MATHEMATICS TEACHERS’ CLASSROOM INSTRUCTION AFTER
PARTICIPATING IN A STEM EDUCATION WORKSHOP IN THAILAND

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by

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ABSTRACT

Literature on teacher professional development has focused on teacher learning as the processes of change in classroom practice, student learning outcomes and teachers’ beliefs and attitudes. In bridging the two literature strands of teacher professional development and teacher change, this study was proposed to examine Thai mathematics teachers’ classroom instruction after participating in a 3-day STEM education workshop in Thailand. In this study, I investigated multiple aspects of STEM education that the teachers integrated in their classrooms and extent to which teachers were able to implement what they gained from the workshop. I conducted four case studies of teachers after they attended the workshop. Using the data from classroom observations, teachers’ interviews, classroom artifacts, and teacher self-reflection reports, I employed a phenomenological analysis approach to analyze each case of teacher’s experience with STEM implementation and look across the cases for the commonalities and differences. The findings from the study revealed that the four teachers exercised classroom instructions differently. Implementation approaches varied from project-based-learning, game-based-activities, independent learning and whole class discussions. Variations were due to teacher beliefs and interpretations of STEM teaching, student context, teacher experience, and time availability related to existing mathematics content curriculum and unexpected school events. All teachers I observed had positive attitudes towards STEM implementation and developed future plans to further integrate STEM skills in their classrooms. On-going STEM education workshops, guidelines and resources should be
provided. Establishment of a professional learning community is needed to encourage teacher academic collaboration in the four STEM disciplines.

**Keywords:** STEM implementation, STEM education workshop, inquiry-based-learning, project-based-learning, game-based-activity, independent learning
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Chapter 1
Introduction, Rationale, and Framework for the Study

Introduction

Teaching-professional communities worldwide have typically encouraged their members to acquire and integrate academic knowledge into subject-matter content using innovative pedagogical practices expected in twenty-first century classrooms. For instance, STEM (Science, Technology, Engineering, and Mathematics) integration is one teaching approach that nowadays schools tend to encourage teachers to apply in the classrooms (Capraro et al., 2016; Dean et al., 2010; English, 2016; Johnson, Peters-Burton, & Moore, 2015; Koellner et al., 2007; Nadelson et al., 2013, Spuck & Jenkins, 2014). Indeed, given the prevailing belief that effective teachers are instrumental in enhancing student development and learning, today’s teachers are expected to be knowledgeable about and skillful in both academic content and pedagogy. Consequently, professional development (PD) educators have attempted to offer a variety of PD programs through which teachers are able to develop the knowledge and skills required to make effective changes in classroom practices (Capraro et al., 2016; Guskey, 1986, 2002; Liljedahl, 2010; Pang, 2012). PD researchers investigate teachers’ learning through the process of change in classroom practices in order to effectively design PD programs to meet teachers’ needs and interests. Their study of teachers’ learning has led to a broadening in the scope of PD programs (Arbaugh, 2003; Arbaugh, Lanin, Jones, & Baker, 2010; Fennema & Carpenter, 1991; Harris, Stevens, & Higgins 2011; Rogers et
al., 2007; Zehetmeier & Krainer, 2011). Today, PD programs link to every domain of educational activities and management in schools, and especially to the role of teachers and their proficiencies as well as the organizational support the teachers receive.

To achieve the ultimate goal of an educational system that maximizes students’ learning achievement, teachers need to be professionally well-prepared in both content-matter and pedagogical learning. Thus, PD programs must be designed to support teachers’ professional growth, to encourage teachers to become involved in school activities, and to promote teachers’ adoption of leadership roles such as in school policymaking and curriculum development and assessment (Costa & Garmston, 2002; Darling-Hammond, Bransford, & LePage, 2005; Glickman, Gordon, & Ross-Gordon, 2014; Loucks-Horsley et al. 2010; Rice, 2003). In addition, it is crucial that PD programs are aligned with national goals regarding education, curricula, and the needs of teachers, students, and stakeholders (Gaible & Burns, 2005; Loucks-Horsley et al. 2010). Of course, it is difficult to assess the effectiveness of PD programs due to the factors that influence teacher professional development, such as cultural and contextual elements. Ultimately, however, effective PD programs should facilitate a better understanding by teachers of how to make classroom improvements. Effective PD programs should also guide teachers in constructing innovative learning and classroom activities (Gaible & Burns, 2005; Loucks-Horsley et al. 2010; Rogers et al., 2007; Zehetmeier & Krainer, 2011). If a program does this, its teachers will be able to efficiently differentiate among the classroom lessons, activities, and tasks that matter most for their students’ conceptual development with regard to differences in abilities and learning experiences.
As a global connection of professionals, PD educators design the PD programs to serve not only national purposes, but also to be applied on the international level. As a result, well-designed PD programs can be modified to benefit teachers and learners in appropriate cultures and contexts of implementation (Avalos, 2011; Gaible & Burns, 2005; Glickman, Gordon, & Ross-Gordon, 2014). STEM education in development of twenty-first century skills is one example of how worldwide PD educators attempt to design the PD programs to improve proficiencies of the teachers and related educational staffs. The mainstream of STEM education has driven all nations to adjust instructional practices through all educational levels, K-12 level in particular (Capraro et al., 2016; English, 2016; Johnson et al., 2015; Livingston, 2014; Nadelson et al., 2013). In Thailand, PD educators, especially in the STEM fields led by the Institute for the Promotion of Teaching Science and Technology (IPST) respond to the needs of the nation to prepare its young people with essential abilities and skills for the 21st century. PD educators from the IPST provide a variety of STEM education PD programs to prepare teachers for multidisciplinary teaching in schools since STEM education has only recently been introduced in Thailand.

Given the variety of Thai social and cultural perspectives, the effectiveness of teachers’ practices and students’ learning experiences can be very complex to explain or directly compare using only a single criterion. Indeed, some confounding variables including curriculum, societal expectations, parental involvement, socioeconomic status, and cultural differences may influence school management and teachers’ classroom practices (Bianco & Slaughter, 2016; Hallinger & Kantamara, 2000; Kainzbauer & Hunt, 2016; Senajuk, Sakorn, Sriwapee, & Trisupakitti, 2016). Additionally, international
competition may affect the levels of Thai educational accountability and limit academic and economic comparison on an international scale. The degree of international influence felt encourages Thailand to adopt better educational models in response to its own embedded cultural contexts (Senajuk et al., 2016; Siripatrachai, 2013).

**Study Purpose** The purpose of this study was to examine Thai mathematics teachers’ classroom instruction. The study examines the knowledge and skills teachers integrated into their classrooms after participating in a STEM education workshop in Thailand. The study also investigates the extent to which teachers were able to implement what they learned during the STEM education workshop.

**Background and Study Rationale**

Over a decade since the first education reform (1999-2008) was set out in Thailand’s strategic teacher developmental plans, in-service teachers have been provided academic workshops and trained in the areas of content knowledge and pedagogical practices. However, the outcomes of past efforts from the first education reform suggest that the quality of teachers’ practices, and the students’ academic achievement in science and mathematics in particular, have not been at a satisfactory level (Office of the Education Council [OEC], 2009, 2010). An overall national assessment conducted by the Office for National Education Standards and Quality Assessment (ONESQA) indicates that basic educational institutions face shortages of quality teachers. These results explicitly reflect the urgent crisis in Thai education, and in particular, the need for high-caliber professional development programs — in order to improve teacher quality. Thailand’s Ministry of Education (MOE) has been searching for appropriate solutions for promoting a nationwide *quality-based education standard* through the development of
teachers’ pedagogical practices. As a consequence, a revised professional development framework for a new generation of Thai teachers has been one of the highlights of the nation’s second decade of education reform (2009-2018) (OEC, 2009, 2010).

At the same time, the movement of integrated STEM education and Framework of 21st Century Learning from the United States (Dean et al., 2010; Johnson et al., 2015) influenced countries around the world to shift their educational paradigm moving toward global academic change. It has drawn the interest of PD educators and researchers all over the world to investigate how to implement STEM in their own countries. In Thailand, STEM education was introduced in 2013 as a new learning innovation (Mullis & Martin, 2013). Although STEM education was first known superficially as an integration of four subjects in classroom instructions, it now increases awareness of Thai educators with its emphasis on developing necessary skills for the 21st century (Boonruang, 2015; National STEM Education Center [NSEC], 2014; Siripatrachai, 2013; Senajuk et al., 2016).

Recently, Thailand’s Minister of Education (MOE), Downpong Ratanasuwan, established STEM education as an urgent policy in the country’s strategic educational plans. The Minister stipulated the goal and timeline in an action scheme in which STEM education must be implemented in every school nationwide within five years (2016-2021). By the end of year 2016, the Ministry of Education in cooperation with seven Thai public agencies expected to initiate STEM education in 2,495 schools nationwide. The Minister officially pronounced the STEM implementation road map to these seven agencies and stakeholders (e.g., school directors and teachers). The Minister also reported that STEM curriculum, STEM activities student workbooks, and STEM teacher
handbooks for Grades 1-12 have been in progress. Concurrently, all of them have been publicly posted online (http://www.stemedthailand.org, The Ministry of Education [MOE], 2016).

The Institute for the Promotion of Teaching Science and Technology (IPST) is one of the aforementioned agencies and it is an autonomous entity with budget support and policy direction from the MOE. The IPST attempts to increase the effectiveness of learning methods and develop training programs with an emphasis on enhancing teaching and learning skills for teachers and learners. Now, the IPST extends its responsibilities for the development of basic education curriculum, methodology, standard assessment and evaluation as well as policy advisory on science, mathematics and technology. Training of mathematics and science teachers to enhance students’ performance and increase their talents in STEM is another important responsibility of IPST. In short, the IPST plays a major role to elevate national science, mathematics, and technology education and design the curricula implemented from elementary to high schools. The IPST also works as the National Teacher Professional Development (TPD) unit to share knowledge and practices to STEM teachers. The major responsibility of the IPST is to provide teaching support for mathematics and science teachers rather than to evaluate their practices (http://www.ipst.ac.th). With the commitment of implementing STEM education nationwide, the IPST established a national STEM center and network of 13 regional STEM centers hosted by schools. The STEM centers in collaboration with university partnerships provide opportunities for teachers in the four academic disciplines to acquire knowledge and skills through STEM education workshops (Boonruang, 2015; NSEC, 2014; Mullis & Martin, 2013).
Because of my research interest in the area of teacher professional development and effective teaching in mathematics, I decided to conduct this study. Evidence shows Thai teachers have received a number of PD programs, but nevertheless monitoring the effectiveness of teachers’ classroom implementations has rarely been studied or reported. As a consequence, it has been difficult to determine if the provided PD programs corresponded to the needs of the teachers or what obstacles to implementing the gained knowledge and skills in the actual classrooms might exist.

Generally, PD programs aim at enabling teachers to make effective changes in their practices. These instructional changes are designed to improve student learning. Once the teachers see positive improvements in student learning, they are better able to change their beliefs and attitudes. The change in teacher’s beliefs and attitudes refers to the change in the nature of subject, teaching and learning, and the role of teachers (Guskey, 1986, 2002; Warfield, Wood, & Lehman, 2005). The effective change in classroom practices, student learning outcomes, and teacher’s beliefs and attitudes is the ultimate goal of teacher professional development for teacher and student learning. As previously mentioned, this study focused on mathematics teachers’ classroom implementation after participating in a STEM education workshop and in doing so addresses the following main research question:

**Research Question:** What aspects of a STEM education workshop in Thailand do mathematics teachers integrate into their classroom after participation?

According to Avalos (2011), learning and change in teachers is very complex and is influenced by macro-conditions and social cultures. Macro-conditions refer to conditions such as the nature and operation of educational systems, policy environments
and reforms, teachers’ working conditions, and historic factors that affect professional development, while social cultures reflect the ethos, traditions, and beliefs of the schools and its society. Consequently, specific practical and behavioral changes made by teachers as the result of participating in PD programs can improve student learning (Loucks-Horsley & Matsumoto, 1999). For this reason, PD educators have sought to design PD programs that elevate the competency and effectiveness of teachers. Nevertheless, the lessons learned during teacher professional development remain challenging to implement. Teachers must apply innovative practices in the classroom and bring about changes in their beliefs and attitudes to improve student learning. PD educators have conducted research on teachers’ classroom experiences in order to elicit in-depth information on effective PD programs (Capraro et al., 2016; Franke, Carpenter, Levi, & Fennema, 2001; Liljedahl, 2010; Nadelson et al., 2013; Pang, 2012; Warfield, Wood, & Lehman, 2005). At the end, the results from my study can benefit PD educators to redesign effective PD programs in the future.

**Conceptual Framework**

The conceptual framework of this study consists of three parts. The first part presents an overall picture of the study including a description of STEM education workshop, teacher learning, and classroom implementation. The second part addresses the key components and the characteristics of effective mathematics teaching in the context of Thailand. The final part provides a conceptualization of teacher change in order to examine teacher learning in the classroom.

Professional development intends to impact teachers’ learning which can propel the process of change (Loucks-Horsley & Matsumoto, 1999; Loucks-Horsley et al., 2003, 2010). This statement explains the three central ideas of my study: STEM education workshop, teacher learning, and teacher change. Recognizing the differences in sociocultural contexts, the needs and the characteristics of teachers, and societal and national expectations, STEM education activities in Thailand can be uniquely implemented in response to those factors. For this study, I have developed a conceptual framework (Figure 1-1) that consists of three components: STEM education workshop, teacher learning, and classroom implementation.

