, picture, infographics Presenting ideas and designs
Fourth indicator – plan and implement solution	Able to plan a step-by-step solution to the problem	Action plan Activity sheet Workflow diagram
	Able to solve the problem while using tools and equipment correctly and safely	Performance observation record form Output and instruction

STEM standards indicators	In the aspect of vocational education	
	Stage	**Output, evidence, trace, expression**
	Record problem solving steps and results of solution, based on facts and in alignment with the problem	Step-by-step activity record form
Fifth indicator – testing, evaluation and improvement of solution	Test, evaluate and improve to enhance the effectiveness of the solution or product	Test result record form Activity record form Experimental result record form Output evaluation form Output / instruction report
Sixth indicator – presenting how to solve the problem and the result of the solution implementation	Present solution and results for others to understand while using effective communication skills	Output report Problem solving report Presenting the outcome in front of the class Exhibition Contest Poster presentation Brochure presentation Presentation using technologies
	Able to explain issues or problems arising from the solution and suggest improvement for the problem-solving process	Improvement record form Guideline for problem solving process improvement
	Present the approach used to solve problems to solve other problems with similar conditions	Performance report Answering questions

STEM Education Integration

The main objective of STEM Education is to integrate knowledge from the areas of science, technology, engineering and mathematics into another subject. Therefore, the level of integration is different across subjects depending on conditions and the scope of instructional management handled by the teacher (Changtong, Maneejak & Yasri, 2020). There are four levels of integration: disciplinary, multidisciplinary, interdisciplinary and transdisciplinary integration.

The four levels have the following descriptions. The disciplinary STEM education approach means learning knowledge and skills for each STEM subject in isolation. (The Institute for the Promotion of Teaching Science and Technology, 2013) Examples are: learning the basics of electricity in a science class, learning the basics of electricity in a technology class, learning the basics of electrical circuits in an engineering class and learning how to calculate an electricity bill in mathematics. In each class, students learn only the content of the subject but they need to know how to apply the knowledge of other STEM subjects. This is a disciplinary STEM education approach. An integrated STEM learning environment breaks down disciplinary boundaries and enables students to apply multidisciplinary knowledge in solving problems (Yang & Baldwin, 2020).

A multidisciplinary STEM education approach means the teachers of all subjects need to design content and skills in the curriculum together. All subjects have the same main topic, but each subject has a different content relating to the topic. The content of all subjects is interrelated and refers to the knowledge of the other subjects. For example, in order to effectively enhanced these competences, student labs should be designed as authentic productive learning environments, based on three design principles: 1) Realistic, complex task situations, 2) Multidisciplinary, and 3) Social interaction (Admiraal et al., 2019). The learners can interrelate the content of all subjects and see the relation between the subjects. For example, the teachers of science, technology, engineering and mathematics classes teach about electricity as the main topic, and the sub-topics in each subject are the source of electricity, wiring electrical circuits, analyzing electrical circuits and calculating an electricity bill respectively. This allows students to think about how to use the knowledge in their daily life.

The interdisciplinary STEM Education approach means the teachers of at least two subjects need to plan class activities together. The activities require using knowledge of multiple subjects. Each STEM subject has a different main topic, but the topics should benefit other subjects. For example, the science teacher teaches about the structure of an atom, the technology teacher assign students to create a slide presentation about an atom, the engineering teacher teaches how to build an atom model and the mathematics teacher teaches how to calculate the appropriate size of the atom model. This approach allows students to use the knowledge gained in one subject in another subject despite learning about different topics. The interdisciplinary nature of sustainability and STEM education has several intersecting points ((Doganca Kucuk et al., 2021).

