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The Development of STEM Education Instruction Model for Science Teachers

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Abstract

The purpose of this research was to develop STEM education instruction for science teachers. The participants comprised three experts for verification of the research tools and 45 science teachers who volunteered to participate in the research project. The research instruments were STEM education instruction training documents, a STEM education instruction plan assessment form, and a STEM education instruction readiness evaluation form. The data was analysed by using the frequency, percentage, mean, standard deviation and content analysis. The study output was the development of a STEM education instruction model that integrates the Thai context, literacy skills, 21st-century skills and design thinking (InThai21DT). The model consists of 4 components: (1) principles, (2) objectives, and (3) instruction processes and (4) measurement and evaluation. InThai21DT, the instruction process promotes integration of the Thai context, literacy skills, 21st-century skills and design thinking and comprises 5 steps, which are (3.1) empathize, (3.2) define, (3.3) ideate, (3.4) prototype, and (3.5) test. The results of evaluating the STEM education instruction plan assessment showed an overall mean of consistency, coherence, comprehensiveness and appropriateness at the highest level. A high level of STEM education learning management readiness was found among the teachers.

Keywords: 21st-century skills, design thinking, literacy skills, science teachers, STEM education, instruction model.

1. Introduction

"STEM" stands for the English language terms describing four disciplines: Science, Technology, Engineering and Mathematics. STEM education aims to lead to thinking, solving problems and creating innovations in daily life and work as well as produce manpower in science, mathematics and technology to be able to compete at the international level and create future technology entrepreneurs. According to the assessment report of the STEM Integration Project, STEM training for school administrators, supervisors and teacher leaders and providing online courses for science, mathematics and technology teachers, and the development of STEM teachers through the remote system, it was found that the staff lacked confidence in applying the knowledge from their training to teaching in the classroom because some teachers did not study in fields related to science or mathematics. Teachers reported that the training was difficult to understand, and lacked a variety of examples for STEM teaching. Based on suggestions from the participants, the top five training topics were (1) STEM projects and STEM media creation, (2) STEM teaching techniques, (3) innovation creation, (4) the preparation of a learning management plan; and (5) the teaching of analytical thinking skills. There was also a recommendation from the site visit evaluation that IPST, which is an institution which operates on education in science, mathematics and technology in terms of curriculum, media and learning management process, develop teachers to raise the quality of learning management, produce and develop talents to build Thailand's competitiveness, should lead teachers to write a plan first as a first step in thinking, to gradually make it clear to the teacher before taking it to the students (Institute for the Promotion of Teaching Science and Technology, 2018).

Research has found that most science teacher preparation courses are aimed at developing science teachers in specific fields such as primary or secondary level, chemistry, biology or physics (Faikhamta et al., 2018). Student teachers should have the opportunity to learn about the integration of interdisciplinary fields (interdisciplinary) and across disciplines (transdisciplinary) or learn to teach integrated STEM because STEM integration makes science specialisation difficult (Faikhamta et al., 2018). Other research has explored the efficiency of STEM education for primary teachers through professional development, which revealed that many teachers understood STEM education, and were satisfied with STEM Education (Suebsing & Nuangchalerm, 2021).

In addition, Hanover Research (2011) suggested opportunities for professional development in STEM teachers should be ongoing. Surveys of teachers suggested that teachers are most interested in developing STEM-focused careers that emphasise career awareness. Conducting quest-based and interdisciplinary activities visits and tours or workshop activities are the most preferred methods.

2. Literature Review

The (National Research Council of the United States, 2012) defines science, technology, engineering and mathematics as well as compares the skills and practices of the four sciences (Vasquez et al., 2013). Scientific practice is largely the same as engineering practice, i.e., both disciplines develop and implement operational models, and design research to conduct, collect, and analyse data. Both science and engineering require mathematical skills. In addition, both scientists and engineers use evidence to corroborate concepts that may answer questions about nature, and finally, such ideas must be evaluated and communicated. However, there are two differences between the two practices: (1) Whereas science seeks questions to learn and understand nature, engineering seeks to define problems arising from dissatisfaction and the desire to improve the quality of human life, and (2) the result of scientific work is to deepen our understanding of nature, while the outcome of engineering work is in finding solutions to improve the quality of human life, and such methods in engineering often produce new or innovative technology.