Figure 1-1: Conceptual framework of STEM education workshop, teacher learning, and classroom implementation in Thailand.
The three components in Figure 1-1 are circumscribed by the contextual rectangle. This means that each box is affected by those contextual elements. The STEM education workshop component was investigated for its types of activities and models (e.g., project-based-learning [PBL], inquiry-based-learning [IBL]) and characteristics such as content focus, active learning, coherence, duration, and collective participation (Desimone, 2009). The teacher learning component represents increased knowledge and skills as well as teacher change as a result of STEM education workshop participation. The last component, classroom implementation, describes how teachers make changes in their classroom practices.

**Framework Part 2:** Key components and Characteristics of effective mathematics instruction in Thailand

Through the analysis and synthesis of effective teaching characteristics from the literature, I have developed a conceptual framework for this study. In Figure 1-2, I elucidate each element in the framework to examine effective mathematics teaching in Thailand. Since I focus on teachers’ learning development, I consider the teachers the first component of the framework. The framework components are: (1) the teacher component, which includes professional backgrounds, teaching knowledge bases, skills, and attitudes/beliefs; (2) the other supports within/outside school component, which enriches the teachers and positively influences; (3) the mathematics classroom implementation component; and finally, (4) the characteristics of effective mathematics instruction component, which includes evaluations of four different domains: classroom climate, teacher preparation, teaching and learning process, and teacher and student learning.
Figure 1-2: Key components and characteristics of effective secondary mathematics instruction in Thailand.
**Framework Part 3:** Teacher change in STEM classroom implementation in Thailand

I have used Guskey’s (1986, 2002) idea of teacher change to create a conceptual framework (Figure 1-3). This framework suggests that the way to examine change in the Thai teachers who participated in a STEM education workshop is by observing the process of change in the teachers’ classroom practices, as well as in their beliefs and attitudes.

![Diagram](image)

**Figure 1-3:** Teacher change in classroom implementation in Thailand.

Figure 1-3 describes the teachers’ process of change after participating in a STEM education workshop. The first step is to identify STEM education workshop components that address: (1) project-based-activity or (2) inquiry-based-activity. The instructors assigned the teachers to engage in the group projects. The teachers had to investigate and solve the authentic challenging problems. These two programs emphasize the teachers’ understanding of students’ mathematical thinking and problem-solving skills through hands-on activities and questions in real-life situations.

The next step is to examine teacher change in classroom practices. This examination involves three sub-components: teaching preparation, teaching strategy/approach, and classroom discourse/climate. The characteristics of effective
mathematics instruction, as mentioned in Framework: Part 2 (Figure 1-2), are used to evaluate this change. Teaching preparation includes lesson plans, classroom materials, tasks, hands-on activities, formative and summative assessment, and evaluation forms. Teaching strategy/approach and classroom discourse/climate are observed during teachers’ daily lessons. The mathematics classroom discourse to which I refer has been defined by Lloyd (2005) as “the ways that teachers and students interact during classroom activities and the ways that mathematics is represented and developed through those interactions” (p. 442).

The third step is to report on the change in students’ learning outcomes. Guskey has stated (2002) that “learning outcomes include whatever kinds of evidence teachers use to judge the effectiveness of their teaching” (p. 384). Therefore, the change in students’ learning outcomes are evaluated based on teachers’ reports and reflections. The evaluation may be based on cognitive achievement, as reflected in test scores from all kinds of academic assessments, or on students’ behavioral and attitudinal changes, such as changes in learning motivation, level of learning satisfaction, and classroom involvement, among others.

The last step, teacher change in beliefs and attitudes component, comprises beliefs about the nature of mathematics, mathematics learning, mathematics teaching, and the role of the teacher. This last component is investigated by having teachers participate in a self-reflection and interview process.

Chapter Conclusion

This study provides an analysis of teachers’ classroom implementation after attending a STEM education workshop in Thailand. The change of teachers in learning
and the impact of a STEM education workshop on teachers’ classroom instruction are investigated. The investigation takes into account the school’s cultural and contextual components as well as adopted curriculum and policies from the national agency. Three frameworks are applied in this study: the characteristics of STEM education workshop, the characteristics of effective mathematics teaching, and the process of teacher change.
Chapter 2

Literature Review

In order to introduce this study of teachers’ classroom implementation after participating in an STEM education workshop in Thailand, I present a brief review of the literature in four sections. First, I review how previous researchers have considered mathematics professional development (PD) programs for empowering teacher learning. Then, I describe effective mathematics instruction and its characteristics based on this literature. As teacher learning is the process of teacher change, the third section addresses the study of teacher change as a result of PD based on the literature in mathematics education. The last section focuses on STEM education and its impacts.

Effective Mathematics Professional Development (PD)

Teacher professional development (TPD) research has shifted its focus from the national level to the local level, or individual schools, as a result of educational reform. PD educators’ main responsibility is to prepare quality teachers to meet national needs. To create PD programs, research on how to design sustainable and effective programs for promoting teachers’ professional growth must first be conducted. The main purpose of this TPD research is to identify beliefs about teachers’ learning development through the provided PD programs as a means of improving student learning. The features and definitions of effective PD programs, however, may be variously defined. In order to understand these differences, I present this section regarding PD literature in two parts. I begin with the distinctive PD conceptual frameworks that have been developed by
different scholars and PD educators. Then, I highlight the mathematics PD research on teachers’ perspectives and their aspects of learning from the PD programs.

**Distinctive PD Conceptual Frameworks**

Loucks-Horsley and Matsumoto (1999) have reviewed prior research in order to provide a foundation for understanding the rationales and pathways of TPD. They apply the model created by Guskey and Sparks (1996), that of a school’s “sphere of influence” (Figure 2-1), to capture the aspects of effective PD initiatives. The applied model (Figure 2-1) represents the relationship among the *quality of PD, teacher learning, and student learning*. The quality of PD consists of four key elements: *content, process, strategies and structure*, and *context*. Clearly, quality PD programs must assist teachers in creating lesson plans, organizing subject-matter content, and applying strategies that support student learning.

**Figure 2-1**: The relationship among the quality of PD, teacher learning, and student learning (Loucks-Horsley & Matsumoto, 1999, p. 260).
Teacher learning as the first outcome, with student learning as the end-product of quality PD. Professional growth opportunities provide new knowledge and teaching skills that ultimate create teacher learning, or changes in beliefs. This outcome is illustrated by changes in classroom practices. Teachers’ adoption of leadership roles in fields such as curriculum implementation has also been recognized as an outcome of teacher learning. Eventually, scholars believe, teacher learning will lead to improved student learning. In order for this to occur, however, important stakeholders such as school administrators, school districts, states, and national leaders need to show support of this change (Loucks-Horsley & Matsumoto, 1999).

PD design guided by intentional framework. Together with Stiles, Mundry, Love, and Hewson (2003, 2010), Loucks-Horsley and Matsumoto have provided a book of PD guidelines entitled Designing Professional Development for Teachers of Science and Mathematics. There, the authors stress that “professional development was not about importing models or following formulas. It was a process of thoughtful, conscious decision making” designed to facilitate teachers’ and students’ learning success (Loucks-Horsley et al., 2003, p. 3). The authors indicate that current PD programs should be more purposeful in and attentive to improving student learning. In the field of mathematics, PD programs emphasize content knowledge and pedagogical content knowledge.

Additionally, Loucks-Horsley et al. (2003) have encouraged PD educators to strengthen the bridge between theory and practice in order to design effective PD programs for teachers. Three strategies they introduce are lesson study, the alignment and selection of the curriculum, and demonstration lessons. Instead of directly implementing the provided strategies, however, PD educators should make critical decisions about
which strategies are most appropriate, given the critical social and cultural contexts in which they work. The following frameworks (Figure 2-2 and Figure 2-3) represent the five stages of decision-making for PD educators in science and mathematics, as suggested by Loucks-Horsley et al. in 2003 and 2010, respectively.

**Figure 2-2:** PD design framework in science and mathematics (Loucks-Horsley et al., 2003, p. 4).

The 2003 framework comprises six main design-process input boxes: committing to a vision and standards, analyzing student learning data, setting goals, planning, doing, and evaluating. Each stage has consequences for the later stages. The “bubble” elements are significant factors in the specific stages of PD planning. For example, “knowledge and beliefs” are important from the first stage of “committing to a vision and standards” through the end of the “evaluation” stage. The following five knowledge bases facilitate PD educators’ understanding of their work: learners and learning, teachers and teaching, the nature of the disciplines of subject matter, the principles of effective professional development, and the change process. The beliefs that correspond to each of these five
distinct knowledge bases may shape the perceptions and actions of all stakeholders when committing to visions of PD programs. Context is used as a determinant for “analyzing student learning data”. Contextual factors include students’ characteristics, various sets of standards, student performances, the needs of teachers and students in teaching and learning, information about the curriculum, instruction and assessment, the organizational culture, structure and leadership, policies, available resources, PD histories, and parents and the community. Critical issues come into play at the beginning of “setting goals”. Common challenges facing PD educators include finding time for PD, ensuring equity and diversity, building a professional culture, developing leadership, building capacity for sustainability, scaling up, and garnering public support. Strategies need to be considered during the planning stage. Skillful PD educators prefer to guide multiple teachers’ learning strategies in accordance with contexts and purposes in the PD plan. Next is the implementation of the PD design that fuels the above components, or the “doing” stage. The implementation process logically happens over time. Finally, PD educators evaluate the effectiveness of the program. The “evaluating” stage allows PD educators to reflect on their PD design by referring to each “bubble” element that has influenced the establishment of their PD programs.

Seven years later, Loucks-Horsley et al. (2010) introduced a third edition of this book with some changes. Critically, the strategies element was added to “doing” stage in the design framework (see Figure 2-3).

In adding the strategies element to the “planning” and “doing” stages, the framework aims to better support teachers in classroom PD implementation. The most important stage is the transitional phase from “planning” stage into “doing” stage.
Figure 2-3: PD design framework in science and mathematics (Loucks-Horsley et al., 2010, p. 18).

From Figure 2-3, PD educators need to pay close attention to those moments in which teachers struggle to implement new instructional approaches in their classrooms. During implementation, classroom visits should be regularly scheduled to provide teachers with instructional and emotional support. Given this meaningful support, teachers are more likely to commit to changes in their teaching practices and eventually experience changes in their beliefs and attitudes. Finally, PD educators must be able to monitor and evaluate PD implementation. These evaluation results may be used to revise the PD programs and all input elements as well.

PD’s main purpose is developing teacher learning. One of the four goals of teacher professional development is the goal of teacher learning (Loucks-Horsley et al., 2003, 2010), specifically in content knowledge and pedagogical content knowledge in the teachers’ given disciplines. For this reason, Desimone (2011) has recommended that PD educators design PD programs emphasizing teacher learning rather than teacher satisfaction, attitudinal change, or commitment to innovation (p. 68). There are a variety
of formal and informal teacher learning opportunities that teachers may participate in to increase their knowledge and skills, as well as the breadth of their teaching experience. For example, taking special courses or attending PD activities such as workshops, seminars, and conferences helps teachers to build their professional networks. Collaborating with colleagues, coaches, and mentors on lesson plans or student work, as well as completing self-reflections and observations in their own classrooms, are also powerful learning experiences. Furthermore, involvement in school improvement plans such as designing the curriculum and professional programs or planning school assessment and evaluation may empower teachers in the role of leadership (Desimone, 2009, 2011). Desimone (2009) has proposed the basic model shown in Figure 2-4 for studying teachers’ professional development as gained through PD programs. The model represents an interactive, non-recursive relationship among the core features of PD, classroom practices, and student outcomes (p. 184).

**Figure 2-4:** Core conceptual framework for studying the effects of PD on teachers and students (Desimone, 2009, p. 185).

The model highlights the core features of PD activities resulting in teacher learning rather than the types of PD activities. The core features are derived from
Desimone’s earlier empirical study using a nationally representative sample of teachers. The core features, which appear in five forms—content focus, active learning, coherence, duration, and collective participation—may be used to assess the effectiveness of PD. According to Desimone’s model (Figure 2-4), effective PD focuses on subject-matter content and how students learn that content. Coherence is defined as the alignment of all PD activities with teachers’ knowledge and beliefs and schools’ and districts’ policies. In terms of duration, PD activities should take place progressively over a semester, with at least 20 hours of contact time. The last core feature is building up an interactive learning community, which can be accomplished via the collective participation in professional activities of teachers working in the same grade, level, and subject (Desimone, 2009, 2011).

In addition to conceptualizing these five core features of effective PD, Desimone has described her model as a core theory of action for PD in four steps:

1. Teachers experience effective professional development.
2. The professional development increases teachers’ knowledge and skills and/or changes their attitudes and beliefs.
3. Teachers use their knowledge and skills, attitudes, and beliefs to improve the content of their instruction or their approach to pedagogy, or both.
4. The instructional changes foster increased student learning (Desimone, 2009, p. 184).