The transdisciplinary STEM Education approach means allowing students to apply the knowledge from science, technology, engineering and mathematics to their daily lives. Transdisciplinary defines a system that involves merging disciplines beyond their disciplinary boundaries, and creating new conceptions of disciplines (Wu, Cheng, & Koszalka, 2021). This system thus transfers the knowledge from the classroom into practice. The knowledge gained can be applied to other subjects to solve problems (Chae, Purzer, & Cardella, 2010), work in projects and apply the knowledge to develop the community and society. For example, in a social study class, the students could be expected to create something useful for the society using their STEM knowledge. If the community needs students' help to solve a water pollution problem, the students can carry out a project to solve the problem using their science, technology, engineering and mathematics knowledge, without having to learn specifically about water pollution.

STEM Literacy

Literacy means the capability to define, understand, translate, create, communicate and calculate and use the knowledge to write in the context of the subject. Literacy in certain subject areas leads to better learning of the subject area. Literacy is individual (UNESCO, 2005). STEM literacy is not about knowing the content of science, technology, engineering or mathematics per se, but it is about the meaning of logic that will lead to learning the content (Techakosit & Nilsook, 2018). The components are skills, abilities, factual knowledge, procedures, concepts and metacognitive capacities (Zollman, 2012). In order to evaluate the student's engagement in STEM Education, different statements can be made for each issue for students to rate their level of agreement. For example, science is exciting, technology is fascinating, engineering is enticing, or mathematics is challenging (Tyler-Wood, Knezek,& Christensen, 2010).

STEM literacy is crucial for students who will pursue their career in the future. STEM literacy is at the core of essential 21st century skills for students to be an advanced problem solver, innovator, technology specialist, engineer and literate citizen. STEM literacy is part of an interdisciplinary approach connecting the four subjects, i.e. which are science, technology, engineering and mathematics. Therefore, STEM literacy does not mean only accomplishment in each of the four subjects (National Science & Technology Council, 2018). STEM literacy has been defined as follows:

Techakosit and Nilsook (2018) stated that STEM education was an input provided to students while STEM literacy was the outcome of STEM education. STEM literacy is developed within the student and it includes knowledge, skills and attitudes. Havice, Havice, Waugaman, and Walker (2018) defined STEM literacy as the ability to identify and apply concepts and knowledge from science, technology, engineering and mathematics to understand and overcome problems and challenges that could not be solved by a method in any one subject. National Science & Technology Council, USA (National Science & Technology Council, 2018) stated that STEM literacy was a branch of an interdisciplinary area of study that connected science, technology, engineering and mathematics.

STEM literacy led to accomplishment in each of the four subjects. Therefore, the STEM classroom would change how students learn from a memorization strategy to investigating and asking questions relating to the world. Bybee (2010) stated that, generally, STEM literacy comprised of conceptual understandings, procedural skills and abilities of each student to talk about individual, social and world issues relating to STEM. STEM literacy was about integration of STEM subjects and consisted of four interrelated components that support one another. The meaning of STEM literacy is as follows:

1. The acquisition of scientific, technological, engineering and mathematical knowledge and using the knowledge to identify issues, acquire new knowledge and apply the knowledge to issues relating to STEM.
2. The understanding of characteristics of each STEM subject as human endeavor consisting of investigating, designing and analyzing.
3. The realization that STEM methods can be used for defining the material, the intellectual and the cultural world.

4. The contribution to STEM issues using concepts of science, technology, engineering and mathematics as a caring and creative citizen.

Zollman (2012) stated that STEM literacy was a dynamic process, focusing on three steps: 1) being literate in science, technology, engineering, mathematics and other related subjects, 2) individual, social and economic needs and, 3) learning in cognitive, affective and psychomotor domains. Kanadlı (2019) stated that STEM literacy was related to the student's ability to comprehend and apply scientific, technological, engineering and mathematical concepts to solve complex problems. The goal of the STEM classroom was to promote advanced thinking skills, problem solving and intellectual curiosity. It also enabled students to communicate their ideas and information effectively and creatively. Chae, Purzer and Cardella (2010) stated that STEM literacy consisted of important skills, namely the ability to discuss, rationally analyze and criticize, and make decisions relating to individual, local and national issues regarding engineering problem solving, understand and be able to explain basic needs e.g. water, food and energy. These abilities were developed by solving problems in daily life using scientific, technological and mathematical concepts and patterns.

