การพัฒนาการรู้เรื่องสะเต็มของครูก่อนประจำการด้วยแนวคิดแบบเมกเกอร์ร่วมกับประสบการณ์ภาคสนามด้านสะเต็มศึกษา

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บทคัดย่อ

การวิจัยในครั้งนี้ มีวัตถุประสงค์เพื่อ 1) ศึกษาแนวทางการพัฒนาการรู้เรื่องสะเต็มของครูก่อนประจำการด้วยแนวคิดแบบเมกเกอร์และประสบการณ์ภาคสนาม และ 2) ศึกษาการรู้เรื่องสะเต็มของครูก่อนประจำการที่เข้าร่วมกิจกรรมการพัฒนาวิชาชีพครูด้วยแนวคิดแบบเมกเกอร์และประสบ-การณ์ภาคสนาม กลุ่มเป้าหมายที่เข้าร่วมโครงการนี้คือนักศึกษาสาขาวิชาวิทยาศาสตร์ จำนวน 35 คน ในการศึกษาการรู้เรื่องสะเต็มจะใช้การสุ่มแบบกลุ่มได้ 1 กลุ่มจำนวน 17 คน และเก็บข้อมูลเชิงคุณภาพจากนักศึกษา 13 คน จากการเลือกแบบเจาะจง และการเลือกแบบอาสาสมัคร ข้อมูลเชิงปริมาณวิเคราะห์โดยใช้การเปรียบเทียบสถิติทดสอบความแตกต่างของค่าเฉลี่ยระหว่างประชากรสองกลุ่มที่ไม่เป็นอิสระต่อกัน และวิเคราะห์ความแปรปรวนด้วยโปรแกรม SPSS ข้อมูลเชิงคุณภาพวิเคราะห์ด้วยวิธี content Analysis และ constant comparative ด้วยโปรแกรม Atlas.ti ซึ่งผลการวิจัยพบว่า แนวทางการพัฒนาการรู้เรื่องสะเต็มของครูก่อนประจำการด้วยแนวคิดแบบเมกเกอร์และประสบการณ์ภาคสนามมีขั้นตอน 4 ขั้น ประกอบด้วย 1) ขั้นกำหนดจุดมุ่งหมายในการไปศึกษาจากประสบการณ์ภาคสนามด้านสะเต็ม 2) ขั้นการเตรียมการก่อนการพาไปศึกษาจากประสบการณ์ภาคสนามด้านสะเต็ม 3) ขั้นการลงประสบการณ์ภาคสนามด้านสะเต็ม และ 4) ขั้นหลังประสบการณ์ภาคสนามด้านสะเต็ม ผลวิจัยในส่วนการรู้เรื่องสะเต็มพบว่ามีพัฒนาการรู้เรื่องสะเต็มอย่างมีนัยสำคัญที่ช่วงความเชื่อมั่น .05 และเมื่อพิจารณารายโดเมนของการรู้เรื่องสะเต็มพบว่าแนวคิดสะเต็ม แนวปฏิบัติสะเต็ม การประยุกต์ใช้สะเต็ม เจตคติด้านสะเต็ม/ต่อสะเต็ม และการเชื่อมโยงสะเต็มกับบริบทมีการพัฒนาขึ้นทุกโดเมน โดยไม่มีผลจากประสบการณ์ด้านสะเต็มศึกษาที่มีมาก่อนเข้าโครงการวิจัย จากผลวิจัยแสดงให้เห็นว่ากิจกรรมตามแนวคิดแบบเมกเกอร์และประสบการณ์ภาคสนามสามารถพัฒนาการรู้เรื่องสะเต็มของครูก่อนประจำการได้ ซึ่งการรู้เรื่องสะเต็มของครูจะส่งผลต่อความสามารถในการออกแบบและสอนกิจกรรมการเรียนรู้ตามแนวทางสะเต็มศึกษาได้ในอนาคตซึ่งเป็นเป้าหมายสำคัญอย่างหนึ่งของการจัดการศึกษาในปัจจุบัน

คำสำคัญ: การพัฒนาวิชาชีพครูสะเต็ม ครูก่อนประจำการ แนวคิดเมกเกอร์ สะเต็มศึกษา

Development for Pre–Service Teachers' STEM Literacy through the Maker Concepts and Field Experiences in STEM Education

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Abstract

This study first explored the approach toward developing pre–service teachers' science, technology, engineering, and mathematics (STEM) literacy using the maker concept and field experience in STEM education. Secondly, it examined the STEM literacy of pre–service teachers who participated in this research project. The population of the study comprised 35 pre–service science teachers. A group of 17 pre–service teachers, selected through cluster sampling, were investigated using the STEM Literacy Questionnaire before and after participating in maker activities and field experiences. Quantitative data from the questionnaire were analyzed by SPSS program using the dependent sample *t*–test and ANOVA. The qualitative data were collected from 13 pre–service teachers, acquired by purposive and volunteer sampling. The qualitative data were analyzed by content analysis and constant comparative method using Atlas.ti. The research results indicated that the developmental approach for pre–service teachers' STEM literacy through the maker concepts and field experience comprises four stages: 1) determining the STEM field experience objectives, 2) pre–STEM field experience, 3) STEM field experience, and 4) post–STEM field experience. The exploration of pre–service teachers' STEM literacy resulted in its mean score after participating in activities based on the maker concept and field experiences being higher at 0.05 significance level. STEM literacy domains in descending order from most improved include STEM conceptualization, STEM methodology, STEM application, STEM attitude/attitude toward STEM, and STEM–related contexts, respectively, regardless of prior experience in STEM education. The findings signified that the activities based on the maker concept together with STEM field experience could develop pre–service teachers'

STEM literacy, which consequently improves their abilities to design and implement STEM activities in the classroom in the future. Teachers' competency in STEM education is presently among the critical educational goals.