These four steps can be used to evaluate the effectiveness of PD activities in terms of teacher learning, teacher change in practices, and student achievement. The change in these three outcomes can be examined through well-constructed and well-administered tools such as observations, interviews, and surveys (Desimone, 2009, 2011). Notably, this model shares with the previous models the basic elements of the PD process (e.g.,
Guskey, 1986, 2002; Loucks-Horsley & Matsumoto, 1999). It has also been adapted by Telese (2012), who has studied the impact of PD on teacher and student learning.

**PD Research on Teachers’ Perspectives and Their Aspects of Learning, and PD Models**

Some PD researchers (e.g., Arbaugh, 2003; Arbaugh, Lanin, Jones, & Baker, 2010; Rogers et al., 2007; Zehetmeier & Krainer, 2011) have investigated teachers’ perspectives on the Mathematics PD programs in which they participate. They have then used the results to assess the quality of the PD programs and establish the characteristics of effective mathematics PD programs. Other researchers have focused on the design of mathematics teacher development programs for enhancing teacher learning (e.g., Frank, Carpenter, Levi, & Fennema, 2001; Fennema & Carpenter, 1991; Harris, Stevens, & Higgins; 2011; Koellner et al., 2007).

**Teachers’ perspectives and their aspects of learning from the PD programs**

Arbaugh (2003) has examined the value teachers place on their participation in ongoing study groups and the influence of the groups’ organizational aspects on teachers’ continued participation. A school-based study group was designed to explore teacher learning and the value of this type of training program. As defined by Arbaugh, a study group is “a group of educators who came together on a regular basis to support each other as they work collaboratively to both develop professionally and to change their practice” (p. 141). Seven mathematics teachers working in high-school geometry classrooms participated in Arbaugh’s study group from October 1999 through March 2000. During this time, the teachers were cognitively engaged in a variety of activities, including some drawn from the Mathematical Tasks Framework.
Arbaugh applied a set of coding schemes taken from Birchak et al.’s (1998) work on teachers’ study groups to analyze and interpret the data. These coding schemes included: *building community and relationships, making connections across theory and practice, supporting curriculum reform, and developing a sense of professionalism.* The first finding corresponding to the *building community and relationships* scheme suggested that the teachers highly valued the study group as a way in which to professionally interact with and discuss teaching practices and challenges with their colleagues. Teachers likewise expressed that by working on mathematical tasks and reading research articles as part of study-group activities, they acquired a knowledge base for making connections between their beliefs and practices. These teachers’ responses were in accordance with the author’s belief in mathematical engagement. Arbaugh believed that engaging teachers in mathematical tasks from the Mathematical Tasks Framework (Stein et al., 2000, as cited in Arbaugh, 2003) would encourage teachers’ thinking and decision-making regarding their own instruction. Importantly, this study group was able to help teachers by building their capabilities using well-fit task selections so that the teachers could then implement a student-centered and inquiry-based classroom. The teachers could also work collaboratively and gain deep curriculum knowledge from research pertaining to geometry curriculum reform. Finally, teachers appreciated that the study group allowed them to act as the learners (Costa & Garmston, 2002; Franke, Carpenter, Levi, & Fennema, 2001; Rogers et al., 2007) and be engaged in the learning process through reflection on their own practices and the opportunity to learn from others. Eventually, the teachers were able to develop a sense of professionalism from engaging in the study group. The teachers confirmed that the study group gave them
self-confidence because they received praise from other participants when sharing successful teaching practices.

The teacher study group would be a successful model for on-going training if there were organizational support for the teachers’ efforts. The teachers shared their thoughts on four aspects of the study group’s organization, drawing the following conclusions. The release time from “full plate” work was very important to the teachers to be able to achieve professional development. As teachers were already tasked with a lot of extra responsibilities related to school matters, it was decided that it would be better not to include any requirements outside of the study group time. The teachers recognized that the frequency and length of the study group meetings should also be taken into consideration. They also believed that the number of study group members should be limited to between 4 to 10, with respect to the diversity of experiences, ideas, and individual contributions.

Arbaugh subsequently designed another training program called *The Textbook-Specific PD Project* with her research team, Lanin, Jones, and Barker (2010). This training program examined the impact of a PD project on eighth- to twelfth-grade secondary mathematics teachers’ knowledge and their views of student learning and instructional practices. The PD project was implemented using the *Problems-Based Math* textbook series. It included both summer workshops and academic-year study groups. The teachers said that the PD project made them more knowledgeable, helping them to articulate the contents within and across all four different textbooks in the series. In addition, this textbook-specific PD had an impact on the teachers’ beliefs and attitudes. Some teachers started implementing the problem-based approach from the PD project in
their classrooms. The teachers likewise viewed the PD project as a catalyst (p. 99) for shifting their instructional practices and classroom assessment, strategies, and organization to be more student-centered. Lastly, the teachers came to view student learning differently when they implemented the new Problems-Based Math approach. The teachers were more patient and conscientious in their thinking regarding students’ ways of learning, thinking, and working. Ultimately, Arbaugh et al. (2010) were able to use this report on teachers’ perspectives to assess the effectiveness of textbook-specific PD and establish guidelines for designing and improving new PD projects to better serve the needs of teachers.

Like Arbaugh, Rogers et al. (2007) conducted research on teachers’ perspectives regarding effective PD programs in science and mathematics. Yet this study included the PD facilitators’ perspectives as well in order to compare both of these groups’ perspectives to the characteristics of effective PD and the PD standards addressed by other researchers and in policy documents. The findings from both the PD facilitators and the teachers are displayed in Table 2-1.

Comparing both groups’ perspectives on the effectiveness of PD to other research findings, policy documents and standards, the authors found that the PD facilitators and the teachers did not mention (a) challenging teachers’ beliefs and knowledge of a subject area through transformative learning (Thompson & Zeuli, 1999); (b) encouraging teachers to serve in school leadership roles in order to help sustain improvement resulting from PD experiences (Loucks-Horsley et al., 2003); or (c) using changes in student learning as a means of determining learning priorities and measuring the effectiveness of PD projects (Guskey, 2003; Loucks-Horsley et al., 2003).
Table 2-1: Views of effective PD, as expressed by teachers and PD facilitators (Rogers et al., 2007).

<table>
<thead>
<tr>
<th>Teachers’ Views</th>
<th>PD Facilitators’ Views</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Classroom applicability</strong>: having practical applications, meeting teachers’ curriculum needs; providing supporting materials and resources</td>
<td><strong>1. Classroom application</strong>: having a direct application to the classroom; providing ready-to-use instructional ideas and ready-made materials and resources</td>
</tr>
<tr>
<td><strong>2. Teacher opportunity</strong> in the aspect of teacher as learner: experiencing activities and learning concepts similarly to their students</td>
<td><strong>2. Teacher as learner</strong>: achieving effective PD depends on teachers’ level of participation as both students and professionals</td>
</tr>
<tr>
<td><strong>3. Teacher networking</strong> as a colleague-based support system during and after the PD session</td>
<td><strong>3. Collegial relationship with teachers</strong>: building trust starts when the PD program starts</td>
</tr>
<tr>
<td></td>
<td><strong>4. Teacher knowledge</strong>: improving both teachers’ content knowledge and pedagogical knowledge</td>
</tr>
</tbody>
</table>

The aforementioned three omissions appear to have later become the focus of Zehetmeier and Krainer (2011)’s study on assessing Austria’s Innovation Makes Schools Top (IMST) project, which was conducted from 2000 to 2002 and whose data was reexamined in 2005 and 2010. The purpose of this study was to analyze the sustainability impact of the IMST project eight years after its termination. The sustainability of a PD program was measured by the researchers as “the capability of individuals and institutions to (a) react autonomously [to] changing conditions and (b) create and use processes and products to meet these conditions” (p. 879), even though the program no longer existed.
Their study focused on one secondary mathematics teacher, Andy, during two specific years: 2005 and 2010. The two-year analysis was based on Andy’s self-reports and interviews and suggested that his pedagogical content knowledge and innovations stemmed in large part from the knowledge-exchange that had taken place among teachers during the IMST project. However, lacking long-term networking with other teachers after the project had ended, Andy stopped developing his knowledge. The IMST project sustainably enhanced his self-esteem regarding teaching. Rather than engaging in “trial and error” teaching, Andy confidently designed new practices and implemented them in the classroom. He also applied a student-centered approach and gave students autonomy to reflect on his teaching. He showed how he had used questionnaires, surveys, and video analyses to analyze the data collected from his students’ reflections. He compared his students’ feedback to other sources such as video clips in order to assess and improve the quality of his own innovations. Additionally, Andy established a leadership role for himself in the school by initiating a system of mutual feedback among his experienced colleagues, in the process becoming a role model for novice teachers. Regarding the “Three C’s—content, community, and context” as influencing factors, the findings suggested that students’ reactions, personal and mutual benefits gained from the use of innovative practices, PD facilitators as “critical friends,” and school-based and administrative support all fostered the sustainability of PD. Nonetheless, the lack of community-building and networking after the completion of the PD program and the decrease of collegial engagement as time went by hindered the sustainability of PD.

**Mathematics PD models for teacher learning development.** A subset of mathematics PD educators have sought to develop effective training programs to
implement in classrooms. This section discusses programs that emphasize mathematical content and pedagogy (e.g., the Problem-Solving Cycle [PSC]), as well as programs that focus on students’ learning and thinking as the main factors for improving teacher learning (e.g., Cognitively Guided Instruction [CGI]).

The Problem-Solving Cycle (PSC) Model. Koellner et al. (2007) designed this training model with the aim of enhancing teachers’ mathematical content knowledge (CK) and pedagogical content knowledge (PCK) around rich mathematical tasks using three workshops (Figure 2-5). The three workshops were interconnected and emphasized the use of artifacts in the teachers’ daily work. The researchers believed through these workshops, the teachers would then be able to improve their instructional practices. The research team focused on the constructivist learning theory (learners construct their own understanding, p. 274) and situative theories (learning [is the change] in participation in socially organized activity, p. 278) to conceptualize the central three principles of the PSC model. These three principles are: fostering active teacher participation in the learning process, using teachers’ own classrooms as a powerful context for their learning, and enhancing teacher learning by creating a supportive professional community (p. 278).

Figure 2-5: The PSC model of professional development (Koellner et al., 2007, p. 279).
During the first workshop, teachers tended to focus on content knowledge by solving “PSC problems” in order to prepare lesson plans for teaching. The teachers had to analyze and reflect upon video clips from this first workshop focusing on their role as teachers in the second workshop. This second workshop was designed to help teachers to develop pedagogical knowledge. The final workshop focused on the analysis of student thinking from video clips, as well as students’ written work on PSC problems. The research team set the goals, activities, and knowledge objectives for each workshop; these served as brief guidelines for PSC implementation. The concepts of “knowledge of mathematics for teaching” (Ball, Thames, & Phelps, 2005, as cited in Koellner et al., 2007) were addressed during each workshop.

Throughout the three PSC workshops, the teachers delved into issues of content, pedagogy, and student thinking. They were able to enhance their common knowledge (e.g., skills, procedures, and concepts) and specialized content knowledge (e.g., connection among various mathematics topics, strands, and strategies) as a result of the first workshop. In the second workshop, the processes of planning, analyzing, and reflecting gave the teachers both content and pedagogical knowledge. Finally, the third workshop helped the teachers develop knowledge of content and students. The PSC model also provided teachers with shared ideas, reflective practices, and meaningful feedback. Eventually, the PSC model encouraged the teachers to build up a supportive professional community.

West Texas Middle School Math Partnership (WTMSMP). Similar to the PSC model, the training model developed by Harris, Stevens, and Higgins (2011) focuses on acquiring a deep conceptual understanding of mathematics. WTMSMP was designed for
middle-school mathematics teachers in Texas. The model comprises three intensive mathematics courses taught in two-week summer sessions at four institutions of higher education. The researchers constructed a conceptual framework by juxtaposing Shulman’s (1987) *pedagogical content knowledge* (PCK) with Ball, Thames, and Phelps’s (2008, as cited in Harris et al., 2011) *mathematical knowledge for teaching* (MKT). The key to MKT is *specialized content knowledge* (SCK) on a theoretical and conceptual basis. SCK prizes *promoting knowledge and critical skills such as detecting and correcting misconceptions and helping students’ problem-solving via several approaches corresponding to the middle-school mathematics curriculum*. For this reason, the researchers viewed MKT as appropriate to use in developing their training model’s courses.

After a two-year (2009 and 2010) implementation in Course 1: Integers and Fractions and Course 2: Size in Theory and Practice, the researchers examined the influence of the training model on mathematical content knowledge (MCK) and mathematics knowledge of teaching (MKT). The results showed that there were two moderate correlations: between MCK and MKT, and between MCK and the teachers’ self-reported mathematical backgrounds. Yet there was no significant correlation between MCK and the teachers’ numbers of years teaching. The MKT results revealed that the teachers who took mathematics courses beyond college algebra scored higher than their counterparts who had not. In short, the teachers improved their mathematical knowledge of teaching and conceptual understanding by participating in the training.

**Cognitively Guided Instruction (CGI).** Fennema and Carpenter (1991) introduced CGI in order to integrate the cognitive and instructional sciences into the
study of teachers’ pedagogical content knowledge (p. 8). They rationalized that the teachers’ decisions regarding classroom instruction hinged on the effects of students’ learning as revealed in the students’ cognition. Therefore, they saw CGI as an approach to help teachers reach instructional decisions based on their assessments of students’ cognitive abilities. CGI relied on teachers’ knowledge of content and pedagogy, and the ability to analyze and assess students’ mathematical thinking. The ultimate goal was for teachers to make effective changes in their instructional practices while involving students in the process of that change. The following examples show how the researchers implemented the CGI approach.