Yıldırım (2016) stated that the STEM education instructional model allowed students to be aware of the world they lived in and prepared students to be ready to work in the future. High quality STEM teaching helped students develop their abilities to analyze, collaborate and solve problems. Moreover, it helped to enhance creativity and allowed students to participate in investigating processes. These skills are key for working in the future as jobs relating to STEM subjects have the highest growth rate and 80% of jobs in the future require STEM skills and literacy. Therefore, it could be considered that STEM skills are essential for people in society. Purzer, Senay & Strobel, Johannes and Cardella (2014) stated that a STEM literate person had enough knowledge and skills in all four subjects to make a confident contribution to developing modern society. Moreover, the person could manage and evaluate technologies in daily life, as well as understanding the scientific principles and technological processes required for solving problems, resolving conflicts and making decisions. Yasin, Prima, and Sholihin (2018) stated that STEM literacy was defined as the student's capability to apply a STEM concept in order to comprehend and solve various problems.

The National Research Council (2011) stated that STEM literacy meant knowledge and understanding of scientific and mathematical concepts, the student's decision to participate in citizenship and culture issues, as well as the student's economic output. STEM literacy was the ability to identify, apply and integrate scientific, technological, engineering and mathematical concepts in order to understand more complex problems and work out solutions (Johnson,Mohr-Schroeder, & Moore, 2020). STEM literacy would be achieved when students could apply the knowledge acquired, understand how the world worked and work beyond the scope of the four subjects to develop society, the economy and the environment of local and world communities. Moreover, the students needed to have sufficient experience which they had to accumulate early from their pre-kindergarten years through to Matthayom 6 (12^{th} grade). STEM literacy is the link that connects people and employment to the development of society, the environment and the economy of local and world communities.

Therefore, it is crucial for students to be prepared and be STEM literate, especially for those who enter the job market right after graduating high school. In order to enable students to benefit most from being STEM literate, STEM should be considered the main element for building the knowledge and understanding needed for working and as a pathway to college education. The expected results are as follows:

1. All students develop their foundation skills by using STEM in order to become an enthusiastic learner and actively contribute to this complex science-and-technology-driven society.
2. All students develop the ability to identify and apply scientific, technological, engineering and mathematical concepts so that they can prepare themselves for further education at universities. This will enable them to have jobs that can support their families.
3. An increasing number of students and their diversity lead to STEM education being used to challenge and enhance their learning experiences.

Therefore, it could be said that STEM literacy is the root of all expected results including their contribution to the community, achievement in university education, enhancement and diversity of STEM, understanding of career and continuing studies in university (Falloon, Hatzigianni, Bower, Forbes, & Stevenson, 2020). However, it is not defined in this study that there is only one way or method for students to achieve STEM literacy. Therefore, schools or related parties must design and plan the methods that are most suitable for their context and be able to drive them to success. In conclusion, STEM literacy comprises of its characteristics and capabilities. The characteristics of STEM literacy are being knowledgeable, understanding and realizing the importance of science, technology, engineering and mathematics (Techakosit & Nilsook, 2016).

STEM Literacy of Students in Vocational Education

The abilities of STEM literacy include the ability of a person to identify problems relating to STEM subjects, ability to investigate and acquire new knowledge relating to STEM subjects, ability to apply concepts from STEM subjects and solve problems using such concepts, ability to communicate information relating to STEM subjects and ability to make decisions using concepts and processes of STEM subjects (see Appendix-STEM Literacy Evaluation Form).