Keywords: STEM teacher professional development, Pre–service teacher, Maker concept, STEM education

Introduction

STEM education is a phenomenon of pedagogic shifts (Association of American Universities, 2013; Myers and Berkowicz, 2015), which occurs at an international level. This approach is widely used in kindergarten through primary school, higher education, and lifelong learning (Hawthorne *et al*., 2016). There is much literature (e.g., government documents, policy recommendations, and research reports) regarding the movement of STEM education. There are several agencies for driving STEM education mechanisms: educational, non–profit, private organizations, etc. In particular, Thailand has the Institute for the Promotion of Teaching Science and Technology (IPST), a government agency that supports the STEM educational movement. However, the development of the teaching profession toward STEM education, provided by IPST, is only available for in–service teachers (Chulavatnatol, 2012; IPST, 2017). Also in Thailand, other organizations alongside IPST focus their STEM education development programs on in–service teachers (Office of the Education Council, 2017). Left behind by the central government agency, STEM teacher preparation is solely in the hands of teacher education institutions, such as faculties of education and teacher colleges, where the processes and mechanisms of STEM teacher preparation vary across institutions. The revelation of how and to what extent STEM pre–service teaching is developed leaves a gap regarding research in pre–service teacher preparation for STEM education.

Teacher educators were concerned about the STEM knowledge and practical skills of teachers, particularly the integration of all four disciplines (English, 2016). When considering the conceptual framework of pedagogical content knowledge (PCK) (Ashton, 1990; Park and Oliver, 2008; Shulman, 1986), it was found that teachers facilitate and manage the learning of STEM effectively when they are equipped with content knowledge integrated with pedagogy. Regarding pushing forward STEM education, the factors affecting efficiency in STEM learning are that teachers themselves must have both the content and pedagogical knowledge, which reflects the intricacies of STEM integration. This PCK framework is more complicated when determining the conceptual framework of integrated content knowledge and pedagogical knowledge within the integration of the four disciplines. Teachers who can design and implement lessons to meet the framework of STEM education have to acquire content knowledge along with STEM pedagogical knowledge (STEM pedagogical content knowledge, STEM–PCK, or STEM–PACK). Although pre–service teachers are non–expert in each discipline of STEM education, they should at least have STEM literacy in domain knowledge, conceptualization, and methodology. This includes understanding the nature of each discipline and the ability to critically and creatively apply knowledge with a set of STEM attitudes during problem solving. The STEM attitude is defined as a unified state of mind and habits where a person tends toward an engineering design process in problem solving or finding new solutions. Meanwhile, attitude toward STEM is defined as the recognition and awareness of the importance of STEM in real life, and interest in STEM careers (Unfried *et al*., 2015). Moreover, they must have the ability to identify matters related to STEM in various contexts with which they interact in everyday life. (Bybee, 2013; Zollman, 2012). Unfortunately, in Thailand, both STEM attitude and attitude toward STEM are inadequate despite the country's need for more human resources to fill the STEM workforce pipeline (Paweenawat and Vechbanyongratana, 2019; Promboon *et al*., 2018), according to Thailand's 20–Year National Strategy (Royal Thai Government Gazette, 2018). This issue needs to be urgently tackled as Thailand becomes an aging society with the struggles of the middle income trap.

However, professional development for pre–service teachers to improve their grasp of STEM education is especially challenging, as STEM understanding cannot be done merely through lectures or superficial STEM activities. Undergraduate teacher education programs that do not provide the degrees or course of STEM education particularly suffer since it is difficult to give a person a deeper understanding of disciplines they neither learned nor had any practical experiences, particularly in engineering (Lederman and Lederman, 2013). Teacher professional development for pre-service teachers with competency in designing learning materials and STEM activities has to start from the foundation, which is to create the capacity for pre–service teachers to achieve a certain level of basic STEM literacy (Zollman, 2012). This foundational knowledge is essential in the design and application of STEM education. The first critical issue in creating competency in teachers is to develop STEM literacy, which comprises STEM conceptualization, STEM methodology, STEM application, STEM attitude/attitude toward STEM and STEM–focused context (Chamrat *et al*., 2019). Such knowledge, skills, and attitudes are essential components of STEM literacy and are elements of STEM content knowledge and STEM pedagogical knowledge in STEM–PCK. However, to develop all the domains of STEM literacy, teachers must have an authentic learning experience that reflects the key characteristics of STEM. It has been found that teaching and learning based on the maker concept can provide practices that engage students in higher–level thinking about STEM concepts (Paganelli *et al*., 2017). The maker concept or maker movement has been recognized as an essential adjunct to support STEM education (Honey and Kantar, 2013). Dougherty (2013) and Martin (2015) described the maker concept as a conceptual framework: "a class of activities focused on designing, building, modifying, and/or repurposing material objects for playful or useful ends oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated." Making often involves traditional craft and hobby techniques, and it often comprises the usage of digital technologies. The maker concept can be applied both in formal classroom and informal settings such as museums, exploratoriums, and real-world contexts (Bevan *et al*., 2015). Research has been conducted to find possible ways to encourage pre–service teachers to involve the maker concept and activities in both formal and informal contexts of education, which is also an effective way for teacher preparation in STEM education. (O'Brien *et al*., 2016).

The provision of STEM education lies in the teachers' ability to regularly design and create lessons or learning activities by themselves. This perspective envisions sustainable teacher professional development. After the end of the teacher professional development program or graduation of the pre–service teachers, the attributes or abilities that build upon STEM literacy will accompany them. Even if changing the science curriculum or future learning reform occurs, teachers can apply this STEM PCK in designing a learning environment with a new paradigm or new educational transformations to cope with the changes. This research, therefore, aimed to distill findings of the development of STEM literacy among pre–service teachers who participated in teacher professional development programs that deployed the maker concept together with field experience in STEM education. The findings will help STEM teachers and teacher educators to apply the maker concept along with the field experience in STEM education for the design and development of teacher professional development activities. Moreover, this concept can be used to design a pre–service teacher development program.