STEM education is an educational management approach that integrates knowledge in four interdisciplinary areas: science, engineering, technology, and mathematics, by focusing on applying knowledge to solve problems in real life, including the development of new processes or products that are beneficial to life and work, or help students to build a connection between the four interdisciplinary areas and real life and work. STEM education involves instruction that does not focus on memorising scientific and mathematic theories or rules. Rather, it builds an understanding of those theories or rules through actual practice, along with developing critical thinking, questioning, problem-solving, researching or analysing new findings, and the ability to apply and integrate those findings into daily life.

From the specifics of STEM subjects, alternative teaching techniques may be required for effective communication of STEM concepts. Examples of common teaching techniques used in STEM-focused schools include traditional, teacher-led instruction, project-based learning, workplace or lab-based learning, use of technology-supported learning tools (Hanover Research, 2011). Moreover, academics have proposed methods/procedures for learning management based on the concept of STEM education, namely the Engineering Design Process (National Research Council of the United States, 2012), Problem-Based Learning (PBL), Inquiry-Based Learning, Project-Based Learning and Design Thinking. In addition, models can be used as a basis to promote the integration of real-world STEM education. Models

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and modelling processes can bridge the gaps between STEM fields through practicality. Models and modelling processes should be used as tools to promote STEM literacy and the transfer of knowledge and skills between contexts inside and outside of the STEM field. Modelling activities can serve as a meaningful pathway to STEM education (Hallström & Schonborn, 2019).

Related literature indicates that engineering design is complex, difficult to learn and even more difficult to teach (Dym et al., 2013). The lack of knowledge in integrated STEM pedagogy among teachers (Wu et al., 2019) is coupled with their lack of experience in design-oriented thinking, which is a human-centred innovation process using prototypes and mindsets that provide a solid foundation for solving different problems. Each country has adopted STEM education models, as demonstrated by Yata et al. (2020), who used engineering concepts from Japan, the United States, and the United Kingdom together with Japanese subject principles through a design process (repeating the steps Design, Build, and Test) and the specifics of mathematics, science, and technology, to link them to the context of engineering. Other researchers have looked into the professional development of science teachers, such as Aykan and Yıldırım (2022), who investigated the integration of a Lesson Study Model (LSM) into distance STEM education during the COVID-19 pandemic. Also, a study on physics teachers' readiness to conduct STEM learning (Sulaeman et al., 2022) suggested that professional development in STEM education is necessary to develop their readiness.

In defining student learning concepts and teachers' practices in a 21st-century learning context, Carroll (2015) lists five steps in learning management that can be integrated with Thai context learning skills and skills in the 21st century, which is the origin of the model of STEM learning management that is utilised in the present study. The two research questions for this study were as follows: 1) What should be the characteristics of the STEM instruction model that is suitable for the learning management of science teachers under the Office of the Basic Education Commission? 2) How does the application of the developed STEM instruction model affect the readiness in learning management of science teachers under the Office of the Basic Education Commission? Correspondingly, the objectives of this research were to 1) develop a STEM instruction model for science teachers under the Office of the Basic Education Commission and 2) study the application of the developed STEM instruction model that affects the readiness in learning management of the science teachers.

3. Research Method

The participants of this study included three experts, for verification of the research tools, and 45 science teachers selected from science teachers who volunteered to participate in the research project. The sample size for the science teachers was determined using the G*Power program at an effect size of 0.50 and selected from science teachers who applied to participate in the research project, considered sufficient to provide complete and useful information from the questionnaire on the problems of STEM education for science teachers.

Data was collected by providing workshops on STEM instruction that integrated the Thai context, learning skills, 21st-century skills and design thinking (InThai21DT) to science teachers under the Office of the Basic Education Commission. The workshops were conducted for two days at the meeting room of Wat Sai Ma community school, Nonthaburi province and using the training materials on STEM instruction that integrated the Thai context, learning skills, 21st-century skills and design thinking (InThai21DT) created by the researcher. In the workshop, participants were assigned to create STEM instruction plans that integrate learning in the Thai context, learning skills, 21st-century skills and design thinking (InThai21DT). The instruction plans were examined and scores were recorded in the instruction plan assessment form that focused on the STEM instruction model created by the researcher. Finally, the participants completed the readiness for STEM instruction measurement form.

4. Findings

4.1. STEM education instruction model

The results of STEM education instruction problems from studies in Thailand and abroad were used for the development of the STEM instructional model for science teachers, that integrated the Thai context, literacy skills, 21st-century skills and design thinking (InThai21DT), Figure 1. The model consisted of four components: (1) principles, (2) objectives, (3) a learning management process and (4) measurement and evaluation. The third component, the learning management process, was designed to promote the integration of the Thai context, literacy skills, 21st-century skills and design thinking (InThai21DT), and was made up 5 steps: (3.1) empathize, (3.2) define, (3.3) ideate, (3.4) prototype, and (3.5) test.