According to Table 1, the synthesis of definitions of STEM shows that STEM literacy consists of six abilities, which are:

1. The ability to identify STEM problems
2. The ability to investigate and acquire new knowledge
3. The ability to apply concepts from STEM
4. The ability to solve problems with STEM
5. The ability to communicate STEM information
6. The ability to make decisions using STEM

Table 4. Synthetizing STEM Literacy

	Concepts							
Ability of STEM Literacy	Techakosit & Nilsook (2018)	National Science & Technology Council (2018)	Bybee (2010)	Kanadlı (2019)	Chae, Purzer & Cardella (2010)	Yildirim (2016)	Purzer, Strobel and Cardella (2014)	Peters-Burton & Johnson (2018
Ability to identify STEM problems	✓	✓	✓	✓				✓
Ability to investigate and acquire new knowledge	✓	✓	✓		✓	✓		✓
Ability to apply concepts from STEM	✓		✓	✓	✓		✓	✓
Ability to solve problem with STEM	✓	✓		✓	✓	✓	✓	
Ability to communicate STEM information		✓		✓		✓	✓	✓
Ability to make decisions using STEM					✓	✓	✓	✓

Idea for STEM Activity for Vocational Students

1. A certain amount of material is given to students for them to design a project according to the assigned problem statement and invent tools or equipment from the given materials.
2. In order to start the STEM education process, the teacher must give the vocational students an introduction and a context, then present stories of examples and give them the problem statement to work on.
3. Students learn from the scientific + mathematical + technological points of view and use an engineering process to create output.
4. Students can have different outputs and they should test the outputs against the requirements themselves.
5. Under the concept of STEM, they should lead projects with science, not technology or mathematics. Technology should be used as a tool. Mathematics should be the logic behind the problem solving. Engineering should be integrated in implementation or problem-solving methods.

STEM Education Activities for Vocational Students

STEM education activities for vocational students are given in Table 5.

Table 5. STEM Education Activities for Vocational Students

Science	Engineering	Technology	Mathematics
Asking questions (to understand the nature)	Define the problem (to enhance the quality of life)	Realize the importance of technology in society	Try to understand and solve the problem
Develop and use the model	Develop and use the model		Use mathematics to create a model
Design, then explore, research and test	Design, then explore, research and test	Learn how to use new technologies	Use appropriate tools to solve the problem
Analyze data	Analyze data		Prioritize precision
Use mathematics to calculate	Use mathematics to calculate	Understand the role of technology in the development of science and engineering	Use numbers to tell the story or give an explanation
Give explanation	Design a problem-solving method		Try to find and use a project to solve the problem
Use evidence to confirm the idea	Use evidence to confirm the idea	Make decisions regarding what technology to use based on societal and environmental impact	Argue and be able to criticize the arguments of others
Evaluate and communicate the idea	Evaluate and communicate the idea		Look for and present a method to give reasons repetitively

Discussion

The following activity can be used as the starting point of STEM education. In all classes, the teacher should provide four types of easy-to-find material in his school to represent the four concepts of science, engineering, technology and mathematics (McDonald, 2016) . Students would then be divided into a group of 3-4 students and every group should have the same problem statement, which is "Students brainstorm to come up with a tangible invention in their current class by using their current knowledge."

Step1 : Students should brainstorm ideas for inventing an object relating to the class they are taking. The students then gather leftover material, e.g. milk cans, plastic cups, paper, plastic bags, etc. depending on what the group wants to invent.

Step 2: Students invent an object from the material gathered in Step 1 according to their plan. The invention should emphasize creativity and the output of each group can be different. The important thing is that every student participates and collaborates to make the invention.

Step 3: After the invention is finished, the group should record how many steps they have taken in the procedure to invent the object.

Step 4; The students in each group should measure the width, length and height of the object, estimate its price and take its photo or make a video using their mobile phones.

Step 5: The students summarize all the details using the STEM approach.

5.1 Scientific process: what were the steps taken in the invention of the object?

5. 2 Technology: what technology was used to create the invention?

5. 3 Engineering: how is the invention aligned with the subject?

5. 4 Mathematics: calculating size and weight of the invented object

Step 6: All students in each group present the invention and communicate the summarized details, as well as identifying the problems, the obstacles and the solution. The students also answer questions from other groups.