Methods

Research objectives

1. To explore the approach toward developing pre–service teachers' STEM literacy using the maker concept and field experience in STEM education.

2. To explore the STEM literacy of pre–service teachers who participated in this

research project.

Research participants

There were 35 pre–service science teachers in this research. Of 35, 17 pre–service teachers were randomly selected by cluster sampling (from two groups of 18 and 17 pre–service teachers). They completed a STEM literacy questionnaire before and after participating in a series of STEM field experiences. From this cluster, 13 pre–service teachers volunteered to complete five reflective journal entries after participating in each field experience in STEM education.

STEM activity based on the maker concept

There were 16 activities that were designed and developed based on the maker concept. The end products of each activity could be artifacts, methods, or solutions to solving the given problems. All activities were designed by researchers based on the indicators and concepts in scientific subjects according to the core curriculum of basic education. The activities were derived from learning indicators for grades 7–9. The concepts of the activities can be categorized into physical, life, earth, and astronomy/space sciences. Some activities focused on mathematics or emphasized it based on the subject. All the activities addressed the conceptual framework of STEM education that integrated STEM relevant to the context of the real world.

Pre–service teachers chose 11 from the list of 16 activities in Table 1 to study in–depth and to modify them because they had to be assistant trainers in STEM teacher professional development twice (PD 1–2). They then had to be group leaders and facilitators for secondary students in STEM camp twice (Socially Engage Scholarships, SES 1–2).

Table 1 STEM activities and end products based on the maker concept

No.	STEM Activities	End Product (Artifacts/Solutions)	Dominant Concept
1	Electrical Circuit	Paper circuit/Art robot	Physical Science
2	Voices of the Body	DIY stethoscope and DIY functional heart model	Life Science
3	Space Debris	Extending grabber from popsicle sticks	Space Science
4	Drinking by Design	A bottle of a beverage that has 4% w/v of sugar and a bottle label design	Physical Science
5	Saline for Life	DIY normal saline solution (0.9% w/v of Sodium chloride)	Physical Science
6	Harvest the Rain	The design of a rainwater tank to store the rain that meets the needs of the individual students' house	Earth Science
7	Measure the Leaf	The methods of plant leaf measurement	Life Science
8	Bioplastic	Plastics from milk and different kinds of flours	Physical Science

Table 1 STEM activities and end products based on the maker concept (continued)

No.	STEM Activities	End Product (Artifacts/Solutions)	Dominant Concept
9	Ice Cream Trading	DIY ice cream and ice cream packaging	Physical Science
10	Smart Packaging	The calculation of box packaging in different sizes/ the search for new packaging methods	Mathematics
11	Solar Cell and Solar Cell-Powered Car	Parallel and series solar circuits/ Modified solar-powered toy car	Physical Science
12	Frog Farming	The design of a frog farm habitat	Life Science
13	Thai Massage	The modern diagrams of traditional Thai massage manipulation techniques	Life Science
14	Crispiness of Snack	A recipe of a long-lasting crispy snack	Physical Science
15	Rafting Captain	A river rafting trail in Chiang Mai	Physical Science
16	Jewelry Design by GSP	A bead bracelet designed using The Geometer's Sketchpad	Mathematics

After participating in STEM teacher professional development as assistant trainers and in STEM camps as facilitators, pre–service teachers presented their works at the annual STEM festival in Chiang Mai. This STEM annual symposium of the northern region is hosted by the Northern STEM Center, under the supervision of the Thai Office of the Basic Education Commission (OBEC) and the IPST. Figure 1 presents the process of this research.

Data Collection

The main research instrument used for data collection was the STEM Literacy Questionnaire, which was used to collect data before and after participating in this research activity. The questionnaire comprised 30 statements that cover five domains and 16 subdomains of STEM literacy. Each item comprised a statement that respondents were asked to rate their degree of agreement or disagreement on a scale of 1 to 5 (strongly disagree, disagree, fair, agree, and strongly agree). The reflective journals and lesson plans written by the pre-service teachers were also used for qualitative data collection. After each field experience, pre–service teachers were asked to reflect on what they had learned in reflective journals. There were a total of five journal entries for each pre-service teacher.

Data Analysis

This study uses the “mixed–method” research approach. The data gathered from the STEM Literacy Questionnaire were analyzed using SPSS. To compare STEM literacy before and after participating in the activities, researchers used inferential statistics to analyze the relationships of variables. We used *t*–test statistics to compare the mean difference of two dependent or paired samples and the one–way ANOVA, Scheffe’s *post hoc* by determin-

