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Science student teachers' ability in preparing 5E inquiry-based STEM lessons

Siriporn Kruatong, Nantarat Kruea-In, Kulthida Nugultham, Tussatrin Wannagatesiri*

Faculty of Education and Development Sciences, Kasetsart University (Kamphaeng Saen Campus), Nakhon Pathom 73140, Thailand

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Abstract

This research aimed to develop science student teachers' ability to prepare 5E inquiry-based STEM lessons in the science teaching methods course. This approach was proposed as 5E inquiry and STEM activities were integrated in the Elaboration stage. Research participants were 49 science student teachers (SSTs) who were third-year students in the Teacher Education program in Thailand. The research instruments included an inquiry-based STEM lesson assessment form and a semi-structured interview. The lessons were evaluated with an analytical *rubric* using two raters; *inter-rater* reliability was 0.82. The results from SSTs' 5E inquiry-based STEM lessons analysis revealed that 77.55 and 67.35 percent of SSTs were able to identify learning indicators and learning covering STEM disciplines, respectively. More than 73.47 percent were able to design inquiry-based STEM lessons at the good level of the 5E phases. For their STEM activities, 89.80 percent related to big ideas of science content. Furthermore, 81 percent of SSTs responded that they would bring a 5E inquiry-based STEM learning approach into future classrooms. These results illustrate that this approach can be an alternative approach for teaching and learning STEM by using science as the core content for driving the integration of all STEM disciplines.

Introduction

STEM Education is an interdisciplinary learning approach that integrates science, technology, engineering and mathematics to promote the application of knowledge, solve real-world problems, and empower students with 21st-century skills. Preparing students in work and practice requires knowledge and skills in the scientific process, mathematics and technology, including innovation in the future (National Academy of Engineering and National Research Council [NAE & NRC], 2014; Vasquez et al., 2013). Learning through STEM approaches was often reported as having positive impacts on students' concepts and practice among STEM disciplines. STEM education seemed to promote successfully meaningful learning and positive attitudes to STEM careers (NAE & NRC, 2014; Tseng et al., 2013).

Countries need to offer a comprehensive curriculum, teacher training, guidance, and assessment for high-quality STEM education programs, integrate technology and engineering into the science and mathematics curriculum, and promote engineering design pedagogy and scientific inquiry (Kennedy & Odell, 2014). In Thailand, various STEM workshops have been conducted to encourage

* Corresponding author.
E-mail address: tussatrin.k@ku.th (T. Wannagatesiri).

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in-service teachers to understand and implement STEM activities in their classrooms. Examples include STEM challenge and activity examples (Autid, 2017), STEM learning approach and process (Ladachart et al., 2019; Yuenyong, 2019), and inquiry-based learning (Ngaewkoodrua & Yuenyong, 2018), and designing STEM lessons (Khumwong, 2017). However, there has been little research done to expose how STEM education workshops or learning activities for science student teachers (SSTs) have been included in the Initial Teacher Education program.

Student teachers' preparation is a crucial part of teaching STEM subjects. In a study with SSTs, Pimthong and Williams (2020) found that SSTs did not have a deep understanding of STEM, such as integrating disciplinary concepts and skills, and their focus on STEM varied based on their discipline major. Similar to another study by Vichaidit and Faikhamta (2017), SSTs had an inadequate understanding of STEM and STEM teaching. Kruatong et al. (2018) reflected that SSTs had difficulty in identifying not only the technology, mathematics or other content related to the given everyday inventions, but also the science content. Seemingly, SSTs were having problems understanding and enacting STEM-based lessons in their respective classes.