Principle: The STEM instruction model promotes the integration of the Thai context learning skills, 21st-century skills and design thinking.

Objective: To develop a STEM instruction model that promotes the integration of Thai contexts, learning skills, 21st-century skills and design-oriented thinking for students in junior high school.

Some Thai contexts, such as the agricultural society and Thailand 4.0, which focused on innovation, sustainability and using more technology, would be integrated.

Learning skills for students include reading, writing, listening and speaking.

21st-century skills for STEM students included (1) critical thinking and problem-solving (2) communications, information, and media literacy (3) collaboration, teamwork and leadership (4) creativity and innovation (5) computing and ICT literacy (6) career and learning self–reliance) and (7) cross-cultural understanding.

The instruction process consisted of 5 steps, as mentioned earlier, using real problems in daily life or events/situations such as newspapers, articles, video clips of the actual event, local situations or situations created by teachers with documented events. There are criteria for teachers and requirements for students. Students work in cooperative groups, but with interdependence within each group. There are responsibilities for each member. The teacher acts as a coach and gives feedback to students.

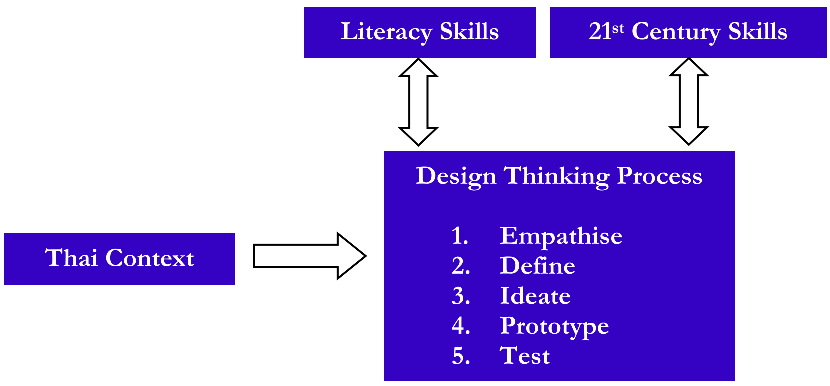

Figure 1. Integration of Thai Context, Literacy Skills, 21st Century Skills and Design Thinking: InThai21DT

Measurement and evaluation were conducted according to the following steps:
1) Assessing knowledge of science subjects;
2) Using the design thinking process;
3) Working together as a team;
4) Matching quality of student workpieces to performance criteria; and
5) Developing criteria related to communication, presentation, innovation, creativity skills, technology integration and working together as a team.

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In addition, measurement and evaluation were carried out using observations, expressions, speech, activities, presentations, etc., by using the specified scoring rubrics in two ways, for group and individual measurement and evaluation, respectively. Group measurement and evaluation involved measuring (1) science content knowledge (2) design thinking process (3) teamwork (4) quality of work that meets criteria and requirement, while individual measurement and evaluation concerned measuring (1) 21st century skills such as communication, presentation, innovation and creativity, technology integration and working together as a team.

4.2. The assessment of 45 STEM education instruction plans

The results of the assessment of 45 STEM education instruction plans found that the mean (*M*) level of consistency/connection/coverage/appropriateness, overall, it was 4.7 (the highest level) and the standard deviation (*SD*) was 0.6, with details of each side and item in Table 1.

Table 1. Mean (*M*), standard deviation (*SD*), and the meaning of the STEM instruction plan and teachers' readiness