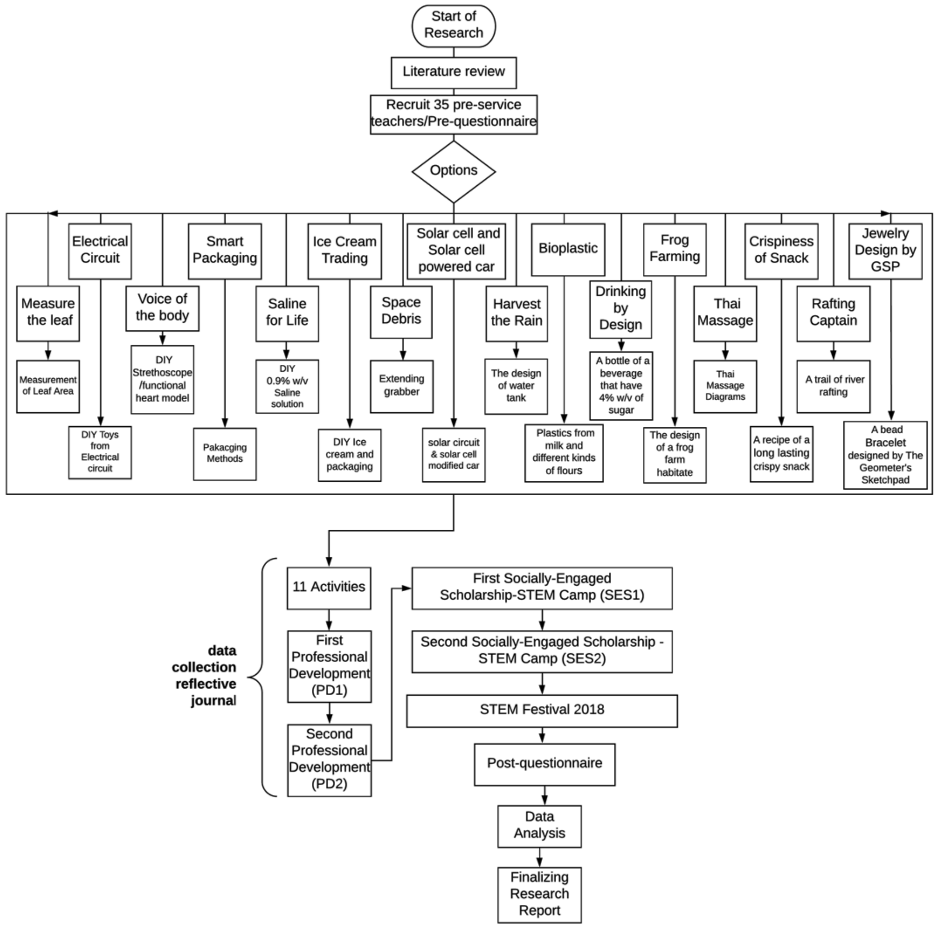

Figure 1 The research process

ing the significance at $p < 0.05$.

Regarding qualitative data, a constant comparative method was applied for content analysis comprising the following processes: 1) preparing, 2) segmenting, 3) coding, 4) comparing and categorizing, 5) constant comparison, and 6) seeking patterns and relationships (Neuendorf, 2016). Using the content analysis process, the researcher applied Atlas.ti as a tool for data analysis. Once the information was coded, researchers used various categories derived from the research to consider the relationships between the categories or patterns of what happened to create a description of the phenomenon studied. This stage is called data display, a process by which researchers present data. Overall, the data collected were reduced and then regrouped into main categories that were developed into the research findings.

Results

The results of the data analysis according to the first objective: To explore the approach toward developing pre–service teachers' STEM literacy using the maker concept and field experience in STEM education.

The results of this data analysis were analyzed from 65 reflective journal entries of 13 pre–service teachers. It revealed various levels of pre–service teachers' STEM literacy. The results were classified into four stages that chronologically comprised 1) determining STEM field experience objective, 2) pre–STEM field experience, (3) STEM field experience, and 4) post–STEM field experience. The details of each stage are as follows:

1) Determining STEM field experience objective

This stage involves meeting and discussion among pre–service teachers and all participants, including researchers, to jointly determine the purpose of the field experience in STEM education. They set the goals of the STEM activities, which were integrated into the objectives and learning activities in accordance with the maker concept. From the repeated comparative analysis of the lesson plans and reflective journals, seven areas of focus were identified to be the objective of STEM field experience based on the frequency of their usage by the code (Figure 2). The most frequently appearing keywords in the lesson plans were "the maker concept" and "creative thinking" (Maker–Creative in the code). All the pre–service teachers emphasized making things with creative thinking as the objective of field experience in STEM education. The words related to "make," "create," "build," "modify," "construct," and "develop" were coded and categorized into Maker–Creative family code.

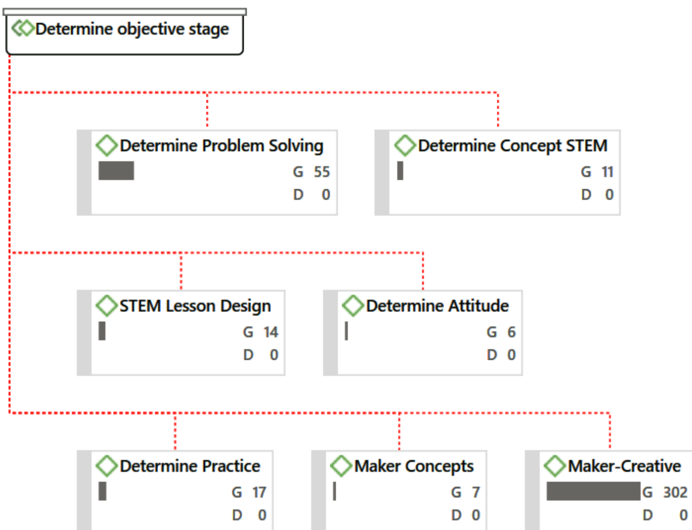

Figure 2 Components for determining the objective of STEM field experience

The other objectives ranked by frequency of their appearance in the reflective journals were problem solving, STEM methodology, designing STEM activities and lesson plans based on the maker concept, and developing STEM attitudes, respectively.

The findings revealed that at the stage of determining STEM field experience objectives, pre–service teachers' objectives for participating in STEM field experiences were to develop their creative thinking by making things in STEM activities. The findings also stated this goal in the lesson planning for teacher professional development and STEM camp for middle school students. Furthermore, they also indicated that STEM–related problem solving, conceptualization, methodology, attitudes, and the need to design and implement activities based on the maker concept were the objectives of the STEM field experiences.