In science teaching and learning in Thailand, the 5E inquiry-based pedagogy is more practical than practical, compared to other pedagogies. Mostly and basically, Thai SSTs are given strong foundations of inquiry-based learning. Previous research using inquiry-based strategies for enhancing students' STEM education learning revealed that inquiry-based learning could foster the cause of integration in STEM pedagogy (Deák et al., 2021; Lai, 2018; Tecson et al., 2021). Seemingly, it might be highly possible for the science student teacher to be able to integrate inquiry-based and STEM-based education in their future science classrooms. Hence, this research study took this initial expectation for enhancing STTs' ability to design inquiry-based STEM lessons for the middle school science level. The research questions guiding this study were: (1) what are the levels of inquiry-based STEM lessons qualities designed by the SSTs teachers?; and (2) what are the SSTs' thoughts on STEM education?

Literature Review

Preparing science student teachers for STEM integration is a significant requirement that corresponds to STEM workforce demand in the future (Michalow, 2015). According to Bartels et al. (2019), science student teachers (SSTs) should be introduced to STEM education and allowed to design and teach integrated STEM as early as during their studies. However, there are challenges and obstacles to implementing integrated STEM education, as has been reported by Pantu (2019), where the teachers in STEM workshops cannot design STEM lessons to suit the subject, context, and students' potential. Lomarak (2019) revealed that teachers who attend STEM workshops were not proficient in all the essential elements of STEM teaching. Shernoff et al. (2017) reflected that challenges and obstacles to implementing integrated STEM education include lack of knowledge and lack of time for collaborative preparation and instruction.

Hence future teachers should consider how STEM subjects can be integrated into meaningful ways for prospective students. Michalow (2015) indicated that student teachers could verify their inquiry and STEM training by participating in the program called "Verification of Inquiry & STEM Education Skills". The student teachers needed to understand inquiry-based and STEM based education, completing assignments (for example; doing an internet search of current science or science education articles, finding internet science games which relate to such, being inquiry/STEM based, creating a lesson unit plan of inquiry based and STEM based) and completing the indicator tasks to get a certificate awarded from the program. All these activities could give student teachers expertise in STEM teaching. Saratapan, Pitiporntapin, and Hines (2019) studied ways to enhance student teachers' integration of STEM education into home economics lessons. The program included an introduction to STEM, analyzing examples of STEM education in classrooms, and developing lesson plans in STEM education. The lesson can incorporate real-world experiences and problems, immerse students in hands-on inquiry, and involve students in productive teamwork, guided by the engineering process, and integrate content from mathematics and science courses. A study by Muslihin et al. (2018) trained SSTs to design the lesson using the 5E instructional model through the chemistry teaching methods course. The SSTs analyzed a STEM-Green Technology chemistry lesson which integrated science (thermochemistry), technology (concept maps), engineering (creating hot packs and cold packs), mathematics (calculating ΔH from Hproducts - Hreactants of a chemical reaction). The challenge activities, for example, creating hot packs and cold packs, and making ice-cream with the salts were introduced to the chemistry student teachers. However, how the STEM activity integrated into the 5E inquiry approach in the previous research is unclear in terms of teaching stages. The impacts of the training programs on the SSTs' ability to prepare inquiry-based STEM lessons are roughly determined.

It is a challenge for a science teacher education program to prepare SSTs to be able to integrate inquiry-based and STEM-based education in their future science classrooms. The framework of this research study, the integration of the 5E Inquiry learning model by Bybee (1993) and STEM-based education was simply verified; as the following 5E phases: Engagement, Exploration, Explanation, Elaboration with the STEM challenge activity, and Evaluation called "5E inquiry-based STEM learning model". The STEM elements were incorporated into the elaboration phase. This rigorous model aims to help the SSTs in the initial design of STEM lessons. In the elaboration phase, students are encouraged to apply their new understanding of concepts, develop products, share information and ideas, or apply their knowledge and skills to other disciplines (Duran and Duran, 2004). In designing STEM activities, the SSTs need to consider: (1) level of integration; (2) content and situation/context; (3) writing the situation; (4) define criteria and constraints; (5) document and record; (6) describe the guideline of implementation; and (7) criteria for activities evaluation. According to Michalow (2015) and Bartels et al. (2019), in helping the SSTs to learn and know how to design inquiry-based STEM lessons, they should be introduced to STEM and allowed to experience and design integrated STEM as early as during their studies. Then they need to focus on the subjects they teach before exploring the mechanisms for integration across STEM disciplines, as suggested by Kruatong et al. (2018); Pimthong and Williams (2020).