While the STEM Education approach is successful in integrating disciplines in the areas of science and mathematics (Heller & Francois, 2019), it struggles to do so in the areas of language and the arts despite being independent of content. Adjustments were made to overcome the difficulty and the STEAM education approach is being developed to add the element of arts to it so that it does not only integrate science subjects. STEM education is a concept that requires support from techniques and learning processes of project-based learning (PBL) because most of its learning activities attempt to have students go through processes and work on tangible projects. STEM education is suitable for vocational education (Chatwattana et al., 2017) because it focuses on hands-on practice and skill learning. Foundation subjects that support their future career, as well as job-specific subjects, will also benefit from the help of the STEM education approach (Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018). However, The role of teacher education in promoting STEM education by shifting prospective teachers‟ mindsets about mathematics and teaching (Marco-Bujosa, 2021).

Conclusion

Knowledge of all disciplines is more or less equally important and crucial but, in education management, it is important to integrate disciplines so that the knowledge is useful and can be applied to create new things, solve problems and prevent future threats. STEM education for vocational student is not only a trend in education, but also an instructional approach that focuses on students and will lead to sustainable knowledge and learning. STEM education is the foundation of Digital Thailand and Thai vocational education 4.0 and must be aligned with the Industry 4.0 era and adjust its instructional approach in alignment with the era when education focuses on producing innovators. Teachers must also understand and apply STEM to their teaching, adjusting their teaching methods so that they are suitable and in line with vocational education management. This will therefore ensure that the students graduated have suitable skills and meet the country’s real demand.

Acknowledgement

This research was supported by the Office of the Vocational Education Commission, Ministry of Education, Thailand. For all research support, Innovation and Technology Management Research Center and Vocational Education Technology Research Center at the Science and Technology Research Institute, King Mongkut's University of Technology North Bangkok which supported this research.

References

Admiraal, W., Post, L., Guo, P., Saab, N., Makinen, S., Rainio, O., … Danford, G. (2019). Students as future workers: Cross-border multidisciplinary learning labs in higher education. *International Journal of Technology in Education and Science (IJTES)*, *3*(2), 85–94. Retrieved from www.ijtes.net

Almeida, F., & Simoes, J. (2019). The role of serious games, gamification and industry 4.0 tools in the education 4.0 paradigm. *Contemporary Educational Technology*, *10*(2), 120–136. https://doi.org/10.30935/cet.554469

Batdi, V., Talan, T., & Semerci, Ç. (2019). Meta-Analytic and Meta-Analytic and Meta-Thematic Analysis of STEM Education. *International Journal of Education in Mathematics, Science and Technology (IJEMST)*, *7*(4), 382–399.

Bicer, A. (2021). A Systematic Literature Review: Discipline-Specific and General Instructional Practices Fostering the Mathematical Creativity of Students. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 9*(2), 252-281. https://doi.org/10.46328/ijemst.1254

Bybee, R. W. (2010). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher*, *70*, 30–35.

Carla C. Johnson,Margaret J. Mohr-Schroeder,Tamara J. Moore, L. D. E. (2020). *Handbook of Research on STEM Education*. New York: Taylor & Francis Group.

Çetin, A. (2021). Investigation of the Relationship between the STEM Awareness and Questioning Skills of Pre-Service Teachers. *International Journal of Research in Education and Science (IJRES), 7*(1), 65-81. https://doi.org/10.46328/ ijres.1171

Chae, Y., & Purzer, S., & Cardella, M. (2010). Core Concepts For Engineering Literacy: The Interrelationships Among STEM Disciplines. In *2010 Annual Conference & Exposition*. Louisville, Kentucky: 2010 Annual Conference & Exposition. Retrieved from https://peer.asee.org/16440

Chalapati, N., & Chalapati, S. (2020). Building a skilled workforce: Public discourses on vocational education in Thailand. *International Journal for Research in Vocational Education and Training*, *7*(1), 67–90. https://doi.org/10.13152/10.13152/IJRVET.7.1.4