2) Pre–STEM field experience

This stage was about preparation before going into the STEM field experiences. The pre–service teachers clearly understood their role and emphasized what emerged as four components: well preparedness, lesson supervision, co–construction of lessons, and preparation of STEM methodology named "Well–prepare," "Lesson–Supervise," "Co–construction," and "prepare practice" in the code, respectively (Figure 3).

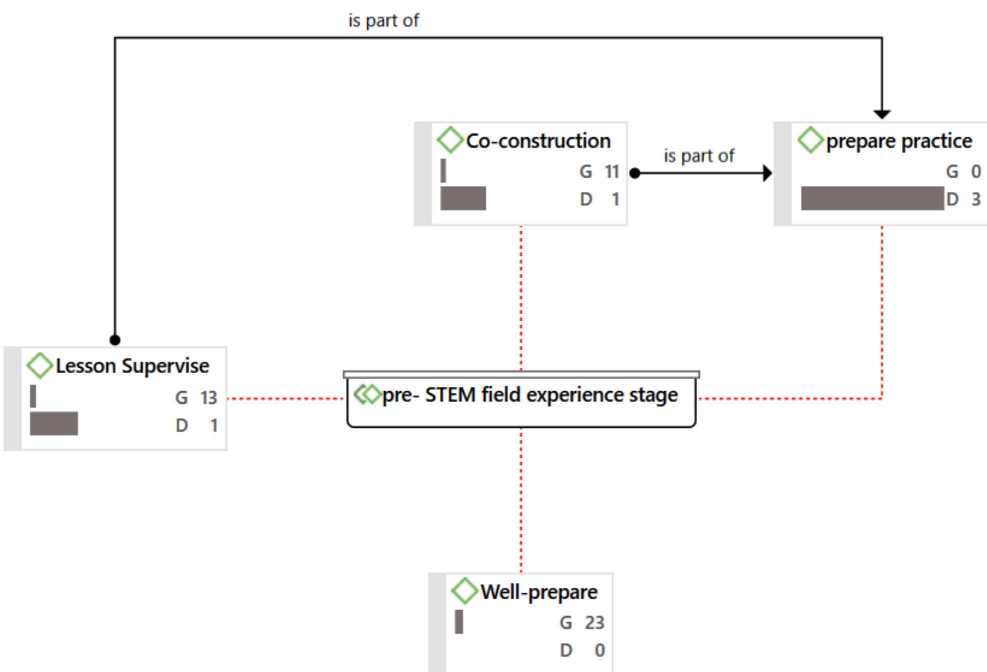

Figure 3 The results of content analysis of the pre–STEM field experience stage

Before becoming assistant trainers, pre–service teachers need to be well prepared regarding understanding and methodology in 11 activities. They needed to get lesson supervision both by core–trainers they assisted and their friends who were more specialized in some activities than themselves. They also wanted to add more details of STEM activities to the lesson plan. This happened when they learned and engaged with 11 STEM activities before participating in the STEM field experiences. By adding features in STEM activities, pre–service teachers became co-constructors in the STEM activities, shifting from users to developers of the lessons. In this stage, pre-service teachers must go beyond the understanding of STEM lessons; they have to master the STEM lessons to try them out and modify them.

3) STEM field experience

In this stage, pre–service teachers applied the concepts and methods identified during the determination of purpose and preparation into different situations in STEM field experiences. In this study, pre–service teachers participated in five STEM field experiences, which comprised STEM professional development twice (PD 1 and PD 2) as assistant trainers and facilitators. The professional development focused on in–service teacher training in STEM education held by the Faculty of Education. In these field experiences, pre–service teachers worked with a group of in–service teachers to assist them while they learned how to organize activities and observed STEM activities. The pre-service teachers then changed roles to co-trainers and facilitators in the academic services (Socially Engaged Scholarship, SES 1 and SES 2) performed in secondary and primary schools twice to organize a STEM camp for students. The responsibility of the pre-service teachers was to actively engage as leaders in activities, more than in the past two STEM professional development activities. For the last field experience, pre–service teachers participated in presentations and STEM activities at an academic symposium, the annual STEM festival for the northern region of Thailand, which is held in Chiang Mai.

The observations from the last field experience were that—before attending the venue—pre–service teachers discussed learning activities again to review, exchanged learning plans, and shared photos of maker end products, which included both artifacts and solutions for problems from the 11 STEM activities. This also occurred between activities. The most discussed issues were how to use basic and specialized devices for organized activities, for example, the use of a refractometer in STEM activity number four, Drinking by Design. Once the activity was performed, the devices were calibrated and retested. At each stage of the event, there were reflections on the activities that continued in both the lunch break and the evening in the form of After–Action Review and Reflection (AARR) sessions that were modified from Morrison and Meliza (1999). This unique approach was taken as it is something pre–service teachers will have to experience in the field in the form of questions from both teacher professional development and STEM camp students.