Methodology

This research was pre-experimental research. The research participants were 49 SSTs (41 females and 8 males) who were third-year undergraduate students in the Teacher Education program, Thailand. They had no teaching experience.

The Context of the Study: 18 hours of learning activities about a 5E inquiry-based STEM education in the science teaching method course (3 hours per week) were established for developing SSTs' ability to design 5E inquiry–based STEM lessons. The learning topics and activities are shown in Table 1; it consists of: (1) introduction to STEM education; (2) performing three inquiry-based STEM lessons; and (3) designing the lessons. The instructor explained 5E inquiry-based STEM instruction was incorporated in the 5E inquiry

Table 1 Outline of the six weeks for inquiry-based STEM Instruction

Week	Content	Implementation process
1	Introduction to STEM education	Introduce STEM Education, STEM-related content and its relatedness to the 21st century.
2–4	Inquiry-based STEM lesson instruction: 1. Engagement, 2. Exploration, 3. Explanation, 4. Elaboration with STEM activity: 4.1 content and situation/context, 4.2 writing the situation, 4.3 define criteria and constraint, 4.4 document and record, 4.5 description the guideline of implementation, 4.6 criteria for activities evaluation. 5. Evaluation	Demonstrate STEM classroom activities using a 5E inquiry-based learning by design model which includes encouraging students to learn relevant concepts through a hands-on inquiry-based method before drawing the concepts to construct a product with engineering design challenges in the Elaboration phase. *STEM Activity 1:* Tug Boat Guided worksheet instructed for planning, designing, constructing, and testing of capacity and the speed of movement of the "Tug Boat". Different materials and the load were provided Reflection on the activity. *STEM Activity 2:* Handy Water Purifier Guided worksheet instructed for planning, designing, constructing, and testing of the quality of water (amount, flowing rate, pH, clearness) of the "Handy Water Purifier". Different wastewater and materials were provided Reflection on the activity *STEM Activity 3:* Air Freshener Spray Guided worksheet instructed for planning, creating a recipe, testing of maintaining air quality of the "Air Freshener Spray". Different solutes and solvents were provided Reflection on the activity
5–6	Designing an inquiry-based STEM lesson plan.	Assign individual students to design their STEM lesson with the following stages, activities: 1. select the science content 2. identify learning standards and Indicators 3. identify the learning objectives 4. design activity for each phase of the inquiry-based STEM learning 5. evaluate the STEM lesson and provide the reflection 6. revise the STEM lesson.

learning cycle; Engagement, Exploration, Explanation, Elaboration and Evaluation (Bybee, 1993), with STEM activities in the elaboration phase. The aim of doing STEM activities in the elaboration phase was to ensure that students had enough science content for solving problems in real-life situations. During the science teaching methods course, participants were assigned to develop the inquiry-based STEM lesson in groups depending on their interest in science content in weeks 5–6 and present such to the whole class for feedback from the instructor and peers. After that, they were assigned to develop individual lesson plans of specific science standards and indicators as the instructor recommended to each person, a procedure to create a STEM unit applied from Robert's guidelines for STEM lessons (Robert, 2013). They could give suggestions and feedback from the instructor via email and out of the classroom for improving their lesson plan. The revised lesson plans were turned in to the instructor at the end of the course.

Research instruments. The research instruments included an inquiry-based STEM lesson assessment form and a semi-structured interview. Two science educators and one professor in engineering reviewed all instruments on correction and validation, the details of which are described below.