Changtong, N., Maneejak, M., Yasri, P. (2020). Approaches for Implementing STEM (Science , Technology , Engineering & Mathematics) Activities among Middle School Students in Thailand. *International Journal of Educational Methodology*, *6*(1), 185–198. https://doi.org/10.12973/ijem.6.1.185

Chatwattana, P., Nilsook, P., Awad, H., Abdeljaber, M., Ahmad, S., Elazhary, H. H., … Arabia, S. (2017). Vol 12 , No 05 (2017) Table of Contents, *12*(05), 202–209.

Chomphuphra, P., Chaipidech, P., & Yuenyong, C. (2019). Trends and Research Issues of STEM Education : A Review of Academic Publications from 2007 to 2017 Trends and Research Issues of STEM Education : A Review of Academic Publications from 2007 to 2017. In *International Annual Meeting on STEM Education*. https://doi.org/10.1088/1742-6596/1340/1/012069

Chou, C.-M., Shen, C.-H., Hsiao, H.-C., & Shen, T.-C. (2018). Industry 4.0 Manpower and its Teaching Connotation in Technical and Vocational Education: Adjust 107 Curriculum Reform. *International Journal of Psychology and Educational Studies*, *5*(1), 9–14. https://doi.org/10.17220/ijpes.2018.01.002

Doganca Kucuk, Z., Yabas, D., Boyaci, H. S., & Corlu, M. S. (2021). The Impact of the earlySTEM Program on

Teacher and Student Outcomes: The Role of Teachers’ Involvement in the Program Development. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 9*(3), 371-405. https://doi.org/10.46328/ijemst.1279

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM Education: a Framework for Developing STEM Literacy. *Journal of Science Education and Technology*, *29*(3), 369–385. https://doi.org/10.1007/s10956-020-09823-x

Gonzalez, H. B., & Kuenzi, J. J. (2012). Mathematics (STEM) Education : A Primer.

Havice, W., Havice, P., Waugaman, C., & Walker, K. (2018). Evaluating the effectiveness of integrative STEM education: Teacher and administrator professional development. *Journal of Technology Education*, *29*(2), 73–90. https://doi.org/10.21061/jte.v29i2.a.5

Heller, N., &, & Francois, B. (2019). Organizing Peer Correction in Tertiary STEM Education : An Approach and its Evaluation. *International Journal of Engineering Pedagogy*, *9*(4), 16–32.

Holdren, J. P. (2013). *Federal Science, Technology, Engineering, and Mathematics (STEM) Education 5-Year Strategic Plan.* Washington, D.C.

Hussin, A. A. (2018). Education 4 . 0 Made Simple : Ideas For Teaching. *International Journal of Education and Literacy Studies*, *6*(3), 92–98.

Kanadlı, S. (2019). A Meta-Summary of Qualitative Findings about STEM Education. *International Journal of Instruction*, *12*(1), 959–976.

Kartal, B., & Taşdemir, A. (2021). Pre-Service Teachers’ Attitudes towards STEM: Differences Based on Multiple Variables and the Relationship with Academic Achievement. *International Journal of Technology in Education*, *4*(2), 200–228. https://doi.org/10.46328/ijte.58

Marco-Bujosa, L. (2021). Prospective Secondary Math Teachers Encountering STEM in a Methods Course: When Math is More Than “Just Math.” *International Journal of Technology in Education*, *4*(2), 247–286. https://doi.org/10.46328/ijte.41

McDonald, C. (2016). STEM Education: A Review of the Contribution of the Disciplines of Science, Technology, Engineering and Mathematics. *Science Education International*, *27*(4), 530–569.

National Research Council. (2011). *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*. Washington, DC.: The National Academies Press.

National Science & Technology Council. (2018). *Charting a Course for Success : America’s Strategy for STEM Education.* Washington, D.C.: Committee on STEM Education of the National Science & Technology Council. Retrieved from https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Office of the Education Council. (2017). *Education in Thailand*. Bangkok: Ministry of Education.