4) Post–STEM field experience

In the post–STEM field experience stage, once returned to the university, pre–service teachers had to write reflective journals. The researchers divided the pre–service teachers into three groups based on their experiences in STEM education before participating in this research: 1) four novices in STEM education, 2) three beginners in STEM education, and 3) six pre–service teachers with an intermediate level in STEM education. Data analysis was performed using the Word Clouds function in Atlast.ti to count words related to the research conceptual framework. It was found that pre–service teachers could reflect on many STEM education ideas, including STEM literacy, which comprises conceptualization, methodology, application, STEM attitudes, and STEM regarding real life, economy, society, and the environment. The reflective journal writing protocol did not define the writing framework or topic determination in advance, yet "STEM" was the word that frequently appeared in the pre-service teachers' reflective journals. Therefore, it can be considered a matter of record that pre–service teachers naturally leaned mainly toward STEM concepts and eventually developed a general understanding of STEM concepts and methodology in STEM education in the later stages of the field experiences. Moreover, pre–service teachers stated that:

"*Each teacher of the group will receive a device to connect electrical circuits easily to produce New Year postcards. This activity relates physics knowledge to daily life and uses creativity in designing interesting cards. The second activity is the Space Debris activity, which has content related to astronomy and physics in the subject of objects orbiting the planet and links to mathematics about rhombuses. Each group must record the time each person takes to walk in the orbit without colliding to promote team planning and collaboration. It also applies engineering skills in the invention of a longer and stronger Space Debris Extension Arm. Drinking by design is the following activity in which each group has to make fruit and vegetable juice with only 4% sugar concentration by mass per volume and to design the packaging of juice, including product price evaluation, an activity that requires skills in many fields. Each teacher in the group has different skills; hence, they are grouped according to their aptitudes. However, some groups do not have teachers who have an understanding of concentration; therefore, they will need more explanation. This activity uses chemical knowledge of concentration or percentage in mathematics to help calculate the concentration of sugar. It also utilizes creativity to design attractive packaging as well as the application of career and technological knowledge in product price evaluation.*"

(Reflective Journal, D17, Novice in STEM education)

Based on the differences in reflections between the three groups of pre–service teachers, the researcher analyzed each group using constant comparatives of quotes in the reflective journals. The Word Clouds analysis found that the reflections of pre–service teachers in the group of novices in STEM education focused on the characteristics of the STEM activities related to the maker concept "creativity." The word "creativity" and related words, such as "creative thinking" and "new ideas," appeared from the beginning while determining the objectives of STEM field experiences. These groups' tendencies when reflecting upon the elements of the STEM activities indicated more obvious and easily understood aspects of STEM education. The beginners in STEM education were more likely to relate STEM with the maker concept, reflecting on less straightforward STEM characteristics but more frequently stating the outcomes of the STEM activities with and identifying crucial features involving creativity and innovation. The last group of pre–service teachers who had some experience in STEM education revealed through their reflective journals that they could link STEM education field experiences to pedagogical knowledge. The words identified in their journals were related to conceptualization, methodology, application, STEM attitudes, and attitudes toward STEM.

Moreover, this was the only group where the word "maker" appeared in the journals. The pre–service teacher in this group could identify various factors related to the learning approach utilized in STEM education. This finding appeared in both the Cloud Words and constant comparative analytical methods of the reflective journals after the field experiences, indicating that this group of pre–service teachers could link STEM literacy to the design of learning based on STEM education.

The results of the data analysis according to the second objective: To explore the STEM literacy of pre–service teachers who participated in this research project.

The results were based on the STEM Literacy Questionnaire to answer the research questions about the development of STEM literacy of pre–service teachers participating in this study. The written report was analyzed using both the *t*–test and the Scheffe's *post hoc* test in one–way ANOVA. The data were acquired from a randomly sampled group of pre-service teachers through cluster sampling (two clusters with half–half samples) comprising 17 teachers from a total population of 35 people. The data were collected using the 30–item questionnaire before and after participating in the development process of STEM literacy through the maker concept together with the field experience in STEM education. The researchers thereupon compared the mean score of pre–service teachers' STEM literacy using paired samples *t*–test from the same person twice. The results were shown in Table 2.

In addition, a comparison of the STEM literacy mean score of pre–service teachers overall and in each domain is shown in Table 3.

Table 2 The dependent sample *t*–test of pre–service teachers' STEM literacy before and after participating in maker concepts and field experiences in STEM education

	Mean	SD	SE	95% confidence interval of the difference		*t*	df	Sig. (2–tailed)
				Lower	Upper			
STEM literacy	–.39694	.44371	.10762	–.62508	–.16881	–3.689	16	.002*

Note: *$p < .01$

Table 3 The dependent sample *t*–test of pre–service teachers' STEM literacy by domains before and after participating in the maker concept and field experiences in STEM education (df = 16)

STEM literacy domain	Mean	SD	SE	95% confidence interval of the difference		*t*	Sig. (2–tailed)
				Lower	Upper		
Overall	–.39694	.44371	.10762	–.62508	–.16881	–3.689	.002*
STEM conceptualization	–.39819	.58535	.14197	–.69915	–.09723	-2.805	.013*
STEM methodology	–.40095	.55170	.13381	–.68461	–.11729	-2.996	.009*
STEM application	–.37696	.57106	.13850	–.67057	–.08335	-2.722	.015*
STEM attitude/attitude toward STEM	–.34755	.61448	.14903	–.66349	–.03161	-2.332	.033*
STEM–related contexts	–.37479	.57957	.14057	–.67278	–.07680	-2.666	.017*

Note: *$p < .05$

From the results in Table 3, it can be concluded that STEM literacy was significantly developed both at the overall and subdomain level. Listed in descending order of development are STEM methodology, STEM conceptualization and STEM application, STEM–related contexts, and STEM attitude/attitude toward STEM.

Therefore, the researchers are interested in comparing STEM literacy of pre–service teachers with three different levels of STEM education experiences: 1) novices in STEM education, 2) beginners in STEM education, and 3) intermediates in STEM education. They were classified by the number of attendances in STEM education activities before participating in this research. Based on data collection from the STEM Literacy Questionnaire, we compared different groups of pre–service teachers according to their level of STEM education experiences and their mean scores in STEM literacy. The Scheffe's *post hoc* results indicated that there was no significant difference in the development of STEM literacy between the three experience groups (novices, beginners, and intermediates) before and after participating in STEM field experiences, indicating that the initial STEM experience does not affect STEM literacy development in pre–service teachers. The data showed that after participating in teacher professional development activities based on the maker concept and field experience, STEM literacy developed as a whole in all domains. Based on the data, all three groups had similar levels of STEM literacy after participating in the study, which comparatively exceeded that before attendance.