An inquiry-based STEM lesson assessment form was used to capture SSTs' ability to design inquiry-based STEM lessons. The features and rubrics were constructed, corresponding to the 3 features: (1) identifying learning standards and indicators covering STEM disciplines; (2) identifying learning objectives covering STEM disciplines; and (3) designing inquiry-based STEM learning processes by creating 5E and STEM activities related to big ideas of science content. Each feature was rated on three levels; good, moderate and needs to improve. The researcher and a science educator checked the lessons and the inter-rater agreement was 82 percent. The features used in the classification of lesson plan level were modified from literature, for example, Kim and Bolger (2016), and some were generated by the researcher (see Table 2). The frequencies and percentages of each feature in the evaluation criteria were determined.

2. Semi-structured interview questions were used for investigating the SSTs' thoughts on inquiry-based STEM models. The semi-structured interview was conducted after the course was completed for a 20-minute individual interview. The semi-structured interview questions were: What are the difficult parts of developing inquiry-based STEM lesson plans? What are the problems in developing lessons? What is the advantage of developing an inquiry-based STEM lesson plan? Are you willing to recommend using inquiry-based STEM instruction in the future?

Table 2 A feature and rubrics of SSTs' ability to design inquiry-based STEM lesson

Features	Levels		
	Good	Moderate	Need to improve
1. Identifying learning standards and Indicators	Identify appropriate standards for science, technology and mathematics and relate them to engineering. (3)	Identify standards and indicators between 2–3 disciplines. (2)	Identify standards and indicators in only one discipline or identify only the science topic. (1)
2. Identifying learning objectives for STEM	The objectives are comprehensively, clearly defined and related to each discipline's learning standards and indicators. (3)	The objectives are comprehensively but not clearly defined and related to learning standards and indicators for each discipline. (2)	The objectives are defined but not related to learning standards and indicators for each discipline. (1)
3. Designing inquiry-based STEM learning process			
3.1 Engagement	There are various methods to engage student interest in content such as questions, hands-on activities, demonstrations or others related to the exploration stage. (3)	There are various methods to engage student interest in content but they are unrelated to the exploration stage. (2)	There is no method to engage student interest in content and it is unrelated to the exploration stage. (1)

Table 2 Continued

Features	Levels		
	Good	Moderate	Need to improve
3.2 Exploration	There are methods/activities that allow students to entirely and appropriately inquire about content knowledge. (3)	There are methods/activities that allow students to explore some of the content appropriately, but not completely. (2)	The method/activities cannot allow students to investigate appropriate and complete content. (1)
3.3 Explanation	Students have the opportunity to clearly explain and summarize the content/concepts from the exploration stage when the teacher asks leading questions. Write a description or make clear conclusions. (3)	Students have the opportunity to explain and summarize the content/concepts from the exploration stage but are not clear or incorrect. Do not write clear explanations or conclusions. (2)	There is no opportunity for students to explain and summarize the content/concepts from the exploration stage. (1)
3.4 Elaboration with STEM activities	Integrate all four disciplines in activities, leading to the use of primary knowledge in science content and appropriately applying other disciplines. Describe STEM-related content in all four disciplines. (3)	Integrate 2–3 disciplines in activities, leading to the use of primary knowledge in science content and applying other disciplines appropriately. Describe STEM-related content in all four subjects. (2)	No integration of other disciplines except science content. (1)
3.4.1 Content and situation/ context	Content and situation/context are appropriate to student Competency level. (3)	Content is appropriate to student competency level but the situation/context is not appropriate. (2)	Content and situation/context are not appropriate to student competency level. (1)
3.4.2 Writing the situation	Writing the situation clearly and appropriately. (3)	Writing the situation but not appropriately. (2)	Writing the situation unclearly and inappropriately. (1)
3.4.3 Define criteria and constraint	Define criteria and constraints appropriate to the activity. (3)	Define criteria and constraints partially but not appropriate to the activity. (2)	Cannot define criteria and constraints of the activity. (1)
3.4.4 Document and record	Document and record form appropriately and include STEM-related content record form. (3)	Document and record form appropriately but not include STEM-related content record form. (2)	No document, STEM-related content and other record forms. (1)
3.4.5 To guideline the process of implementation	To guideline the process of implementation that allows the student to design their task clear and easy to understand. (3)	To describe the processes of implementation but not allow students to design their own task clearly and easy to understand. (2)	No guideline or to describe some process of implementation unclearly. (1)
3.4.6 Criteria for activities evaluation	Criteria for activities evaluation are clear and appropriate. (3)	Criteria for activities evaluation are clear but inappropriately. (2)	Criteria for activities evaluation are unclear and inappropriate. (1)
3.5 Evaluation	Corresponding to the objectives and indicators correctly. (3)	Corresponding but not appropriate with the objectives and indicators. (1)	Not Corresponding with the objectives and indicators. (0)

