Teachers as Makers: The Key Provision of Teacher Preparations for STEM Education

Suthida Chamrat
Department of Curriculum, Instruction and Learning, Faculty of Education, Chiang Mai University
Email: suthida.c@cmu.ac.th

Abstract. This study explores how learning activities based on maker concepts prepared pre-service teachers entering the STEM Education pipeline. 25 pre-service science teachers from the faculty of education at Chiang Mai University enrolled in an Independent Study in Science Teaching course. The course was called “Integrating maker concepts and STEM Education.” The course sought to integrate existing science objectives with maker concepts and activities. Pre-service teachers were divided into 8 groups. Each group had to write and present a proposal, develop their instruments/Makings, try it out in schools, submit full reports, present and review peers’ final reports, attend a regional STEM festival where they participated in poster presentations. Using the collected data from a shared Google Drive, Video recordings, interviews, and extended activities, the findings indicated that STEM concepts and practices could be conveyed to pre-service teachers by instilling the maker mindset. From the 8 groups, 3 themes emerged: research in science education, science project, and STEM Education which consisted of 1, 1 and 6 projects, respectively. The creation of artefacts or Makings required scientific and mathematical concepts, empirical testing, and technological design. These enabled pre-service teachers to understand and practice teaching and learning in the STEM field. Event case study was employed as research methodology. Details of 8 pre-service teacher projects and 5 assertions of research findings are described.

1. Introduction

STEM and STEM education has been recognized as a crucial way of creating in Thailand an innovative economy. The Thailand government declaration in 2016 of a new economic and a social model, a policy known as ‘Thailand 4.0’, makes STEM and STEM education even more important [10]. According to the Thailand Ministry of Education, STEM education will be implemented at every level, from basic education to higher education. The Ministry aims to promote a STEM workforce, as well as develop STEM literacy for students [3]. By using STEM to reform learning in schools, it is expected that more students will enroll in STEM pipelines. Consequently, concerns about the preparedness of teachers, along with the concomitant concerns for teacher education are growing, for teachers are clearly the most critical factor in the future of STEM education. Research shows that teachers influence the educational pathways of students in the STEM fields [14]. However, teacher education still lacks sufficient STEM preparation for pre-service teachers; even for in-service teachers, STEM concepts are frequently left ambiguous [9].

Among the feasible ways to prepare teachers for the STEM education pipeline is to integrate maker concepts into current teacher education, as proposed by such researchers as [4,5] and Martin [11]. The
Maker Movement was developed by researchers who advocated its usefulness to support STEM education [8]. Dougherty [4] and Martin [11] described Maker Movement or Maker Concepts as a conceptual framework which consists of “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 involves the use of digital technologies” [11]. The Maker Movement has been considered as a transformative tool which alters how and what people learn in [13]. Bullock [2] integrated Maker Movement into learning and teaching in the classroom. However, he used the term “Maker Pedagogy” and explained it as an approach that utilizes the principles of ethical hacking (i.e., deconstructing existing technology for the purpose of creating knowledge), adapting (i.e., the freedom to use a technology for new purposes), designing (i.e., selecting components and ideas to solve problems), and creating (i.e., archiving contextual knowledge obtained through engaging in the process of making, as well as the actual tangible products) as part of an overall way of working with those interested in learning about science and technology.

By installing maker Mindsets, pre-service teachers engage in topics they are interested in, which encourages tinkering, playing or exploring stuff that concerns them. This study adopted Maker Concepts and applied them to existing course objectives for pre-service teachers. The results showed how pre-service teachers understand and practice STEM education. This research was guided by the question, “how can we best prepare pre-service teachers to be future teachers of STEM Education?” The research method is described below.