Assessment items	STEM instruction plan			Readiness		
	M	*SD*	Meaning	*M*	*SD*	Level of readiness
1. Consistent with the learning indicators and the core learning subjects of Science, Mathematics and Technology (Revised Edition B.E. 2560)	4.7	0.5	Highest	4.3	0.6	High
2. Content Knowledge used in STEM instruction (Science, Technology, Engineering, Mathematics)	4.7	0.5	Highest	4.3	0.6	High
3. Determine learning objectives in STEM education covering all three areas: knowledge in 4 STEM subjects; process skills and attitude	4.7	0.5	Highest	4.2	0.6	High
4. Learning activities integrated into the Thai context, such as the agricultural society and Thailand 4.0 that emphasizes innovation, sustainability and using more technology, etc.	4.5	0.6	Highest	4.0	0.7	High
5. Learning activities integrated learning skills						
Reading	4.5	0.5	Highest	4.4	0.6	High
Writing	4.7	0.5	Highest	4.2	0.7	High
Listening	4.7	0.4	Highest	4.3	0.6	High
Speaking	4.8	0.4	Highest	4.2	0.7	High
6. 21st century skills integration learning activities						
Critical thinking and problem solving	4.7	0.4	Highest	4.2	0.7	High
Communications, information, and media Literacy	4.3	0.7	High	4.2	0.7	High
Collaboration, teamwork and leadership	4.9	0.4	Highest	4.4	0.6	High
Creativity and innovation	4.8	0.4	Highest	4.1	0.6	High
Computing and ICT literacy	4.4	0.7	High	4.2	0.6	High
Career and learning self–reliance	4.4	0.5	High	4.2	0.6	High
Cross–cultural understanding	4.0	0.6	High	4.0	0.6	High
7. Using the instruction process according to the Design Thinking model						
Empathise	4.7	0.5	Highest	4.2	0.6	High
Define	4.7	0.5	Highest	4.2	0.5	High
Ideate	4.9	0.3	Highest	4.2	0.6	High
Prototype	5.0	0.2	Highest	4.1	0.6	High
Test	4.9	0.3	Highest	4.2	0.6	High
8. Learning materials						
Consistent and suitable for learning subjects and learning activities	4.9	0.4	Highest	4.2	0.5	High
Students can participate in the use of media and learning resources thoroughly.	4.9	0.3	Highest	4.2	0.6	High

Assessment items	STEM instruction plan			Readiness		
	M	*SD*	Meaning	*M*	*SD*	Level of readiness
9. Work piece/workload						
Determining the workpiece/workload is appropriate.	4.9	0.4	Highest	4.1	0.6	High
Doing work/workloads encourages students to develop their learning skills.	4.9	0.3	Highest	4.1	0.6	High
Work/work assignments encourage students to develop 21st century skills.	4.8	0.5	Highest	4.2	0.6	High
10. Measurement and evaluation						
Measurement and evaluation are consistent with the objectives/metrics/learning outcomes.	4.8	0.4	Highest	4.2	0.5	High
Measure knowledge of science subject matter	4.9	0.3	Highest	4.4	0.6	High
Measure the use of the Design Thinking process	4.8	0.5	Highest	4.1	0.6	High
Measure teamwork	4.9	0.3	Highest	4.2	0.6	High
Measure the quality of workpieces that meet criteria and requirements.	4.9	0.3	Highest	4.2	0.6	High
Measure communication, presentation, innovation, creativity skills, technology integration and working together as a team	4.5	0.6	Highest	4.1	0.6	High
Group measurement and evaluation	4.9	0.3	Highest	4.2	0.5	High
Individual measurement and evaluation	4.4	0.6	High	4.2	0.6	High
Using scoring rubrics	4.3	0.8	High	4.2	0.7	High
Students participate in measurement and evaluation.	4.6	0.5	Highest	4.2	0.7	High
Grand Total	**4.7**	**0.6**	**Highest**	**4.2**	**0.7**	**High**

5. Discussion

The synthesised instructional model by promoting the integration of Thai context, learning skills, 21st-century skills and design thinking was in line with Li et al. (2019), who stated that design thinking is essential to creativity and innovation and is becoming increasingly important in the development and movement of current operations. In integrated STEM education, the student's way of thinking in learning and design is developed through design activities. Student development occurs not only in engineering and technology but also in other disciplines as well as integrated STEM education. In accordance with Dotson et al. (2020), who discussed the provision of STEM education courses relevant to solving the most pressing global problems that require innovators, critical thinkers and problem solvers, rural communities around the world often lack the resources to implement adequate curriculum and design thinking in primary and secondary education. Bringing in a model of STEM learning management (IGNITE Model) was an approach for the STEM curriculum which used the framework of the design thinking process and had goals for sustainable development through technology and may solve community or health problems that the students may be facing. According to preliminary studies with students in Guatemala and in the United States, the course had a positive effect on students' STEM awareness (Dotson et al., 2020).

Design thinking differs from the engineering design process (STEM Education Thailand, 2014), which consists of five steps, each of which has the following important characteristics. The first is "empathize", as the foundation of human-centeredness that includes observing user's behaviour in real-life contexts, participate, interact and interview users and can be immersed in the user's experience. Empathy provides insights into what people think and feel and is an important component of design thinking. The second characteristic is "define", which refers to the analysis and synthesis of data with two goals: to develop deep user understanding and insight designed to create an actionable problem statement. This is important to the design process because it is a framework of problems. The third characteristic is "ideating", or the focus on creating ideas. The goal of ideation is to explore the extensive problem-solving

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area, both a large number of ideas and a variety of ideas. The fourth characteristic, “prototype”, can take many forms, such as a physical form that users can interact with, a low-resolution prototype, a storyboard, a roleplay, or a physical object or service. The fifth and final characteristic, “testing”, gives the opportunity to place a prototype in the user's hands so that it can be replicated and refined, or solve problems that better meet the needs of users.