The research team led by Carpenter (as cited in Carpenter & Fennema, 1992) first implemented the CGI approach in an experimental study. The purpose of the study was to determine whether providing teachers with research-based knowledge about students’ thinking could affect positive change in the teachers’ knowledge and beliefs and subsequently be translated into changes in classroom practices and student achievement. Forty first-grade teachers participated in this one-year experimental study. The teachers were randomly assigned to the experimental or control group. A four-week summer workshop was provided for the experimental-group teachers. The researchers provided common content knowledge, strategies for problem solving, and other basic knowledge of mathematics for teaching. During the rest of the workshop, teachers actively engaged in discussions using guided questions. The discussions addressed how to utilize the knowledge acquired during the teachers’ assessments of students’ thinking in order to plan instructional practices. In addition, the teachers were assigned to analyze and synthesize research papers and videotapes about students’ word-problem problem-
solving practices. Then the teachers discussed how these findings could be applied to their own classroom practices. After the workshop, researchers observed the teachers in their classrooms. The results showed that the teachers who received CGI training taught problem solving more effectively than the teachers in the control group. Both groups presented various problem-solving strategies to the students. The CGI teachers thought that instructions should be built upon students’ existing knowledge. The CGI teachers also devoted more time to questions and to listening to students’ explanations, and they did not limit students to only one solution per problem, as did the control-group teachers. Furthermore, the students of the CGI teachers were more likely to recall number facts faster than students of the teachers in control group. In sum, there were significant correlations between CGI teachers’ knowledge and beliefs and students’ problem-solving performances ($r = .52$ and $r = .54$, respectively) (Carpenter & Fennema, 1992).

Another research study on CGI training by Frank, Carpenter, Levi, and Fennema proposed the use of CGI to capture teacher change after PD participation (see Section 3 for further details about teacher change). The researchers believed that once teachers valued and understood students’ thinking, they would be able to draw on their daily work to ground their learning regarding how to teach effectively. Therefore, an effective training model of PD would lead to sustainable or long-term change in teachers’ behaviors, beliefs, and attitudes. Ultimately, teachers would become ongoing-learners capable of creating classroom practices that were responsive to individual students’ needs and interests.
Effective Mathematics Teaching

This section describes the characteristics of effective teaching in mathematics, as outlined in the research literature, other scholarly documents, and policy recommendations. I begin with definitions and characteristics of effective teaching, both in general and in mathematics. Then, I present the key factors for achieving effectiveness in teaching. Other factors for promoting effectiveness in mathematics teaching are addressed at the end of this section.

Definitions and Characteristics of Effective Teaching

Teaching has historically been understood as the process or activity by which one promotes analysis, thinking, and problem solving rather than the mere accumulation of information (P.S. Wilson, Cooney & Stinson, 2005). More recently, Shulman (1987) has emphasized that teaching is “a learned profession” (p. 9) that must “begin with a teacher’s understanding of what is to be learned and how it is to be taught” (p. 7). Teaching is a pedagogical process comprising comprehension and reasoning, transformation, and reflection (p. 13). Shulman has coined the term pedagogical content knowledge (PCK) to represent a teacher’s knowledge base for teaching. PCK has since been viewed as one of the characteristics of teaching effectiveness.

Definition of effective teaching. The definition of effective teaching has been debated among educators across the various subjects. Effective teaching previously referred to how teachers optimally organized and delivered content knowledge using various kinds of activities; this reflected a teacher-centered orientation. In a teacher-centered orientation, the higher number of drills and activities employed is considered to be related to better teaching (P.S. Wilson et al., 2005). Over the last decade, however, the
phrase *good teaching* has shifted to *effective teaching*, and with it has come a shift in focus from this teacher-centered orientation to a focus on teacher-student relationships and the effects of classroom instruction on students (Borich, 2008). Today, *teaching effectiveness* is measured in order to determine how effectively students are learning (Smith, Hofer, Gillepse, Solomon, & Rowe, 2006).

In the late 1990s, teacher quality became recognized as the key element influencing teaching effectiveness (Rice, 2003), as well as the key predictor of student achievement (Rice, 2003; Wenglinsky, 2000, as cited in Smith et al., 2006). No Child Left Behind (NCLB), for example, attempted to forge a link between teacher quality and student outcomes. The designation of “highly qualified” was assigned to teachers based on teachers’ coursework competencies in content knowledge and pedagogy, years of teaching experience, certifications, and performances on standardized assessments (Porter-Magee, 2004; Rice, 2003). However, Porter-Magee (2004) has argued that students’ academic outcomes reflect teachers’ teaching effectiveness in the classroom, not factors in the teachers’ personal and professional histories.

In the area of mathematics, P.S. Wilson et al. (2005) have made an argument about good teaching stemming from M.R. Wilson and Goldenberg’s (1998) work with a middle-school mathematics teacher. P.S. Wilson et al. assert: “[Good mathematics teaching] involves a student-centered instructional style in which mathematics is treated conceptually” (p. 87). Meanwhile, good mathematics teaching as described by Schifter (1998) is “[t]he kind of teaching in which teachers reflect on what students know and consequently see mathematics in terms of students’ constructions of mathematical ideas” (as cited in P.S. Wilson et al. 2005, p. 87). From these definitions, it is possible to
conclude that: *good mathematics teaching is the method of teachers using a student-centered approach in order to reflect the mathematical thinking and understanding of both teachers and students*. That means the effectiveness of mathematics teaching should emphasize both teacher and student learning.

**Characteristics of effective teaching.** Borich (2004, 2008) has identified a set of five key pedagogical behaviors —*lesson clarity, instructional variety, teacher task orientation, engagement in the learning process, and student success rate*— characterizing effective teaching. *Lesson clarity* refers to whether teachers are able to clearly explain lesson objectives, as well as prepare students to connect new lessons with prior knowledge, concepts, and tasks with respect to the students’ degrees of understanding. Teachers should employ a variety of lesson tools and teaching methods, including exercises, illustrations, and demonstrations. They should also review each day’s lesson at the day’s end. *Instructional variety* considers whether teachers are able to present lessons and engage students in meaningful discussions and classroom interactions. Teachers should use various teaching strategies and means, including appropriate learning materials and resources like hands-on activities, technological aids, and different types of questions. The use of positive reinforcement, as well as teachers’ willingness and enthusiasm, as expressed through eye contact, voice, and gestures, are other psychological supports of effective teaching. *Teacher task orientation* asks whether teachers are able to allot appropriate time for classroom tasks including lesson planning, introductions, teaching and discussion, and assessment, while *engagement in the learning process* refers to the amount of time that students are actively engaged in learning (engagement rate) or performing a task. As a means of encouraging students’
involvement, effective teachers should clarify the desired behaviors for each task that students are expected to achieve. Teachers must also provide time for questions and answers, use individual or group assignments when needed, and positively reinforce those students who participate. In addition, teachers should monitor students’ seatwork and check their progress closely. Finally, *student success rate* considers that at the end of the teaching cycle, teachers need to check and evaluate students’ understanding, as well as the completeness and correctness of the students’ exercises, tests, and assignments. All of these items can be assessed as demonstrating high, moderate, and low levels of success by using the learning objectives and the criteria of assessment established at the beginning of the lesson. Later, teachers are able to use these results to reflect upon and improve their teaching practices (Borich, 2004, 2008).

These five key pedagogical behaviors identified by Borich may differ slightly in the specific knowledge and skills they emphasize according to the disciplines in which they are applied. The next section explains the characteristics of effective mathematics teaching through the lens of teachers, students, researchers, and scholars across periods of time, cultures and countries.

**The Characteristics of Effective Mathematics Teaching Through the Lens of Teachers, Researchers, and Scholars**

**The eight Mathematics Teaching Practices.** The National Council of Teachers of Mathematics (NCTM) (2014) launched *Principles to Actions* as a directional and structural guidance for excellent mathematics programs. This set of principles consists of six Guiding Principles for school mathematics: teaching and learning, access and equity, curriculum, tools and technology, assessment, and professionalism. Teaching and
learning is the heart of the Guiding Principles, whereas the others are the Essential Elements to support effective mathematics instruction. Teaching and learning, the first Guiding Principle, requires skillful teachers with deep mathematics understanding and a clear view of student learning.

The eight Mathematics Teaching Practices are teaching skills derived from research-based learning principles that teachers are expected to have in mathematics lessons. The eight Mathematics Teaching Practices for effective teaching of mathematics are described for teachers to—(1) establish mathematical goals to focus learning, (2) implement tasks that promote reasoning and problem solving, (3) use and connect mathematical representations, (4) facilitate meaningful mathematical discourse, (5) pose purposeful questions, (6) build procedural fluency from conceptual understanding, (7) support productive struggle in learning mathematics, and (8) elicit and use evidence of student thinking.

The aforementioned Essential Elements are also required in support of effective teaching for all students. Namely, all students have the opportunity to learn and equitable access to support and resources such as a high-quality curriculum, effective teaching and learning experiences, and adequate time. A robust mathematics curriculum is needed and integrated with other subjects through the context of everyday life problems to gain more student engagement in task investigation. Appropriate use of mathematical tools and technology also helps teachers and students in effective teaching and meaningful learning. A variety of effective assessments such as formative and summative assessments as well as student feedback provides significant evidence to reflect the learning goals and mathematics instruction. Personal and collective professional growth
is the last and most crucial element in which teachers must be supported from the professional learning community in order to collaboratively work with colleagues for strengthening their practices and student learning (NCTM, 2014).

**The five strands of mathematical proficiency.** The Mathematics Learning Study Committee of the National Research Council (NRC) (2001) introduced five strands of mathematical proficiency (Figure 2-6) that are to be used in order to identify effective teaching in mathematics. The corresponding report entitled “Adding It Up” demonstrates that teaching for mathematical proficiency is associated with effectiveness in mathematics teaching and learning. This effectiveness depends on the enactment of teaching as it takes place among these the three elements of mathematical content, teachers, and students in the school context.

**Figure 2-6:** Five strands of mathematical proficiency (NRC & the Mathematics Learning Study Committee, 2001, p. 5).

The five components of mathematical proficiency—*conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive*
disposition—are interwoven, and they are used as a means for teachers to help students achieve various objectives in mathematics learning. Conceptual understanding is the state in which students are able to comprehend mathematical concepts and ideas, operations, and relations in order to avoid errors in problem solving. Being able to variously represent and differentiate among mathematical situations is an indicator of this strand. Procedural fluency, on the other hand, is the state in which students are able to apply acquired knowledge and skills to perform mathematical procedures flexibly, accurately, efficiently, and appropriately. Strategic competence is the state in which students are able to formulate appropriate strategies for solving mathematical problems. They then clearly represent the problems by constructing the problem models with their key features; these models may utilize pictorials, visual symbols, equations, or the mental math. The students then perform computations to problem-solve. Adaptive reasoning is students’ ability to logically think, reflect, explain, and justify the mathematical concepts related to various situations. Both deductive and inductive reasoning are essential elements of adaptive reasoning, but the latter one is used more often to display the ability to reason from patterns, analogies, and metaphors. Students better develop their reasoning abilities when they have sufficient knowledge bases, interesting tasks, and familiar and comfortable contexts. Finally, productive disposition refers to students’ tendency to highly value mathematics for its usefulness. Once students have developed positive attitudes towards mathematics and believe that they are effective doers, they are able to consistently improve their performance along the other four strands.

There has been widespread agreement among researchers to use the five strands of mathematical proficiency as students’ learning goals (e.g., Pang, 2009). However,
Hiebert (2013) has argued that each strand can be interpreted in various ways by different teachers; thus, it might be overly general for teachers to directly use all five strands to improve teaching. In my point of view, teaching mathematics for effectiveness needs to integrate these five components of mathematical proficiency as students’ learning goals. Although such an implementation requires specific skills and teaching strategies, I believe that well-established PD programs can help teachers to empower students to achieve these learning goals.

**Characteristics of effective mathematics teaching from research reviews.**

Reynold and Muijs (1999) have reviewed research on the knowledge bases of effective teaching using three different sources: American academic research, British academic research, and British practitioner studies. The six characteristics of effective teaching discovered in the American studies were: *the high opportunity to learn*, which is related to the length of the school day and year, the breadth of the curriculum, the hours of mathematics instruction, and the use of homework and time-on-task; *an academic orientation from the teacher*, which refers to the time teachers spend on student learning using curriculum-based activities or teachers’ task oriented in supportive environment; *effective classroom management*, or the classroom climate in which teachers carefully organize academic activities, use positive language and reinforcement, and encourage desired classroom behaviors that aid in students’ classroom engagement; *the high teacher expectations of students*, or how teachers use positive expressions and expectations to indicate trust in students’ capabilities, and encourage students to work hard; *a high proportion of whole-class teaching*, or conducting whole-class teaching, rather than relying on an individual focus, and acting lively during
presentations, using examples, reciting, and applying lessons; and *heavily interactive teaching that involves students in classroom attitudes*, or asking questions that are of different levels of difficulty in order to engage students in the classroom discussions with the purpose of checking their understanding and providing feedback.