2. Method

2.1. Context of the Study

The context of the study was an existing course for science teacher education called “Independent Study in Science Education”. Pre-service teachers enrolling in this course were biology and chemistry majors. Of the 25 pre-service teachers, 15 were female. They participated in this research by purposive sampling. The course ran from January - April, 2016. The extended activities finished in July when pre-service teachers participated in poster presentations at the annual STEM festival in Chiang Mai, Thailand. In total, the study took 7 months for research, implementation and data collection.

2.2. Data collection

Google Drive was used for data collection and was shared between teachers and pre-service teachers. The data was compartmentalized and uploaded into folders such as Student handouts, class attendance, PowerPoints, Google Slides, Google Forms, pre-service teachers’ initiatives, independent study proposals, final reports, posters for presentations, activity photos and videos. Video recordings and group interviews were also used. Overall, the study was designed to examine pre-service teachers’ understandings and practices of STEM education based on maker concepts.

2.3. Data analysis

Event case study [1] was used as a theoretical framework of research design in this study. Data from the shared Google Drive (teacher documents, pre-service teachers’ hands out, pre-service teachers’ presentation, artifacts, etc.), Video recordings and group interviews were qualitatively analyzed using thematic analysis as described by Fereday and Muir-Cochrane [7].

3. Findings

After discussing a variety of trends in science education in Thailand and international, pre-service teachers focused their interests on 3 main categories: science projects, scientific concepts and STEM education. Each category was identified by student themselves. During the IS (independent study) project proposal presentation, which took place before midterm examination, pre-service teachers
were asked to explain their ideas on their IS projects, and how these projects related to current trends in science education. They were also asked to give the reasons why their work should be categorized into one theme or another. The projects were divided, based on the decisions of the pre-service teachers, into 3 themes: Science Projects, Research in Science Education and STEM education. IS Projects that were categorized in the theme “research in Science Education” focused on exploring and developing students’ understandings of the mechanisms of sea breezes and land breezes. Pre-service teachers developed conceptual tests that they later administered to students in schools. However, their work demonstrates some degree of maker concepts as shown in Figure 2. The students studying the concepts of sea breeze and land breeze, designated Group 1 (G1), decided to make learning materials for developing concepts of sea breeze and land breeze. Only one of eight groups chose the theme of Science Project. This group was eager to study the effects of lights’ wavelength on plant growth. The other 6 groups, developed new material that could benefit teaching and learning science. Makings developed by Groups 1- 8 (G1-G8) all required scientific and mathematical concepts and practices; however, only groups G3-G8 clearly stated that they had integrated engineering and technological designs into their Makings. Hence, G3-G8 explicitly addressed the stated aim of Stem education for integrating technology, engineering and scientific concepts. The pre-service teachers’ projects are summarized in Table 1. Examples of pre-service teachers’ makings are presented in Figure 1.

Table 1. Summary of Preservice teachers’ IS projects

| IS project Themes                  | IS Project Title                          | Focusing Concept                                      | Makings                                      | Instruments                  |
|-----------------------------------|------------------------------------------|-------------------------------------------------------|----------------------------------------------|------------------------------|
| Research in Science Education (n=1) | G1. Study and development of Sea breeze and Land Breeze Concepts | explanation of sea breeze and land breeze phenomena | Interactive paper board to explain the causes of sea breeze and land breeze phenomena | Concept Test                |
| Science Project (n=1)             | G2. Plant growth and Light color         | Effects of wavelength on plant growth                 | Design of plant cover filter                 |                              |
| STEM Education (n=6)              | G3. The Easy Consistometer               | Viscosity and measurement by Consistometer            | DIY Consistometer from Acrylic              |                              |
|                                   | G4. Mobile-Len for Biology Class         | Study of Cell using microscope                        | Adjustable focus ranges mobile phone Len    | Interview protocol           |
|                                   | G5. Holographic Display of Molecular Structure Learning | Explanation of molecular structure using VSEPR theory | Holographic pyramid and 4 planar molecular VDOs | Interview Protocol Video Recording |
|                                   | G6. Behind the Scene of Rosalind Franklin | The discovery of Double helix structure of DNA         | Projector from shoe box that can project spiral wire shadow on screen. | Open-ended questionnaire     |
|                                   | G7. Electron Configuration Model         | Electron configuration in atoms using Aufbau principle | Rotatable orbit-electron model made from Acrylic plastic | - Questionnaire - Interview Protocol |
|                                   | G8. Functional Heart Model               | Anatomy and Function of Human Hearth                  | DIY functional heart model                  | Concept test                |
Furthermore, there are 5 issues that emerged from the data analysis. These are follows.