The workshop with lectures and practice focused on the components and procedures of instruction according to the InThai21DT model and gave the science teachers the opportunity to analyse and practice writing instruction plans, with a sample of instruction plans in accordance with the InThai21DT model. As a result, the science teachers had the content knowledge and understanding and were able to write a STEM instruction plan according to the InThai21DT format. The subjects in the instruction plan were related to the Thai context and were relevant to the students. For example, a science teacher who teaches in the area along the Chao Phraya River in Nonthaburi Province wrote an instruction plan about dams and erosion, wind shields, bean sprout farmers and water filters. In addition, various instruction plans written by science teachers integrated learning skills, such as reading, writing, listening and speaking skills, and 21st century skills including (1) critical thinking and problem solving (2) information communication and media literacy (3) cooperation, teamwork and leadership (4) creativity and innovation (5) computing and information and communication technology (6) working, learning and self-reliance and (7) cross-cultural understanding of different paradigms clearly stated in the instruction plan. In addition, the science teachers designed student assessments covering knowledge of science subjects, using the design thinking process, quality of workpieces that meet criteria and requirements, communication skills, presentation, innovation, creativity, technological integration and collaboration as a team. In this regard, individual and group assessments were measured and evaluated via observation, expression, speeches, activities, presentations, and etc., using scoring criteria (Scoring Rubrics). Results of the assessment of instruction plans that focused on learning management in STEM education showed the mean (M) conformity/association/coverage/appropriate levels overall was 4.7 (highest level) and the mean (M) level of overall STEM readiness assessment of the science teachers was 4.2 (high level). The results of this research were consistent with Sulaeman et al. (2022), who found that specific examples and sample STEM instruction materials could help teachers understand the design and implementation of STEM education.

This research has the following suggestions for applying the research results:

i. Problems or situations used in the instruction plans should focus on the actual Thai context that occurs around the students, such as the agricultural society of Thailand 4.0.
ii. Learning skills such as reading, writing, listening and speaking should be integrated, and 21st-century skills including (1) critical thinking and problem solving, (2) information communication and media literacy, (3) cooperation, teamwork and leadership, (4) creativity and innovation, (5) computing and information and communication technology (6) working, learning and self-reliance and (7) cross-cultural understanding of different paradigms should be clearly stated in the instruction plans.
iii. Students' learning should be measured to cover their knowledge of science subjects using the design thinking process, quality of workpieces, communication skills, presentation, innovation, creativity, technology integration and team collaboration. In this regard, individual and group assessments are conducted using observations, expressions, speech, activity, and presentations, according to scoring rubrics.
iv. STEM education professional development programmes should provide clear examples of STEM activities that teachers can apply.

6. Conclusion

The development of STEM education instruction of science teachers under the Office of the Basic Education Commission resulted in the learning management model that integrated the Thai context, literacy skills, 21st-century skills and design thinking (InThai21DT). The model consisted of 4 components which were (1) principles, (2) objectives, and (3) a learning management process that promotes the integration of the Thai context, literacy skills, 21st-century skills and design thinking:

InThai21DT, and (4) measurement and evaluation. Moreover, the instruction process consisted of 5 steps which were (3.1) empathize, (3.2) define, (3.3) ideate, (3.4) prototype, and (3.5) test. The result of the STEM education instruction plans assessment revealed that the overall mean of consistency, coherence, comprehensiveness and appropriateness was at the highest level. The assessment focused on important aspects as follows: (1) the learning indicators and the core learning subjects of Science, Mathematics and Technology, (2) content knowledge, (3) learning objectives, (4) learning activities integrated into the Thai context and skills, (5) the instruction processes according to the Design Thinking model, (6) learning materials, (7) workpiece/workload, and (8) measurement and evaluation. The result of the STEM education learning management readiness evaluation of the teachers, on the same important aspects used in instruction plans assessment, showed that the overall mean of STEM education learning management readiness was at a high level.

However, there should be research on the use of the model (integration of Thai context, literacy skills, 21st-century skills and design thinking: InThai21DT), which applies to students and to study the effects of STEM knowledge on students and understand the dependent variables such as learning skills, 21st-century skills and design thinking of learners.

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