The characteristics of teaching effectiveness as described in British academic research were similar to those found in American academic research but were given in either a “process-product” model or an “active teaching” model (p. 274). The process-product model is used to study the relationship between teacher behaviors (what teachers do in their classroom) and student achievement (Hill, Rowan & Ball, 2005, p. 373). Importantly, British research emphasizes teaching for the whole-class, instead of letting children work on their own without any guided practice, as a maximized gain. In the three 1995-1997 reports from the Office for Standards in Education (OfSTED), the authors reported good practices in mathematics from professional teachers and educators who had significant experience in mathematics teaching. They cited an emphasis on transitioning between different activities and recalling existing knowledge and skills to add to new ones via careful questioning and paying attention when misconceptions occurred as additional characteristics of effective teaching. The authors also recommended using individual and group work after whole-class work in order to reinforce and extend students’ understanding. Lastly, the lesson should be concluded with a whole-class summary and discussion (Reynold & Muijs, 1999).

**Effective mathematics teaching from teachers’ perspectives.** P.S. Wilson et al. (2005) have examined the compatibility of notions of good mathematics teaching from the perspective of teachers and teacher educators. The two overarching research questions
were what good mathematics teaching constitutes and how its necessary skills can be
developed. The researchers identified four characteristics of good mathematics teaching
from the teachers’ perspectives. First and foremost, *good teaching requires prerequisite
knowledge*. Teachers should have both mathematics knowledge and knowledge of
learners in order to teach for understanding. Pedagogical strategies and teachers’
confidence in their mathematical knowledge are also required. In addition, *good teaching
promotes mathematical understanding*. To enable students to understand and apply
mathematical principles, teachers need to empower students with the skills necessary for
different types of mathematical learning: procedural, conceptual, and real-life relevance.
The following are four recommendations for teachers to enhance student understanding:
connecting and transitioning from one mathematical topic to another and from theory to
application; visualizing mathematics via technological aids and other visual
presentations; assessing understanding using frequent, quick questions during lessons;
and refraining from using a telling-approach by instead using several activities and
technological supports that avoid rote memorization. The teachers also believed that *good
teaching engages and motivates students*. Teachers need to use a variety of approaches to
engage students in the learning process. These approaches may include using technology,
having students write mathematical expressions and word-problem solutions, having
students do group work and hands-on activities, and allowing students to move around
the classroom. Students are more engaged if teachers place individuals needs ahead of a
specific approach. Lastly, *good teaching requires effective management*. Teachers need
classroom management skills, including the teaching flexibility to keep lessons moving
and keep students well-behaved until the end of class.
Yet P.S. Wilson et al. (2005) noticed some conflicts between the beliefs about and the actual practices of teaching. Even though teachers agreed upon and valued a student-centered approach, they continued to use a teacher-centered orientation in their own classrooms. While the NCTM (1980, 2014) and teacher educators have promoted student-centeredness as a goal for classroom implementation, actual circumstances may make its implementation difficult. Student-centered and process-oriented approaches are strongly valued as high-quality teaching and learning methods among Western educators. In the East, on the other hand, notions of good teaching have both important similarities and differences from notions of good teaching in the West. In fact, “context specificity,” which includes beliefs, social values and norms, philosophical backgrounds, cultures and traditions, school contexts, and differentiated professional supports, has a significant impact on teaching practices, making them more complex (Bryan et al., 2007; Kaur, 2009; Pang, 2009; Reynold & Muijs, 1999; Wong, 2007). Recognizing the importance of taking different cultural contexts into consideration when discussing teacher effectiveness, Pang (2009) identified the characteristics of Asian mathematics classrooms as teacher-dominated, content-oriented, examination-driven, and featuring whole-class teaching, large class sizes, and minimal student involvement, all of which the author considers poor and unfriendly practices (p. 349). In these classrooms, the students were subject to “passive transmission” and “rote drilling” as methods of learning (Biggs, 1991, 1994; Morris, 1985, as cited in Lim, 2007). Lim (2007) has suggested that these classroom conditions would not be conducive to effective mathematics learning in the eyes of most Western educators. Yet there is empirical evidence to suggest that these methods are successful: students from South Korea, Singapore, China, Hong Kong SAR,
and Japan scored in the top-five rank on the Trend in International Mathematics and Science Study (TIMSS 2011), the assessment of student achievement (National Center for Education Statistics [NCES], 2011), surpassing students from the West. The TIMSS results have raised doubts among scholars and researchers about what constitutes high-quality teaching and learning. This is the reason why educators have subsequently paid more attention to the study of Asian mathematics classrooms.

**Effective mathematics teaching through the lens of the East.** Pang (2009) conducted one-year case study of a sixth-grade Korean teacher. The two aspects of learning environment and actual learning were used to assess the way the teacher implemented instruction in her classroom. She employed Korean cultural context to bear upon the assessment of good elementary mathematics instruction amid diversities and cultural differences. The key characteristics of good mathematics instruction considered as effective teaching in the Korean context were: *lesson flow and detailed guidance,* *reconstruction of textbook,* *discourse focused on mathematical thinking,* *mathematical concepts based on students’ activity,* and *emphasis on important contents among multiple solution methods.* The key points of good mathematics teaching based on the general “Korean Vision” were: *emphasis on mathematical contents,* *consideration of students’ knowledge and ability,* *reflection on multiple solution methods and connections,* *good textbooks and teacher’s construction,* and *teacher’s commitment to good instruction.*

Bryan, Wang, Perry, Wong, and Cai (2007) conducted a cross-cultural study of effective mathematics teaching. They considered similarities and differences in perceptions of effective mathematics teaching among groups of teachers from four regions: Australia, mainland China, Hong Kong SAR, and the United States. The teachers
characterized good mathematics lessons as those that featured: *active engagement of students, group activities/in-class student collaboration, coherence, flexibility of teaching fits individual students’ needs, and cultivating students’ interests.* The American teachers agreed that using hands-on activities and concrete examples would lead to student engagement and interaction. Although Chinese teachers agreed that this physical engagement would serve the purpose of student understanding, given time and class size constraints, the Chinese teachers instead sought to demonstrate activities for the whole class. The teachers from Australia and Hong Kong viewed verbal involvement and vocalized classroom interactions as indicators of student participation and understanding. Group activities and in-class collaboration were strongly preferred by the American teachers as components of effective lessons compared to the teachers from the other countries. In terms of knowledge content, the teachers from mainland China and Hong Kong heavily emphasized the importance of well-structured lessons. Australian teachers mentioned the need for clear lesson objectives, while American teachers made no comments on this topic. Flexibility in terms of focusing on individual needs and stages of student development were characteristics that not only the American and Australian teachers desired, but also the Chinese teachers—with some attention to the constraints of large class sizes and the breadth of the curriculum. Lastly, all teachers agreed that cultivating students’ interest was another indicator of effective learning. Teachers should encourage students to think by asking good questions and engaging students in interesting activities.

Wong (2007), one of the authors of the aforementioned study, went on to explore with twelve experienced elementary mathematics teachers in Hong Kong what constitutes
good mathematics lessons. The teachers’ responses indicated that having a clear set of mathematics objectives was necessary for teachers perform well. Students’ demonstration of understanding the lesson contents and their new knowledge gains provided empirical evidence to evaluate teaching performances. Students’ participation, level of subject-matter interest, and academic success also were considered indicators of good teaching. Furthermore, stimulating students’ thinking with challenging questions that required the use of basic to higher order thinking skills was considered another criterion of good teaching. Using well-designed drills and exercises was indispensable to facilitating students’ understanding of and fluency in calculations. However, the quality and quantity of drills should be determined according to their purpose as well as students’ interest (Bryan et al., 2007; Wong, 2007). Using questions connected to real-life situations prompts students to link mathematical principles to their daily experiences, thereby helping them to later establish abstract concepts from concrete examples. This finding is in accord with the results of Bryan et al. (2007), which indicate that the teaching of abstract thinking from real-life problems is more heavily emphasized in Eastern regions such as Hong Kong SAR and mainland China than in Australia and the United States (Bryan, et al., 2007). Teaching abstract thinking serves a means of helping students move from rote memorization to actual understanding, the former of which is less likely to be seen as good mathematics teaching in the eyes of the American teachers and educators (Lim, 2007). In fact, the process of rote memorization was primarily valued among teachers from mainland China as a means of instilling in students the knowledge converted from understanding as the end results. Australian teachers viewed it as the recall of pertinent information but not the transitional step to understanding (Bryan, et al.,
2007). Interestingly, classroom management was less of a concern among teachers from Australia, mainland China, and Hong Kong SAR, than among American teachers (Bryan et al., 2007). An analysis of longitudinal survey data by Opdenakker and Van Damme (2006) in the context of the Belgian secondary education system reveals that good classroom management skills can enhance classroom mathematics practices.

In order to teach effectively, teachers need to have well-prepared lessons, each with a clear set of objectives; have multiple skills and strategies for teaching and questioning; and be able to manage classrooms efficiently in terms of time, teaching pace, and student discipline. Moreover, teachers should understand students’ individual differences with respect to needs, learning abilities, and inclinations. This knowledge will help teachers to design effective mathematics lessons and learning activities and to cultivate students’ interest (Wong, 2007). These findings have given me several perspectives on effective mathematics instruction through the lens of Hong Kong teachers working in the Confucian Heritage Culture (CHC) classrooms. The CHC classrooms can be viewed as teacher-centered, as the teacher is dominant; however, there is more active student engagement, and the environment is more likely to be learning-centered.

Kaur (2009), a mathematics educator from Singapore’s National Institute of Education (NIE), has examined the characteristics of good mathematics teaching in Singaporean secondary mathematics by juxtaposing two different perspectives. First, teacher perspectives were accounted for by examining the instructional approaches of three competent teachers. Second, the perspectives of eighth-graders regarding the desired characteristics of good mathematics teaching were determined from their
responses to the three teachers’ lessons. Kaur analyzed 30 sequenced lessons by coding video data. With an emphasis on instructional practices and patterns, Kaur found that the sequences of instructional practices that the teachers approached similarly in their classrooms were whole-class demonstration [D], student seatwork [S], and the review of student work and feedback [R]. Within a lesson, there were several activity segments during which each teacher specified different instructional objectives. There were a number of instructional cycles counted by assigned mathematical tasks with the same instructional objectives (repetition). As a result of this repetition, the most frequent pattern seen was D, S, and R, with SR often recurrent. Significantly, when a teacher moved from one sequential instructional cycle to another, the new mathematical knowledge of the students was incrementally improved. Ultimately, the characteristics of good teaching as perceived by 59 focused students with respect to three teachers’ instructional segments were as follows:

(1) Whole-class demonstration (exposition).
Teacher:
- explained clearly the concepts and procedural steps;
- made complex knowledge able to be easily assimilated through demonstrations, use of manipulatives, and real-life examples; and
- introduced new knowledge.

(2) Seatwork/out of class assignment.
Teacher:
- gave clear instructions related to mathematical activities for in-class and after-class work;
- provided interesting activities for students to work on individually or in small groups; and
- provided sufficient practice tasks for preparation towards examinations.

(3) Review and feedback.
Teacher:
- reviewed past knowledge; and
- used student work/group presentations to give feedback to individuals or the whole class (Kaur, 2009, p. 346).
In sum, teaching in Singapore was likely to be teacher-centered, and the classroom discourse focused on students’ work. Singaporean teachers attempted to correct students’ misconceptions using the students’ erroneous work, subsequently helping the students to build new conceptual knowledge with more advanced exercises. Kaur’s findings are in line with those of other researchers who have found that the Eastern classroom methods of mathematics teaching are teacher-centered but focus on students’ active learning. Due to the influence of Confucianism in Thailand, I have drawn on the views of Eastern scholars to conceptualize a conceptual framework of effective teaching for examining Thai teachers’ mathematics classrooms.

Key Factors for Achieving Effectiveness in Mathematics Teaching

There are several factors that help teachers to teach effectively. These include the teachers’ educational backgrounds, including the number of courses in both content and pedagogy taken in college; teacher attributes; teaching experience; teaching styles and skills; and opportunities for professional growth, among other factors. They can be categorized as follows:

The teacher-related factor. The teacher is the school-related factor that most affects student achievement. In other words, teacher quality is a powerful predictor of student performance (Rice, 2003, p. 2). An expert in U.S. educational policy, Rice (2003) analyzed three decades of literature to examine the relationship between teacher attributes and teacher effectiveness with the aim of making a policy recommendation for teacher-quality investment. She used five specific characteristics of teachers—teacher experience, preparation program and degree, certification, coursework, and test score—as indicators of teacher quality. Her analysis showed that: (1) teacher experience
measured by the number of years worked in service had more sustained effects on high-school student achievement; (2) although there was little evidence to support the impact of teacher-preparation programs and degree on teacher effectiveness, teachers who obtained advanced degrees in mathematics had positive effects on student achievement; (3) teachers who possessed subject-specific certification had positive effects only on high-school mathematics; (4) specific coursework in both pedagogy and content significantly affected student outcomes at all grade levels, but content emphasis had more impact at the secondary level; and (5) teachers’ basic-skill performances on the National Teacher Examination and other state-mandated tests contributed to student outcomes (Rice, 2003).