3.1. Giving pre-service teachers a choice based on their interests will enable a higher success rate and higher quality of project, one which better reflects their understanding and practice of STEM education.

Interestingly, given that the pre-service teachers had been allowed to choose their own topics, only one group (G5) changed their title and concept of their project at a very beginning. The data from the Google Form asked the pre-service teachers 3 times if they were content with the topics they had chosen: at the beginning, during the process and near the end of the project, prior to submitting their final report. Project titles focus concepts and statement of problems were self-chosen. Hence, most students stated clear goals and obvious processes to accomplish their projects.

3.2. Instilling a Maker mindset in pre-service teachers is excellent preparation for the STEM education pipeline.

During the study, data gathered from personal and group interviews indicated that the highest quality projects, as voted for by their peers, reflected important aspects of Maker Mindsets. These
aspects can be grouped into the following 5 categories: 1) these groups worked collaboratively to create Maker Spaces; 2) they were not afraid of failure; 3) they loved tinkering; 4) they choose topics they loved to do; 5) and they embraced a Growth Mindset as described by O’Brien and Harlow (2016). During classroom presentations of the final reports, pre-service teachers were asked to tell the stories behind their works. The findings from pre-service teachers when asked what they thought were the best projects proved consistent with the mindsets of makers – i.e., numbers 1 to 5 above. The top three projects as voted for by peers were G4, G5 and G8 (Figure 2). These three groups all had Maker Mindset in common. One of the members from G4, the group which successfully constructed a functional heart model, told her story to the class:

“There were many versions of a heart model. At first, we thought of using a squeezing bottle. It didn’t work so we tried other materials. Then we found the foggy bottle which can pump the colored water from one to another bottle. It worked! But it needs to be sealed by a hot glue gun. We also constructed the structure using plywood that we bought from a building and construction materials shop.” (the pre-service teacher from G8 group)

![Figure 2. Number of pre-service teachers that voted for the top 3 IS project](image)

3.3. The complete cycle of a maker pathway is necessary in order for pre-service teachers to experience STEM education in a real context.

The preservice teachers participated in a full cycle of maker pathway. They wrote and presented a proposal; developed their instruments; tried out their learning innovation in schools; submitted a full report; presented their final report to their, as well as reviewing their peers’ final reports; finally, they attended a regional annual STEM festival and participated in poster presentations. These processes are portrayed by the diagram in Figure 3. The entire study lasted 7 months: 4 months of the semester, in addition to 3 months of extended activities outside the university, including time spent in classrooms, as well as at the annual STEM festival. There was no single process. Rather, students were exposed to authentic classroom environments, for it is here where they must develop their competencies. Additionally, it is as in-service in the classroom teachers where they will continue to develop the design and implementation for STEM Education.
Figure 3. The complete cycle of pre-services’ Teachers as Makers pathway in this study

3.4. Maker Concept is a continuous spectrum of progression

The groups showed progressive use of maker concepts. For example, when G8 constructed their Functional Heart Model, they had to construct their design according to a variety of factors, and were challenged to turn a paper design into a physical model. Figure 4 illustrates the original version of their Functional Heart Model. But in the original model, the water pressure caused leakage, as can be clearly seen. Similarly, the color indicator representing low and high oxygen levels in the blood,
seemed not to be working. Working collaboratively, the group systematically identified, diagnosed and solved both problems.