According to the analysis of the questionnaire, both quantitative and qualitative data analysis can be summarized as follows.

Pre–service teachers had higher levels of STEM literacy after attending the teacher professional development program based on the maker concept and field experiences in STEM education, with the mean difference being significant at 0.05 level. The most to least developed domains after attending the program were STEM methodology, STEM conceptualization, STEM application, STEM–related contexts, and STEM attitude/attitude toward STEM, respectively. Pre–service teachers' background in STEM education, which comprised novices, beginners, and intermediates in STEM education experience, did not affect the level of development of STEM literacy. All three groups could develop STEM literacy at each and overall domain.

Discussion

Related studies have presented the various methods for developing the STEM teacher profession among pre–service teachers (Adams *et al*., 2014; Hudson *et al*., 2005; O' Brien *et al*., 2016; Schmidt and Fulton, 2016). The maker concept plays an essential role as a framework that enhances STEM literacy for both teachers and students. Bevan *et al*. (2015) specified that the maker concept can improve STEM conceptualization as the activities were learner–driven and emphasized inquiry–oriented pedagogies. This is because the maker concept focuses on creativity and action (Halverson and Sheridan, 2014; Martin, 2015). Additionally, they are relevant to real–world contexts, such as innovative social creation (Tabarés–gutiérrez, 2016), environmental problem solving (Niederhauser and Schrum, 2016), and connected to business opportunities through the creation of startups (Bowler, 2014). Honey and Kantar (2013) suggested that learning activities according to the maker concept framework with a focus on maker mindsets usually occur in informal studies, including education in real-world contexts. Learning is successful when taking place where students are interested, such as museums in which students can participate in creative inventions (Bevan *et al*., 2015; Halverson and Sheridan, 2014) or places reflecting the real world (Schön *et al*., 2014).

The findings showed that the four stages of field experiences reflect that the chronological process could also be applied to developing pre–service teachers' STEM literacy, where the maker concept must be integrated at each stage. Starting with Stage 1, determining the objectives of field experience, it was required to set goals for the activity from which it was found that the most important goal of the maker concept framework is to develop creativity. This was seen in the pre–service teachers designing and performing activities during the program that focused on creativity and inventions. Most of the participants used the terms "make," “create,” “creative thinking,” or “innovation” more frequently than many others. However, since this program focused on STEM activities, the aim was to cover both the framework of the maker concept and the domains of STEM literacy, including STEM conceptualization, STEM methodology, STEM application, STEM–related contexts, and the development of STEM attitude/ attitude toward STEM. It defined the purposes of the study from the field experience, comprising at least five domains, as mentioned.

At this stage, pre–service teachers were opportune to design the lessons by themselves, which were used in the field experience in both professional development and student development via STEM camp. Input factors that were considered included transformative processes that lead to change, determining the output and the desired result, and the environment required for the effects to occur due to the interactive nature of the components. The expected impact of pre–service teacher professional development was the ability to design and create STEM activities that they can use in the future as interns and in–service teachers. Achieving the purposes of this step is to determine the input factors that will bring about the process that causes change. The inputs are the maker mindset and activities that involve the domains of STEM literacy.

Regarding the maker concept, it was found that the pre-service teachers who succeeded in maker activities had at least five features of a maker mindset: 1) the ability to create cooperation in learning together in places called makerspaces, 2) no fear of failure, 3) love of doing things like dismantling and repairing called tinkering, 4) the ability to independently choose topics for artifact creation, and 5) a growth mindset (Dweck, 2012).

The second stage of the STEM field experience reflected these concepts. During the pre–STEM field experience stage, there was an activity selection process. Pre–service teachers chose STEM activities to proceed on their own to prepare for the upcoming PD 1, PD 2, SES 1, SES 2, and STEM festival the five activities in this research program. According to the meeting minutes of the first stage where STEM field experiences' objecttives were determined, the pre–service teachers were yet unable to design activities on their own. The researchers, therefore, presented 16 STEM activities, 11 of which were chosen, that were partly designed and developed by researchers so that pre–service teachers could adapt and elaborate upon under advisement; this kind of STEM activity learning is called co–construction. Most importantly in this stage, STEM literacy was developed in the process of redesigning and co–constructing STEM activities alongside the preparation for all 11 activities before performing the actual STEM field experiences. From the results of the STEM Literacy Questionnaire, the intense pre–STEM field experience stage together with five STEM field experiences over an extended period addressed and developed STEM literacy, particularly in three domains: STEM methodology, STEM conceptualization, and STEM applications.

In the third stage, the pre–service teachers performed five activities where they learned to reflect on STEM concepts and methodologies as they facilitated and led the STEM activities, including answering questions as they arose. This period was the application stage of the maker concept framework through the field experience. It was a significant stage in teacher STEM literacy development. This approach was also similar to O'Broien *et al.*'s (2016), who brought 33 pre–service teachers to a primary school to participate in a maker fair with a theoretical research framework that included the maker concept. However, this study occurred over a short period in which O'Broien *et al*. (2016) found that pre–service teachers require preparation before undertaking the field experience. It was also found that a plan that includes posing questions, activity design, and characteristics of activity participation is essential.

The final stage provided the pre–service teachers with the opportunity to reflect on what they had learned after being immersed in STEM field experiences. The reflective journals after each experience helped the researchers understand how pre–service teachers with different levels of STEM education developed their STEM literacy with STEM field experiences based on the maker concept.