Rice’s study offered guidance for federal policymakers who sought to efficiently invest in the process of teacher production. Notably, Rice’s determinants of teacher quality were limited to *measurable teacher characteristics*. Indeed, there are other factors that either enhance or constrain teachers’ effectiveness on student achievement. Opdenakker and Van Damme (2006) have provided reassurance that teacher characteristics including behavioral, educational, and pedagogical variables, as well as job satisfaction, classroom management, and teaching styles also positively affect the effectiveness of mathematics classroom practices.

The study of P.S. Wilson et al. (2005) also highlights the teacher-related impact on student learning. Their study identifies key elements that help teachers to develop their effectiveness in mathematics teaching. Four categories were suggested by a group of nine experienced secondary mathematics teachers: *experience*, or the valuing of all of one’s own past teaching experiences and collegial relationships in order to improve
pedagogical content knowledge (PCK), with PCK being the special knowledge representing teachers’ understanding (Shulman, 1987); *education*, or the knowledge gains made possible by advanced mathematics courses in college and that will help teachers effectively practice; *personal reading and reflection*, or the process of teacher inquiry and reflection in service of improvement, as well as teachers’ engagement in professional growth opportunities such as conferences or other PD activities; and *working with colleagues*, or eagerly learning from colleagues through collaboratively working on, sharing, and discussing classroom practices. Classroom observation with feedback also assists teachers in improving their own practices. It is obvious that a Professional Learning Community (PLC) can sustainably empower teachers’ capabilities for effective teaching in the long-term (DuFour, 1998, 2004). In short, I agree with P.S. Wilson et al. (2005) that these four elements are important for teachers to achieve the goal of teaching for mathematical understanding. However, I disagree with those teachers who emphasized that learning from experience and colleagues were better ways of promoting good teaching than other ways.

The study of mathematics classroom practices has become a national expectation pertaining to the effectiveness of education as a whole. Regarding the aforementioned subject-matter and national education policy relevance, mathematics educators tend to produce knowledgeable and skilled teacher-learners. In short, the study of teacher-related factors helps guide teacher-educators in the design of courses for enhancing pre-service teachers’ readiness, while ongoing PD programs serve to strengthen the skills of in-service teachers.
The development of the problem-solving skills-related factor. Another perspective on teaching mathematics for effectiveness suggests that it is crucial not only to teach basic knowledge but also to encourage students to develop skills of higher order thinking and problem solving. In the United States, An Agenda for Action (1980) inaugurated the problem-solving movement in mathematics education, as led by NCTM. The Agenda included a number of substantial changes in mathematics textbooks and materials, curricula, teaching approaches, as well as the professional teachers (NCTM, 1980). It was published alongside the creation of Curriculum and Evaluation Standards for School Mathematics by NCTM. The Standards emphasized the following important goals of instruction: problem solving, reasoning, making mathematical connections, and communicating with mathematics (Schoenfeld, 2007).

Problem-solving approaches can be interpreted in several ways. According to NCTM, practitioners should help students gain experience in applying mathematics and recognizing its applications to other disciplines. Moreover, the Agenda emphasized the use of emerging technologies in mathematical problem solving (NCTM, 1980). In order to ensure that teachers were prepared to integrate these technologies into their classes, the NCTM called for more stringent teacher training and recommended that all mathematics teachers complete college-level courses in modeling, problem solving, and computer technology. The development of problem-solving approaches applied not only to elementary and secondary education, but also to higher education.

Since the 1980s, problem solving has been a focus of K-12 mathematics. Mathematical researchers and teachers have been developing pedagogical practices to enhance students’ problem-solving skills. Attempts to identify instructional strategies that
effectively teach higher-order thinking skills have been continuous. NCTM led the shift from rule-of-thumb problem-solving approaches to more specific methods in the 1980s. Beginning at that time, teachers were encouraged to teach mathematics by using real-life problems and concrete experiences, as well abstract mathematical concepts generalized from concrete mathematics (Bryan et al., 2007; Wong, 2007). Once the students had come to understand different abstract mathematical concepts, teachers were to help the students integrate all these concepts into a systematical knowledge base (Bryan et al., 2007, p. 331). However, the degree of abstract learning was to be grounded in a recognition of students’ characteristics and capabilities, as well as the nature of the mathematics topics. Teachers were to engage students in several problem-solving approaches and activities. C. Pope and R. Pope (1985) have claimed that drills and practice are important because they can lead to mastery of the knowledge necessary for learning additional concepts. Today, teachers can also use technology for these drills and practices. If it is reasonably and effectively used, technology can help to develop students’ mathematical thinking.

Given that problem solving is a transferable skill for the modern workplace (Moss & Tilly, 1996), it remains an integral part of mathematics learning. Yet it requires a significant commitment in the curriculum at every grade level and in every mathematics topic (Cai & Lester, 2010). The emphasis on TIMSS, as an international example, is to assess problem-solving situations in the four content domains of numbers, algebra, geometry, and chance. Specifically, the eighth-grade test emphasizes applying and reasoning skills rather than the knowing domain (Mullis & Martin, 2013). This reflects
the worldwide value placed on problem solving and suggests the importance of teachers integrating it into their mathematics instruction.

**The teaching approach-related factor.** Instructional methods are key to strengthening students’ mathematical proficiency (National Research Council & Mathematics Learning Study Committee, 2001). Hiebert and Morris (2012) have said that mathematics teaching is the method used to interact with students about content. Kuhs and Ball (1986) have suggested that the way to achieve effectiveness in mathematics teaching is to use a learner-focused approach. This approach supports students’ development of problem-solving skills via the selective content that best suits their needs and interests.

Students are the center of classroom activities, and teachers should stimulate them by posing problems, designing experiences, and asking questions to initiate their explorations. In fact, teachers as facilitators must respond to students’ learning by listening, probing, accepting, restating, encouraging, and providing counter-examples. It is important to know how to stimulate students’ curiosity by using materials, tasks, and situations in the classroom (Kuhs & Ball, 1986). However, the use of these tools should fit the students’ abilities so that they can fully engage in class discussions and activities as well as enjoy doing and learning mathematics by themselves.

Another distinct approach is assigning students to work in small groups. This approach can foster the development of students’ collaborative working and reasoning skills. Eventually, students will become active critics, being able to explain and critically evaluate the mathematical thinking among the group (Kuhs & Ball, 1986; Tripathi, 2009). Likewise, Reynold and Muijs (1999) have reported that the co-operative small
group can serve as a powerful means of helping students to acquire vital skills. Students are able to benefit from small-group discussion and knowledge-sharing among peers while teachers monitor the interactions. In order to establish effective co-operative small-group work, teachers must demonstrate good preparation on group tasks and problems as well as sets of criteria. In addition, this approach relies upon teachers’ mathematical knowledge and classroom-specific skills and behaviors such as discussions, representations, and interactions with students’ mathematical thinking (Hill et al., 2005).

Other Factors for Supporting Effective Mathematics Teaching

The definition of good mathematics teaching varies according to different educators’ perspectives. For example, Kaur (2009) has suggested that good teaching needs the right or required qualities (p. 334). It is not only teachers, but also other stakeholders, who contribute to the outcome of effectiveness in mathematics teaching. There are other factors accelerating the process of shaping effective teaching and learning, too. For instance:

Professional supports in teacher growth. The school, a learning community with a need for capable teachers, must work in collaboration with other professional units and higher-education institutions in order to empower teachers for self-directed growth (Costa & Garmston, 2002); this is called “capacity-building” by Hargreaves and Shirley (as cited in Sahlberg, 2011). Professional development programs can build teachers’ knowledge, skills, and disposition. These three elements are the prerequisites for effective teaching and learning in mathematics (Darling-Hammond, Bransford & LePage, 2005; Loucks-Horsley et al., 2010). Overall assessments of a given school and its system help PD developers to design sustainable PD programs for building teachers’ capabilities
Finally, ongoing PD programs must be well-designed in order for teachers to learn new styles of teaching and pedagogies to suit their varied learning environments, schools, and learners.

**The promotion of teachers as researchers.** Effective teachers should not be learning only to teach but also to research. In order to do so, however, teachers need help from a professional support team who can guide them in transforming and interrelating their knowledge-based practices to research-based understanding. Sparks and Loucks-Horsley (1989) have introduced teacher inquiry as one of five models of professional development that can be used to promote the concept of teachers-as-researchers.

According to Sparks and Loucks-Horsley, individuals or a group of teachers should act as researchers in the classroom by following three steps. First, teachers should identify the problems of interest and formulate their research questions. Second, teachers should search for the ways to collect data through multiple sources such as existing research literature. Finally, teachers should analyze and interpret the data to understand the problems or determine innovations that can be implemented. Similarly, Miller and Hunt (1994) have underscored that the action research of a teacher-as-researcher should be considered a professional development activity. In conclusion, involving teachers in classroom action research can help teachers evaluate the effectiveness of their classroom practices through problem-solving processes (Cross, 1987, as cited in Sparks & Loucks-Horsley, 1989; Glickman, 1986). Moreover, teachers-as-researchers can initiate change beyond the classroom at the school level, which may eventually lead to policy-level changes (Smith et al., 2006).
In summary, I strongly recommend that school leaders encourage teachers to become teacher-researchers. Schools should provide accessible research-based resources and sufficient support in convenient forms such as PD facilities, materials, and coaching, mentoring, and supervisory programs. In addition, schools should establish external collaborations with universities, as well as public and private PD institutions and/or organizations where teachers can participate in workshops and training programs. Provided such support, teachers are more likely to conduct research on the best ways to improve their teaching and learning since they know best their classes and what works for their students. Lastly, in order to achieve effectiveness in mathematics instruction, schools and districts need to provide teachers autonomy (Castle & Aichele, 1994) and opportunities to implement innovations in their own classroom practices.

**Process of Teacher Change**

As defined by Guskey, teacher change is the result of effective professional development (PD) programs. Such change can be examined in three forms: change in classroom practices, change in students’ learning outcomes, and change in teachers’ beliefs and attitudes (Guskey, 1986, 2002). Owing to varied perspectives on teacher change and the ineffective implementation of PD programs in the past decades, Guskey has proposed an alternative model (Figure 2-7) by which to examine this change.

![Figure 2-7: A model of teacher change by Guskey (Guskey, 2002, p. 383).](image-url)
Guskey’s alternative model is based on his assumption that PD activities are able to facilitate change. Notably, this model stresses teachers’ learning processes based on their experiences in PD programs. Thus, the three forms of teacher change are sequentially shown as major consequences of implementing innovations in the classroom. Since teachers’ attitudes and beliefs regarding instructional practices are derived from classroom experiences, the change in teachers’ beliefs and attitudes occurs last. Teachers change their beliefs and attitudes when they receive positive evidence showing improvement in students’ learning outcomes.

Below, I present the research literature regarding teacher change that is based on Guskey’s ideas in two parts: change in teachers’ classroom practices and change in teachers’ beliefs and attitudes. The study of change in students’ learning outcomes is also mentioned partly as the transitional phase to the change in teachers’ beliefs and attitudes.

**Change in Teachers’ Classroom Practices**

Guskey’s alternative model of teacher change has been implemented by many researchers who are interested in the study of PD and the process of teacher change. The study of change in teachers’ classroom practices by Pang (2012), for instance, accounts for the process of change in a sixth-grade teacher’s practice. Pang identifies five dimensions—characteristics of classroom instruction, learning objectives, instructional strategies, mathematics discourse, and learning environment—by which to analyze the change in an actual Korean mathematics classroom. The study highlights three types of change in teaching practices: dramatic change, substantial change, and gradual change. *Dramatic change* occurs in the early stage of teacher change. In Pang’s case study, the teacher skillfully used her instructional materials for students’ activities and exploration.
She employed small-group or individual activities in the permissive classroom with mutual respect. Substantial change occurs in the middle stage when the lesson emphasizes mathematical reasoning and communication. In this case, the teacher used open-ended questions, provided timely feedback, and incorporated students’ ideas into the lesson. The final type of change, gradual change, occurs over a longer period of time in terms of instilling an affirmative disposition. The teacher in Pang’s case study often encouraged her students by relating classroom topics to real-life situations. The teacher-centered instruction decreased, and students came to play an increasingly critical role in class discussion. As a result, strategies such as whole-class organization were used less.

In accordance with Pang, Liljedahl (2010) has described the rapid and profound change that occurred in teachers’ mathematics practices after PD participation according to five mechanisms. He applied two research methods: the observation of in-service mathematics teachers in PD activities and the follow-up on the teachers in school settings. He observed 42 elementary, middle-school, and high-school mathematics teachers to find instances of change.