Results

SSTs' Ability to Design Inquiry-Based STEM Lessons

SSTs' individual lesson plan analysis in a science teaching methods course revealed that 89.80 percent of SSTs were able to integrate STEM activity related to big ideas of science content in the elaboration phase of the inquiry-based lesson as shown in Table 3. SSTs, 77.55 percent were able to identify learning standards and indicators covering STEM disciplines, and 67.35 percent were able to identify learning objectives. The designing of inquiry-based STEM lessons was in good level in engagement (87.76%), exploration (97.96%), explanation (77.55%), elaboration with STEM activities (89.80%) and evaluation (73.47 %). For their STEM activities, 89.80 percent integrated four disciplines by using prior knowledge in science content and applying other disciplines appropriately.

From the above data, most SSTs were able to determine learning outcomes correlated to learning standards, set learning outcomes concerning STEM disciplines and create STEM activities related to the big ideas of science content. The SSTs generated ideas for developing STEM activities involving inventing and innovating solutions related to local problems or issues, such as animal traps, machines for selecting fruits, recyclable products, watering systems for farms, natural universal indicator paper, earthworm condos, protective smoke mask, electromagnet door lock, diet Box and so on.

However the lessons of 5 SSTs showed that their STEM activity needed to be improved because the activity they created focused on a science activity only, did not integrate other disciplines; for example, characteristics and functions of the external structures of plants lesson (SST No 16); the rock lesson with the rock classification activity (SST No.18). SST No.30 designed the climate phenomena and weather forecasts lessons, the elaboration phase assigned students to search weather forecast data from the internet, newspaper and television and then answer questions on the activity sheet. These activities were considered as the usual science inquiry-based activity. The analysis of STEM activity' sub-features revealed that some SSTs were not able to provide clear content and situation/context (8.16 percent), write the situation (14.29 percent), define criteria and constraint (10.2 percent), document and record (16.33 percent), describe the process of implementation (16.33 percent) and criteria for activities evaluation (26.53 percent). For example, SST No. 37 designed the acid and base lesson on making colorful candy from natural indicators. However, all processes were described step by step in a lab cookbook, so the students would not be encouraged to design the task themselves.

SSTs' Thoughts about Inquiry-Based STEM Learning

The interview data revealed that more than half of SSTs were having difficulties designing the inquiry–based STEM lessons identified. Examples; SST No.3 said "It is tough to design STEM activities because