![Image of a functional heart model](image1.png)

**Figure 4.** The original version of Functional Heart Model (G8), later was modified to a better working version which addressed the deficiencies.

From a conversation with the researcher, the pre-service teacher showed progress in her way of thinking as well as progress in working with her model.

“I tried to solve these problem for 4-5 days. There were many problems during the process. The indicators now are working but the problem of water pressure is still unsolved. The first thing to fix is a valve. The second thing is the flowing system that I cannot control. When it circulates, the water pressure creates leakages at many points. I must address two issues in order to repair this: first, I must find more effective valves, and then I must separate the water system so that I can control the water direction” (Conversation between the research and pre-service teacher from G8 group, Facebook Messenger, 9/5/2016 20:43)

After re-engineering the model, Group 8 brought the model into the classroom for teaching and learning about blood circulation (Figure 5).

![Image of pre-service teachers with the model](image2.png)

**Figure 5.** Pre-service teachers prepared their final, re-engineered version of a Functional Heart Model

Even after the final version of model had been used, the need for reconstruction remained. On July 27-29, 2016, all pre-service teachers attended the annual STEM Festival 2016. Many of their artifacts were still works in progress. The Maker concepts focused on how the projects gradually developed.
and progressed during the process. This represents one of the characteristics of Maker which also rely on the conceptual framework of Growth Mindsets.

3.5. Maker concepts does not depend on gender

The data showed no difference in term of quality of makings between males and females. The high-quality groups, G4, G5 and G8 (presented in Figure 2) were composed of 8 females and only one male. There was all female (G4 and G8, 6 females in total) in the best group voted by their peers. There were 2 females and 1 male in G8. Data gathering from the interviews during final report presentations, all members shared certain characteristics in common. All have strong academic backgrounds in biology for G4 (Mobile-Lens) and G8 (the Functional Heart Model). Members of G5 (Holographic Display of Molecular Structure Learning) had a strong chemistry background. However, a strong academic background is only one factor for success. Much depends on how pre-service teachers develop a Maker Mindset, especially, Growth Mindsets.

4. Discussion

The findings showed that pre-service teachers from group 6 to 8 could adopt maker Concepts. The rest were in the beginning steps of Maker Concepts which posed some Maker Mindsets. This confirmed the existing research which shows much promise for Maker movements arising from STEM education. Maker Mindsets appeared to be the most important factor for pre-service teachers developing their understandings and practices of STEM education. Starting from selecting their own topics through to presenting their Makings to the public at the STEM festival, the pre-service teachers who reflected STEM concepts and practices also reflected Maker Mindsets. They had clear topics and concepts at the very beginning of the course. Further, they loved their topic (G4-G8). They developed multiple versions of their Makings (G4, G6, G8). Learning progression [6] was also crucial for developing Maker concepts and STEM Education. With integrating Maker Concepts into course activities, gender showed no effects on the quality of work. Female pre-service teachers were equal to males (G3 G5 G6), or even better if judged by the tenets of Maker Mindsets (G4 G8).

5. Conclusion

Maker concepts that use science, technology and mathematics, together with the design process, further the understanding of core STEM subjects. The results of this study support maker concepts as an important role in STEM education as described by Peppler and Bender [13] and Martin [11]. Key components of the maker mindset need to be addressed and integrated into learning activities of science education, in particular in preparing science teachers. Pre-service teachers must be able to choose their own topics of study. They need to have opportunities to explore the real context in classrooms. Further research topics include how to effectively encourage Maker Mindsets in pre-service science education programs, and the long term implications of the Maker Movement or Maker concept for STEM teachers and the advancement of scientific understandings in students. For recommendation, STEM teacher preparation can be readily implemented within the existing course structures of science education for pre-service teachers by, for example, the implementation of Independent Study courses. It is strongly urged that teacher preparation programs give consideration to the many advantages of the maker movement for science education.
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