Teacher change in Liljedahl’s study was “overwhelmingly observed to be incremental, gradual, and tentative, stretching out over several meetings and involving encouragement, planning, experimentation, and refinement” (p. 412). Rapid and profound change was defined as a shift in teachers’ beliefs and practices that “stand[s] in stark contrast to this more usual form of change…. without apparent trepidation” (p. 412) towards change-making. An example of this kind of rapid and profound change was when a teacher changed from rarely using group work to regularly using it in the classroom after two consecutive meetings.
According to Liljedahl, the transformation of teaching practices occurs in a sequence of five mechanisms. *Conceptual change* starts with the rejection of misconceptions and continues to the replacement of new theories and conceptual understandings that happens after attending effective PD programs. When teachers find some commonalities of PD programs similar to their classroom practices that benefit their students, there could be *accommodating outliers* such as ideas, information, tasks, and activities that help constitute change in practices. The teachers’ efforts for *reification* are then found in the form of teachers’ artifacts such as lesson plans, learning objectives and goals, designed tasks and activities, and assessment forms. When there is one clearly identifiable belief (*a leading belief change*, p. 419), teachers are likely to change their teaching practices. Finally, the *push-pull rhythm of change* is a phenomenon comprising a series of two, three, or four phases of change (p. 420). The first two phases are called “push change” and the latter two are called “pull change.” During the first phase, teachers attempt to execute class tasks and activities regardless of whether the execution represents the full potential of teaching practices or merely completion. The second phase is about the realization of problems beyond the classroom context, such as the curriculum and standards, societal expectations, and standardized tests. The third phase is the change in teachers’ dispositions to empower students in problem solving and task completion. The last phase is the shift from “teaching to learning,” focusing on individual students.

In summary, Pang (2012) and Liljedahl (2010) have attempted to draw from teachers’ actual experiences to describe teachers’ changes in their classroom practices. Their studies align well with Guskey’s idea of change as a process that occurs gradually over time with PD support. Moreover, both Pang’s and Liljedahl’s studies underscore the
role of PD programs in the sustainable professional growth of teachers and effective change in practices. Yet Franke, Carpenter, Levi, and Fennema (2001) have claimed that making powerful changes in teachers’ classroom practices requires attention to school culture and individual teachers’ conceptions.

Franke et al. (2001) have examined teacher learning with an emphasis on understanding the development of students’ mathematical thinking. They conducted a longitudinal study of change by following elementary teachers over a four-year period of participation in a Cognitively Guided Instruction (CGI) PD program. Three key characteristics of teacher learning were captured: *generativity*, or the ability of teachers to continually add new knowledge and skills that help students to apply and solve new problems; *creating structure*, or teachers’ integration of new and existing knowledge to create new knowledge structures; and *learning as a result of own inquiry*, or teachers’ views of knowledge about teaching and learning as constructed, self-created, and continually changing (p. 656). The findings showed that all teachers who were at a high level of student engagement at the end of PD project also exhibited a high level of engagement at the follow-up stage. The teachers at the high level of engagement considered their students’ thinking as the specific utility driving their changes in classroom practices. The teachers did not just describe the way their students thought mathematically; they also tried to develop their own thinking through several strategies and step-by-step explanations of solutions. Finally, they were able to articulate a deeper understanding of effective mathematics teaching. Furthermore, teachers at the high level structured their own practices based on what their students had learned, thought, or struggled with on the given problems. They acted as the learners who actively engage in
the interactions with students, revised their knowledge, and subsequently adapted their practices. Eventually, the teachers were able to adjust to the idea of change in the classroom as the benefits of this change to students’ learning and thinking gradually accumulated.

However, Franke et al. (2001) have inferred that although many teachers hold similar perspectives regarding student learning, their teaching practices may differ from one another. Moreover, the simple listening and learning opportunities provided to students might not be sufficient to create a generative classroom. To foster generative change, teachers should perceive students’ mathematical thinking as their own to create, adapt, and investigate (p. 683). If they do so, they will be able to frame their own practices by using existing knowledge to generate new knowledge for developing students’ thinking.

**Collegial and organizational support for change in classroom practices.**

Collegial support was a strong relationship for everyday school learning. The school community can promote collegial collaboration both within and across grade levels, and this collaboration allows teachers to share ideas and provide feedback on tasks, students, and mathematics teaching and learning. Receiving collegial support during the first two or three years of experience teaching is very helpful for beginning teachers in planning classroom activities (Franke et al., 2001). Sparks and Loucks-Horsley (1989) have highlighted other key organizational factors affecting teachers’ development and their efforts towards change including: *school/organizational climate, leadership attitudes and behaviors of administrators, district policies and systems*, and both “top-down” and “bottom-up” *participant involvement in schools*. When these supports are in place,
teachers with a high level of student engagement are passionate about positively changing their practices. They are willing to support and share with their colleagues the knowledge of students’ thinking. They can initiate classroom action research and practical inquiry in their learning communities. According to Franke et al. (2001), the collegial collaboration and in/out school supports can strengthen teachers’ learning and professional growth in both the PD and school contexts. Furthermore, the process of teacher learning, or how teachers teach and learn how to teach at the same time, is a powerful strategy for improving student achievement (Sergiovanni & Starratt, 2006, p. 250).

**Change in Teachers’ Beliefs and Attitudes**

There are specific circumstances that help to facilitate change in teachers’ beliefs and practices. For example, autonomous teachers who regularly reflect on their classroom teaching practices are more likely to have positive attitudes towards change. Professional autonomy and self-reflective practices can help teachers exercise good judgment regarding their teaching, which in turn helps to determine the effectiveness of student learning (Castle & Aichele, 1994; Rogers et al., 2007). In a school community in which teachers learning together is the goal, “the degree of change is strongly related to which teachers interact with each other and provide technical help to one another” (Fullan, 1982, as cited in Sparks & Loucks-Horsley, 1989, p. 47; Sergiovanni & Starratt, 2006). In fact, the beliefs of teachers regarding content (e.g., the nature of mathematics) and teaching (e.g., mathematics teaching) can either support or constrain their practices. In addition, schools may strongly encourage teachers’ risk-taking if they believe that the implementation of a new program or practice may enhance student learning in a significant way (Sparks & Loucks-Horsley, 1989, p. 47). Consequentially, the outcomes
of student learning are certain to affect change in teachers’ beliefs and attitudes (Guskey, 1986, 2002).

**Beliefs about mathematics, and teaching and learning mathematics.** Warfield, Wood and Lehman (2005) have investigated the relationship among teachers’ learning to teach, their reflection and communication, and their beliefs in learning with a case study featuring seven beginning elementary teachers who participated in a two-year PD project. The teachers were divided into one group of four and one group of three and were individually videotaped during their mathematics lessons. Teachers’ beliefs were analyzed according to three substantive elements, including the teachers’ beliefs about: *mathematics, learning mathematics, and teaching mathematics.* In terms of beliefs about mathematics, the teachers asserted that mathematics was about problem solving. It was utilitarian, and thus it should be taught. Nonetheless, there were a few concerns about the importance of mathematical proofs to doing mathematics. The teachers noticed that students learned mathematics by moving from concrete to abstract ways of solving problems, as well as connecting the problems to more difficult real-life situations. Their reflections were in line with Eastern scholars’ notions of teaching mathematics through daily problem solving (Wong, 2007; Bryan et al., 2007). Since the teachers expressed their beliefs about teaching differently, in studying their reflections I have come to assume that the teachers believed that teaching refers to the meaningful atmosphere created by teachers for enhancing student thinking, sharing ideas and values, and making classrooms discussions. In addition, teachers have to provide supplemental materials and resources. Teachers have to be skillful in their questioning in order to elicit students’ responses and explanations.
Warfield et al. (2005) have argued that teachers’ beliefs about learning and teaching mathematics may not be consistent with their actual practices because of other differences in teachers’ beliefs, such as their beliefs about students (e.g., learning abilities) and the constraints of change in teaching practices (e.g., the time constraints on classroom discussions, the difficulties of advocating for teaching and school, parental and societal expectations). In a two-group teacher comparison, one group focused on management and procedure and had fewer reflections and concerns regarding students’ thinking and discussions. They did not encourage students to become autonomous learners. The other group, however, listened to students’ ideas regarding new strategies for presentations and discussions. The students seemed to be active autonomous learners, while the teachers were facilitators who justified and reflected upon the students’ reasoning (Warfield et al., 2005).

**Beliefs about teacher and student autonomy.** The conclusion of Warfield et al.’s study suggests that beliefs about teacher and student autonomy are the key factors for promoting change in teaching and learning in mathematics. Therefore, PD facilitators should advocate for teachers to become autonomous. Indeed, autonomous teachers are self-directed learners (Costa & Garmston, 2002) who learn, restructure, and construct their own professional knowledge (Castle & Aichele, 1994). Autonomy makes them confident and able to choose the best approach for shaping their students to be capable of creative thinking and decision-making. Ultimately, autonomous teachers create autonomous learners, which is the goal of teaching.

**Beliefs about constructivism.** Not only is autonomy necessary; so too is constructivism an integral part of teachers’ beliefs. Embedded autonomy and
constructivism in teachers can facilitate sustainable change in both classroom practices and beliefs. Beswick (2007), for instance, has investigated whether the influence of teachers’ beliefs on the secondary mathematics classroom environment is consistent with constructivist principles. Individuals’ beliefs, in Beswick’s study, are the knowledge and experiences reflected in the contextual bound and that vary from context to context. Thus, observations of classroom interactions are helpful for identifying the beliefs that the teachers hold. These beliefs lead to teachers exercising different implementation strategies in their classroom practices. The study was conducted in the Australian state of Tasmania. Beswick applied the following four characteristics of a constructivist environment, as taken from Tayler, Fraser, and Fisher (1993): autonomy (independently thinking and learning); prior knowledge (integrating pre-existing knowledge and experiences into learning activities); negotiation (socially interacting for a negotiated consensus); and student-centereness (personally problematic experience in learning) (as cited in Beswick, 2007). The findings from the one-year study included the impressive cases of two teachers whose belief-survey scores were moderate to high on problem-solving views of mathematics. There were nine beliefs identified by these two experienced teachers.

Beswick (2007) divided these nine beliefs into three aspects: (1) beliefs about the nature of mathematics, or whether teachers perceive mathematics as fun and consisting of connecting ideas and sense-making; if a teacher does, he or she creates an organic, challenging, and sense-making classroom in association with constructivist principles; (2) beliefs about mathematics learning, or whether teachers acknowledge that students’ learning is unpredictable and that all students can learn mathematics (p. 114); these
beliefs ignite the establishment of constructivist classrooms in response to individual differences. Teachers accepted that helping students to learn mathematics effectively is their main responsibility; (3) beliefs about the role of the teacher, or whether teachers act differently based on what they view their professional responsibilities to be. Five beliefs included as part of the professional role of teachers were: maintaining ultimate control of classroom discourse, facilitating and guiding students’ construction of mathematical knowledge, inducting students into widely accepted ways of thinking and communicating in mathematics, serving as the authority with respect to social norms that operate in the classroom, and engaging in ongoing learning (Beswick, 2007, p. 115).

The constructivist classroom environment. Given various school contexts in which they work, teachers may hold different sets of beliefs that lead to differences in their creation of the classroom environment. In essence, teachers should set the goal of teaching and provide students with opportunities to experience mathematics based on their understanding and interests. Teachers have the responsibility to actively engage students as individuals, small groups, and a whole class by using appropriate pedagogical approaches and questions. Teachers are responsible for facilitating students’ mathematical connections and sense-making so that they are capable of constructing mathematical concepts and knowledge. Moreover, teachers should be willing to listen to students’ explanations of their thinking and communications in mathematics (Beswick, 2007). I agree with Beswick that teachers who use the three aforementioned strategies will be able to create a “constructivist classroom.” This classroom environment can take students’ learning to engagement in mathematical thinking, understanding, and problem solving.
**Beliefs in the role of teacher.** Along the line of teacher beliefs, Lloyd (2005) conducted a case study of a pre-service secondary mathematics teacher focusing on the teacher’s beliefs regarding his role as a mathematics teacher during his field experience and student-teaching period. The findings included the pre-service teacher’s beliefs regarding his teacher role before and during his student-teaching period. The pre-service teacher described the role of teacher in relation to classroom mathematics discourse and the nature of mathematics activities. His views of the role of teacher before his student-teaching period were that he was to engage students in discussing and explaining mathematics. He criticized lecturing, or teacher-dominated instruction, for limiting students’ engagement. He believed that the teacher should emphasize classroom communication through open-ended questioning, student journal-writing, cooperative group-work assignments, and the facilitation of student presentations. In addition, teachers should attempt to support students’ work and encourage students’ thinking. Lloyd claimed that good characteristics of a mathematics classroom were the portrayal of student-centered activities; however, the pre-service teacher neglected to recognize that the increase in student exploration and communication resulted in a more dynamic classroom discourse because of the gradual change in each day’s content, tasks, and activities. On the one hand, his role as a teacher during his student-teaching period appeared to be more focused on monitoring and facilitating students’ social interactions through routine mathematical problems. Although he attempted to create a more student-centered classroom, he continued to use traditional mathematics problems from textbooks in determining the curriculum for his class. As a result, his teaching lacked student involvement in mathematical processes such as conjecturing, questioning, and
investigating (p. 456). I agree with Lloyd that using fixed approaches to mathematical subject matter and content may curtail the development of meaningful mathematics discourse. From this study, I infer that beliefs regarding the role of teacher are truly formed when student-teachers begin their field experiences and student-teaching periods. Their beliefs are gradually shaped as they undertake actual practices. Teacher educators and experienced teachers will be able to help pre-service teachers to cope with this change and guide them towards practical adjustments suitable for actual school settings.

**STEM Education and Its Impacts**

I have organized this section into three parts. The first part provides another description of STEM education, STEM professional development, and level of STEM integration. The second part presents research-based reports on how STEM is introduced in school as a new integrative approach for classroom practices. The final part focuses on STEM education and its impact in Thailand.