Table 3 SSTs' ability to design the inquiry-based STEM lesson

Features	Frequency of SSTs (Percent)		
	Good	Moderate	Need to improve
1. Identifying learning standards and indicators covering STEM disciplines	38 (77.55)	-	11 (22.45)
2. Identifying learning objectives covering STEM disciplines	33 (67.35)	1 (2.04)	15 (30.61)
3. Designing inquiry-based STEM learning process			
3.1 Engagement	43 (87.76)	4 (8.16)	2 (4.08)
3.2 Exploration	48 (97.96)	-	1 (2.04)
3.3 Explanation	38 (77.55)	9 (18.37)	2 (4.08)
3.4 Elaboration with STEM activities	44 (89.80)	-	5 (10.2)
3.4.1 Content and situation/context	39 (79.59)	4 (8.16)	6 (12.24)
3.4.2 Writing situation	36 (73.47)	7 (14.29)	6 (12.24)
3.4.3 Define criteria and constraint	38 (77.55)	5 (10.2)	6 (12.24)
3.4.4 Document and record	36 (73.47)	8 (16.33)	5 (10.20)
3.4.5 Guideline of implementation	31 (63.27)	8 (16.33)	10 (20.41)
3.4.6 Criteria for STEM evaluation	26 (53.06)	13 (26.53)	9 (18.37)
3.5 Evaluation	36 (73.47)	13 (26.53)	-

the activities have to relate to content strongly. The assessment would be more effective. SST No. 10 said, "I was worried that my STEM activity could not cover all target concepts…" While one-third of SSTs revealed that they did not know how to set the problems or contexts that drove students to find solutions or design the tasks themselves. The SSTs also faced the problem of the lack of STEM content. Many of them needed to spend time searching for more information about the STEM activities to know how things work, how to explain scientifically, and other discipline concerns. They also discussed student basic knowledge and skills, school context, and time available concerning STEM education.

However, the SSTs agreed that the inquiry-based STEM lesson would benefit their science classroom because it allows their students to learn, think, and practice through the STEM activities. Most SSTs (81.63%) responded that they would bring inquiry-based STEM approaches into future classrooms. The advantages of STEM education were mentioned; for examples,

"Doing STEM activities might make a fun classroom." [SST No. 3]

"Students would have a chance to learn by doing and applying what they have learned themselves." [SST No. 9]

"Students would be able to better understand the content by practicing, not just memorizing." [SST No. 18]

"I think I will bring inquiry-based STEM instruction into future classrooms because I like it if the students have a chance to learn and practice doing things by themselves and know how science relates to their real life." [SST No. 12]

Conclusion and Recommendation

This research study provided SSTs with 18 hours of learning activities about a 5E inquiry-based STEM education in the science teaching method course (3 hours per week). STEM activities were integrated the Elaboration phase. After learning the science target concepts via the Engagement, Exploration, and Explanation phases, the STEM disciplines were assessed or evaluated in the Evaluation phase. Analysis of the SSTs' lesson plans revealed that they were able to create their STEM activities, for example, designing and building an earthworm condo and electromagnet door, designing inventions using local materials, and solving everyday problems.

However, some SSTs revealed that they had a limited understanding of STEM content, which is the obstacle that appears when the teacher starts thinking of STEM, which corresponds to findings from the previous research done by Ladachart et al. (2019) and Srikoom et al. (2017). With the rigorous 5E inquiry-based STEM learning approach, most SSTs were able to create and use STEM activities in the science classroom. Another concern proposed by Kruatong et al. (2018), was SSTs' difficulty in identifying science, technology, mathematics or other content related to the given everyday inventions. Then the learning activities in the science teaching methods course were focused on SSTs' ability in identifying the learning objectives of the STEM lesson, which can help most SSTs see the links between inventions/products and each of the STEM content. This research also found that the SSTs needed more support related to the evaluation of STEM activities; further research study might intensely focus on STEM authentic assessments.

After learning, the science students showed positive thinking about STEM education. This is consistent with the study by Kim and Bolger (2016) indicating that experience in designing lesson plans would impact SSTs teaching expectations and positive attitude towards teaching in a short time. However, implementing STEM education in a classroom is challenging; SSTs shared several concerns, for example, student backgrounds, school context, and time available, similar to the finding from previous research (Autid, 2017; Shernoff et al 2017; Wang; 2012). Hence the SSTs still need more support in STEM classroom management and to gain experiences in STEM micro-teaching and implementation of STEM inquiry-based learning in the science classroom before becoming great STEM teachers.

Conflict of Interest

The authors declare no conflict of interest in this research study.

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