Partnership for 21st Century Skills. (2008). *21st Century Skills, Education & Competitiveness*. *Partnership for 21st Century Skills*. https://doi.org/6th August 2016

Peters-Burton, E. E., & Johnson, T. (2018). Cross-case analysis of engineering education experiences in inclusive STEM-focused high schools in the United States. *International Journal of Education in Mathematics, Science and Technology*, *6*(4), 320–342. https://doi.org/10.18404/ijemst.440335

Promboon, F. &, & Kaweekijmanee. (2018). The Evolution and Current Status of STEM Education in Thailand: Policy Directions and Recommendations. In *Education in Thailand. Education in the Asia-Pacific*

Region: Issues, Concerns and Prospects (Vol. 42). Singapore: Springer.

Puriwat, W., & Tripopsakul, S. (2020). Preparing for industry 4.0-will youths have enough essential skills?: An evidence from Thailand. *International Journal of Instruction*, *13*(3), 89–104. https://doi.org/10.29333/iji.2020.1337a

Purzer, Senay & Strobel, Johannes & Cardella, M. (2014). *Engineering in pre-college settings : Synthesizing research, policy, and practices*. West Lafayette, Indiana: Purdue University Press.

Ring-Whalen, E., Dare, E., Roehrig, G., Titu, P., & Crotty, E. (2018). From conception to curricula: The role of science, technology, engineering, and mathematics in integrated STEM units. *International Journal of Education in Mathematics, Science and Technology*, *6*(4), 343–362. https://doi.org/10.18404/ijemst440338

Salmon, G. (2019). May the Fourth Be with You: Creating Education 4.0. *Journal of Learning for Development (JL4D)*, *6*(1), 95–115. Retrieved from www.etymonline.com/word/lecture%0Ahttps://jl4d.org/index.php/ejl4d/article/view/352

Techakosit, S., & Nilsook, P. (2016). The learning process of scientific imagineering through AR in order to enhance STEM literacy. *International Journal of Emerging Technologies in Learning*, *11*(7). https://doi.org/10.3991/ijet.v11i07.5357

Techakosit, S., & Nilsook, P. (2018). The development of STEM literacy using the learning process of scientific imagineering through AR. *International Journal of Emerging Technologies in Learning*. https://doi.org/10.3991/ijet.v13i01.7664

The Institute for the Promotion of Teaching Science and Technology. (2013). *IPST Annual Report Summary*. Bangkok: The Institute for the Promotion of Teaching Science and Technology.

Tyler-Wood, T., Knezek, G. & Christensen, R. (2010). Instruments for Assessing Interest in STEM Content and Careers. *Journal of Technology and Teacher Education*, *18*(2), 345–368.

UNESCO. (2005). *Aspects of Literacy Assessment : Topics and issues from the UNESCO Expert Meeting*. Paris: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0014/001401/140125eo.pdf%0A

Vu, P., Harshbarger, D., Crow, S., & Henderson, S. (2019). Why STEM? Factors That Influence Gifted Students' Choice of College Majors. *International Journal of Technology in Education and Science*, *3*(2), 63–71.

Wu, Y., Cheng, J., & Koszalka, T. A. (2021). Transdisciplinary approach in middle school: A case study of co-teaching practices in STEAM teams. *International Journal of Education in Mathematics, Science, and Technology*, *9*(1), 138–162. https://doi.org/10.46328/ijemst.1017

Yang, D., & Baldwin, S. J. (2020). Using Technology to Support Student Learning in an Integrated STEM Learning Environment. *International Journal of Technology in Education and Science*, *4*(1), 1–11. https://doi.org/10.46328/ijtes.v4i1.22

Yasin, A. I., Prima, E. C., & Sholihin, H. (2018). Learning Electricity using Arduino-Android based Game to Improve STEM Literacy. *Journal of Science Learning*, *1*(3), 77–94. https://doi.org/10.17509/jsl.v1i3.11789

Yıldırım, B. (2016). An Analyses and Meta-Synthesis of Research on STEM Education. *Journal of Education and Practice*, *7*(34), 23–33.