It was found that groups without experience in STEM education before joining this research tended to reflect on the characteristics of STEM activity. They described what happens during the field experiences rather than mentioning the outcomes of the activities as the beginner group did. For the intermediate group, it was found that they not only reflected on STEM education but also linked STEM to teaching and learning in the classroom. They reflected on the issues of students, science curricula, learning theory, individual differences, various aspects of activities, and measurement and evaluation. Based on the findings, the researchers found that the pre–

service teachers with intermediate experiences in STEM education started to show STEM pedagogical content knowledge or STEM–PCK, which is key leading to effective STEM teachers (Uzzo *et al*., 2018). The findings indicated that STEM field experiences based on the maker concept could develop pre–service teachers' STEM literacy and, if the research would like to go further, it could develop the STEM–PCK with pre–service teachers who have prior STEM experiences in particular. Pre–service teachers who have developed STEM–PCK at a high level while having a conceptual framework for the constructivist approach in STEM learning and the ability to reflect on their own teaching experiences can overcome limitations regarding their teaching; they will become the ones capable of adjusting their teaching toward STEM education (Allen *et al*., 2016).

From this study's second objective, which aimed to study STEM literacy of pre–service teachers who participated in teacher professional development activities based on the maker concept and STEM field experience, significant improvements were found in the pre-service teachers' STEM literacy with a significance level of 0.05 compared to STEM literacy prior to this study's professional development activities. When considered as domains, it was found that pre–service teachers had developed STEM literacy in all domains, listed in descending order from most developed as STEM methodology, STEM conceptualization, STEM application, STEM–related contexts, and STEM attitude/attitude toward STEM, respectively. Interestingly, when compared to similar research with in–service teachers conducted by Chamrat *et al*. (2019), it was revealed that the in-service teachers also regularly developed STEM literacy as a whole. However, when considering the five domains of STEM literacy, it was found that in in–service teachers, only three domains were more developed compared to literacy prior to participating in professional development: STEM conceptualization, STEM methodology, and STEM application—indicating the limitations of professional development surrounding STEM–related contexts and STEM attitude/attitude toward STEM. In contrast, this research developed STEM literacy in pre–service teachers in every domain. It could be explained that the conceptual research framework using the maker concept together with field experiences positively affected STEM attitude/attitude toward STEM. The maker mindset in particular is an important component in effectively promoting STEM attitudes (American Society for Engineering Education, 2016). Martin (2015) suggested that developing a maker mindset requires the involvement of aesthetic principles; the concept or attitude of makers have unique characteristics that are conducive to the development or creation of the artifacts/end products by the makers. Additionally, the elements of having field experiences linked to real–world contexts when designing pre–service teacher development activities is an essential factor that allows pre–service teachers to develop the STEM–related context domain.

The last issue concerns the effects of the pre–service teachers' STEM backgrounds before participating in professional development with the maker concept together with field experiences. The research results indicated that there was no significant difference regarding STEM literacy across the groups with different experiences in STEM education and the program. It is not because STEM literacy is easy to develop but the intensity of the field experiences gradually turned novices in STEM experiences into intermediates. Pre–service teachers came across five formal STEM field experiences (PD 1–2, SES 1–2, and the STEM festival) in addition to the discussions and reflections during participation in determining STEM field experience objectives, pre–STEM field experience, and post–STEM field experience. STEM literacy cannot be developed overnight but needs an intensive and constant process of authentic STEM experiences in the field. Nevertheless, when considered jointly with the results from the reflective journals, there were differences in reflections regarding knowledge, content, and methods of teaching and learning—pedagogical aspects. Pre–service teachers with more STEM education experience were more likely to develop STEM–PCK than pre–service teachers with less experience. Additionally, they had a tendency to design and develop STEM learning activities, according to Allen *et al*. findings (2016).

However, when identifying the experiences of pre–service teachers, it was found that the teachers without experience in STEM education were in their second year of study, the group with experience as beginners were in their third year, and the group with the most experience in STEM education were in their fourth year. It is possible that the results were affect by the third and fourth pedagogical knowledge. Therefore, choosing pre–service teachers with different levels may affect initial STEM literacy and the ability to integrate STEM teaching methods.

Conclusion and Recommendations

The findings of this study can be summarized in two main points. First, there are four stages in the STEM education field experience. Those stages comprise 1) determining the STEM field experience' objective, 2) pre–STEM field experience, 3) STEM field experience, and 4) post–STEM field experience. All four stages addressed the maker concept involving maker mindsets, creative thinking, and STEM lesson preparation. All STEM lessons in this study were designed and developed to explicitly reflect STEM conceptualization, methodology, and application as well as STEM attitude/attitude toward STEM and

STEM–related contexts. These constituents are the domains of STEM literacy. The second findings are pre-service teachers who participated in the STEM field experience integrated with the maker concept can develop their STEM literacy level where the mean score of pre–service teachers' STEM literacy after participating in maker activities and field experiences surpassed that before at a significant level of 0.05. All the domains of STEM literacy listed in descending order from most improved are STEM conceptualization, STEM methodology, STEM application, STEM attitude/attitude toward STEM, and STEM–related contexts, respectively, regardless of prior experience in STEM education. Based on the research results, we suggest that activities using the maker concept combined with STEM field experiences can develop STEM literacy. However, the ability to design and develop STEM lesson plans varied. Pre–service teachers with an intermediate level of STEM education experience (>10 times) tended to reflect on their STEM field experience in this study from a pedagogical standpoint more than the novice and beginner groups. These research findings connected STEM literacy to STEM pedagogical content knowledge (STEM–PCK). For future research or teacher professional development programs, STEM activity design and development should be inclusive, considering the experience of pre–service teachers as those with intermediate STEM education experience, as they have advantages over novices and beginners.

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