Zollman, A. (2012). Learning for STEM Literacy: STEM Literacy for Learning. *School Science and*

Mathematics, *112*(1), 12–19. https://doi.org/https://doi.org/10.1111/j.1949-8594.2012.00101.x

Author Information

Panita Wannapiroon
https://orcid.org/0000-0001-8633-5781
King Mongkut's University of Technology North Bangkok
Bangkok
Thailand

Prachyanun Nilsook
https://orcid.org/0000-0003-3019-3635
King Mongkut's University of Technology North Bangkok
Bangkok
Thailand

Somsak Techakosit
https://orcid.org/0000-0001-8624-6535
Kasetsart University
Bangkok
Thailand
Contact e-mail: *Somsak.te@ku.th*

Sayam Kamkhuntod
https://orcid.org/0000-0002-3334-2766
King Mongkut's University of Technology North Bangkok
Bangkok
Thailand

Appendix. STEM Literacy Evaluation Form

(STEM Literacy Inventory: STEMLI)

Instruction

The STEM literacy evaluation form is an evaluation of your perception of integrated science, technology, engineering and mathematics. It is a self-evaluation form to identify your level of STEM literacy. For your benefit, please answer as accurately as possible. You can use this form to evaluate your perception in order to develop a suitable instructional model.

Level of agreement on statements

Strongly agree	2 points.
Agree	1 point.
Not sure	0points.
Disagree	- 1point.
Strongly disagree	- 2points.

Please select the level of agreement that is true for your perception.

No.	Statement	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
	Science					
1.	I realize the importance of science in daily life.					
2.	I use my understanding of science to explain phenomena rather than using beliefs.					
3.	I can show scientific evidence or reference for the solution to problems in daily life.					
4.	I am willing to search for correct information to support my ideas.					
5.	When I do not know something, I make a hypothesis rather than guessing.					
6.	I summarize what has happened using empirical data.					
7.	I have a good attitude towards using scientific processes to solve problems and work in daily life.					

No.	Statement	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
	Technology					
1.	I think that technology is directly relevant to daily life.					
2.	I keep up with news about technologies that I am interested in.					
3.	I only use technology when I think it is simple to use.					
4.	I accept technology when it can be used practically.					
5.	I think technology is important for my career and my daily life.					
6.	I use different technologies regularly depending on the type of work.					
7.	I am fascinated by modern technologies that are launched one after another.					
	Engineering					
1.	I think that learning by doing is the best way to learn.					
2.	I like inventing new things or new methods that I can benefit from.					
3.	I work systematically and in a step-by-step manner.					
4.	I fix broken things myself without help from others.					
5.	I think there are many ways to become successful.					
6.	I am excited to build new things.					
7.	I want to do things myself by following a manual or observing someone doing it.					
	Mathematics					
1.	I always try to figure out reasons behind what happened.					
2.	I like testing principles using existing formulas.					
3.	I do something repeatedly until I get it right.					
4.	I solve problems logically and reasonably.					
5.	When I practice calculating, I start from trying to understand the formula.					
6.	I always try my best to solve equations regardless of whether I will be successful or not.					
7.	I think mathematics challenges my capabilities.					
	Average					

Interpretation

29 to 48 points	you are ready to learn using the STEM approach. You can integrate knowledge from science and mathematics. You can also solve problems and use technology effectively.
1 to 28 points	you are ready to learn using the STEM approach, but you lack integration in some aspects. You are not particularly good at hands-on implementation or solving problems and you cannot use technology with ease.
0 to -28 points	you are not ready to learn using the STEM approach. You cannot integrate scientific and mathematical knowledge. You are not good at solving problems and do not adopt technology to facilitate learning.
-29 to- 48	you are not suitable for learning using the STEM approach.