**STEM Education, STEM Professional Development, and Level of STEM Integration**

STEM (Science, Technology, Engineering, and Mathematics) was initiated in the United States as an effort to improve the quality of mathematics and science education. Later, STEM education was driven as a crucial strategy in preparing young people in science and technology for 21st century workforce competitiveness (Breiner, Harkness, Johnson, & Koehler, 2012; Capraro et al., 2016; Hoachlander, 2014; Wang, Moore, Roehrig, & Park, 2011). The STEM movement emerged from an effort of several top-down stakeholders from federal policy sectors, professional organizations (e.g., National Science Foundation [NSF], National Council of Teachers of Mathematics [NCTM],
Institute for Educational Science [IES]), and higher institutes of education to school-based community (Breiner et al., 2012; Capraro et al., 2016; Koehler, Binns, & Bloom, 2016; Li, 2014; Vasquez, 2015). Particularly, the challenge of K-12 education was driven by the adopted Common Core State Standards in science, mathematics and engineering to be more intensive in STEM integration (Hoachlander, 2014; Koehler et al., 2016) instead of teaching each discipline in silos (Wang et al., 2011) as in the traditional curricular. The USA federal government authorized about $3 billion with an additional $1 billion of private funding in spending of STEM education each year (Li, 2014). As a consequence of the USA’s aggressive STEM movement, the STEM education has become a global educational policy agenda over the past decade.

**What is STEM education.** Views of STEM education vary among educators and researchers as follows: STEM education is viewed “as traditionally defined subject-based education or as an educational undertaking in interconnected STEM fields” (Li, 2014, p. 1). Likewise, Vasquez, Sneider, & Comer (2013) added that “STEM education is an approach to learning that removes the traditional barriers separating the four disciplines and integrates them into real-world, rigorous, relevant learning experiences for students” (p. 4). Additionally, STEM approaches include core concepts and skills being taught separately in each discipline but housed within a common theme (English, 2016, p. 1). Furthermore, integrated STEM was defined by Bryan, Moore, Johnson, and Roehrig (2016) “as the teaching and learning of the content and practices of disciplinary knowledge which included science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technology” (pp. 23-24).
Moore (2008, as cited in Wang et al., 2011) claimed that the reasons for integrating STEM are to: (1) deepen students understanding of each discipline by contextualizing concepts, (2) broaden student understanding of STEM discipline through exposure to socially and culturally relevant STEM contexts, and (3) increase interest in STEM discipline by increasing the pathways for students to enter the STEM fields (p.2).

In order to effectively teach STEM in the classroom, rich content of each STEM discipline needs to be taught guided by developed STEM integration curriculum. New teaching models such as cross-discipline teaching approach should be employed, given the common themes of STEM learning (Wang et al., 2011). Importantly for teaching STEM in the classrooms, Vasquez (2015) stressed real-world application as the heart of STEM education in which teachers need to provide students time in engaging integrated knowledge and essential skills to solve problems. Therefore, she pointed out that not only implementing problem-based or project-based activity is always an approach to teach STEM, but also fully engaging students in applying knowledge and skills through the process of learning.

To deal with varied views of STEM education, Breiner et al. (2012) examined the conception of STEM held by full-time faculty members in various colleges at University of Cincinnati (UC) by sending out two open-ended questions via e-mail listserv. The two questions were “What is STEM?” and “How does STEM influence and/or impact your life?”. The study revealed that over 70% of respondents understand that STEM related to science, technology, engineering, and mathematics. However, 70% of respondents from both STEM and non-STEM fields were unable to determine if STEM has impact to their life based on their own personal perspectives and line of work. The researchers concluded
that it was difficult to define a common conceptualization of STEM. Rather than attempting to set an operational definition of STEM, focusing on shared outcomes of STEM practices is probably better for disseminating STEM initiatives across the nation.

As teachers are key practitioners of STEM, understanding their perspectives and their beliefs regarding STEM integration will guide effective approaches of how to implement STEM in classroom practices. Wang et al. (2011) employed a multi-case study of three teachers from a middle school to study their perceptions and beliefs of STEM integration after one-year participating in teacher professional development (PD). The researchers also examined the connection between the teachers’ beliefs and perceptions and their classroom practices in mathematics, science and engineering. The results showed that differing perceptions and beliefs held by these three teachers can shape their practices differently including designing STEM lesson plans and degree of integration. All of them perceived problem solving is a focal domain of STEM integration. The mathematics and science teachers implemented STEM at a multidiscipline level while the engineering teacher applied engineering-design process in her classroom at interdisciplinary level with higher student engagement. However, the researchers noted that all three teachers had limited view of technology integration when comparing to what was described in the PD program. On the other hand, the teachers claimed that lacking technology resources and good curriculum alignment could impact their level of integration. The finding supported Wang et al.’s (2011) assumption that STEM content knowledge was a concern of the teachers and needs to be taught as a background knowledge before applying in STEM activities. The three teachers also reflected that the STEM professional development program shed light on new ideas of
connecting and integrating STEM disciplines and provided STEM lessons to directly implement in their classrooms.

**STEM Professional Development.** The current demand for STEM integration strongly influences changes of K-12 curriculum and need for teachers with increased STEM instructional skillsets (Bryan et al., 2016) it is a challenge for PD educators to plan and design programs for STEM teacher preparedness. Substantially, STEM teachers were in need of effective STEM PD programs in promoting a sense of efficacy in and confidence for teaching to bring changes in classrooms, beliefs, and attitudes toward STEM curriculum. In response to STEM demand, Nadelson et al. (2013) addressed the importance of STEM PD in teacher perceptions and preparation in STEM teaching both in content and pedagogy. They initiated, SySTEMic Solution, 4-years of ongoing PD programs including a 3-day summer institute, online education module and on-site PD supports for participating elementary school teachers in the western United States. The 3-day SyStemic institute offered the teacher participants experience in inquiry-based STEM of engineering, STEM instruction, and STEM curriculum development with support materials such as PCS Bricklab kit for classroom lessons. During the program, the teachers also engaged in the work of engineers through hands-on activities for classroom instruction both in group and individual assignment. After 2 years, the research team conducted the study of the impact of 3-day SyStemic institute to investigate the comfort level of STEM teaching and its knowledge level, level of efficacy and confidence, and the attitudes toward engineering of the two different cohorts (36 and 32 teachers from Year 1 and Year 2 respectively). The main instrument for gathering data were four sets of web-based surveys consisted of demographic data, confidence for teaching STEM,
efficacy for teaching STEM, and attitude assessment toward engineering while an institute evaluation was used to assess the effectiveness of the 3-day PD activities. The results showed the significantly positive correlations of Year 2 with Year 1 among comforts with STEM teaching, STEM content knowledge, efficacy for, and confidence with teaching STEM. For both Year 1 and Year 2, the comfort with teaching STEM highly correlated with knowledge of STEM at statistical significance level of .01. Likewise, there was significantly positive correlation between confidence and efficacy (p < .01 and p < .05 respectively) for teaching. Only the STEM knowledge of Year 2 cohorts was correlated with attitudes toward engineering at p <.05. Interestingly, the correlation between confidence for teaching STEM and engineering attitudes differed regarding these two variables: years of experience and age. Furthermore, the level of efficacy, confidence, and attitudes significantly increased across both years at p < .01 and it indicated that the 3-day SyStemic institute had consistently impacted on these changes of the two cohorts. The institute evaluation reflected that the teachers most valued spending time on hands-on interactions and manipulatives (Bricklab) as well as curriculum exposure for enhancing teaching capacity, while lecture session guided the application of inquiry-based STEM approach in classroom teaching.

Although Nadelson et al.’s (2013) research did not present in depth the teachers’ classroom implementation, it is an assurance that teachers recognized the importance of ongoing STEM PD programs and remained in need of guidelines for shifting classroom instructions into the mainstream of STEM. The findings are in consistence with Wang et al. (2011) that during the PD programs, knowledge of STEM content and pedagogy domain interacting with hands-on activities was a priority that teachers required.
Similarly, Capraro et al. (2016) further studied impacts of the sustained and systemic STEM PD with support from a professional learning community (PLC) but more focused on teachers’ classroom enactments, teachers’ perspectives and student achievement. A distinction of this PD research was to use STEM project-based-learning (PBL) as an innovation which teachers developed for mathematics and sciences classroom implementation. It was a 3-year longitudinal study of STEM PBL and PLC in the three-district high schools to examine the fidelity of the PD program. The PD program is called systemic, district-level initiated intervention which comprised a PD courses of study (10 days, 60 hours per year), PLC development, and classroom observations on PBL implementations. Topics of the PBL and a STEM PBL guidebook were developed and provided to the teacher participants. The PD courses focused on topics related to the STEM PBL approach such as content knowledge, pedagogical strategies, and assessment. Based on the research findings, the researchers pointed out that a combination of high-quality, research-based PD initiatives, and strong implementation by teachers assisted by the professional learning community significantly affected student learning gains. Nevertheless, the research also showed that great new PD innovation poorly implemented in the classroom can cause negative effects on student learning. Additionally, the teachers appreciated that implementing STEM PBL in the classroom increased the students’ role and engagement, especially for the prior-disengaged students, in real-world projects whereas the teachers played in a more facilitative role. The teachers positively described PLC as a place for shared visions and ideas, collaboratively working and planning, and learning from each other.
Again, the findings from the above PD research significantly support research literature regarding the impact of PD on teacher and student learning, however, the researchers and PD providers continue to broadly explore new innovations and investigate other possible factors for better changes. For instance, “Linked Learning” proposed by ConnectEd, the California for College and Career is a pathway to make students and teachers better understand the connection of the STEM fields and real-world careers. Linked Learning can prepare high school students, in particular, to gain work-based learning experiences in actual workplaces across-STEM discipline. The pathways will accommodate students with the core academic courses, a set of technical courses emphasizing knowledge and skills for real-world application. Then, the students will have opportunities to interact and solve real problems in an actual workplace with personalized student supports from the counselors (Hoachlander, 2014). The engineering-design process (English & Mousoulides, 2015; Nadelson et al., 2013) epitomizes STEM integration, however, teachers had a limited understanding of the concepts and knowledge of engineering and technology integration (Wang et al., 2011). To fill this gap, the Engineering Scholars Training and Retention (STAR) program created by the engineering and education department at Manhattan College is one example of integrative models. The STAR program assists current and future STEM teachers for better training of engineering teaching through hands-on design activities, designing engineering lesson plan for middle and high school students, engaging in 3-day PD programs, experiencing in implementing the designed STEM lesson plans in actual classrooms (Shahbazi, Jacobs, Lehnes, & Mancuso, 2016).
Level of STEM integration Although the notions that STEM might be conceptualized differently among scholars especially who are involved in STEM vs the non-STEM arena, school teachers as key stakeholders have been currently influenced and called for changes in their classroom instruction toward STEM integration. Teachers were encouraged to implement STEM education in their classrooms as much as the lesson context and content permitted. The teachers might have seen themselves integrate STEM in the lesson, however, the question emerged to what level of integration did the teachers implement STEM in their classrooms. Therefore, it is necessary to guide teachers with below descriptions of level of integration so that they can determine how to achieve its level.

Figure 2-8: A continuum of STEM approaches to curriculum integration (Vasquez et al., 2013, p. 17).

Figure 2-8 later coined by Vasquez (2015) as the inclined plane of STEM integration, is well-described for each level’s desirable learning outcomes when teachers
integrate STEM in the classrooms. First, the *disciplinary level* is the bottom part where students learn concepts and skills of STEM subjects separately in different STEM classes. If a common theme of teaching is given among teachers from four disciplines, then students learn STEM’s concepts and skills separately but in association with the theme. That means the teaching moves up to the *multidisciplinary level or thematic integration* (Vasquez et al., 2013; Vasquez, 2015). The teaching can shift up to the next level, *interdisciplinary* when at least two teachers from different STEM disciplines work together in redesigning a new plan of teaching or curriculum. The redesigned curriculum contributes a set of interconnected and interdependent concepts and skills between the disciplines to students in learning process. Lastly, *Transdisciplinary* is the most advanced level of STEM teaching and learning (Vasquez, 2015, p. 12). This level evolves from utilizing either problem-based or project-based activity related real-life situations in the classroom with the use of engineering-design process (Capraro et al., 2016; Vasquez et al., 2013; Vasquez, 2015). Transdisciplinary approach is a means to reinforce students in applying content knowledge and skills (e.g., high-ordered thinking and problem solving) across STEM disciplines until accomplishing the assigned activity. Because of group work, social skills such as communication and collaboration will be increased in addition to aforementioned skills. (Vasquez, 2015).

**STEM Education as New Integrative Approach for Classroom Practices**

As STEM education is perceived differently among STEM scholars, therefore, its implementation embraces a wide-range of methods of integration. Overall, STEM integration in the classroom enhanced students in applying multiple skills (e.g., critical and creative thinking, problem solving skills) through real-life and beyond routine
problems. Regarding different approaches of STEM integration, the research trajectory described how teachers can better implement STEM integration. Additionally, the researchers tend to seek out those substantial factors that promote changes in STEM classroom practices.

For instance, English and Mousoulides (2015) implemented an engineering-based modeling activity for sixth graders. This problem was developed from a real incident where the 35W Bridge in Minneapolis, Minnesota was collapsed in 2007 and the design flaw was likely a cause of it. The bridge-design activity was to develop a model for rebuilding the new bridge. The students were encouraged to engage in the following cyclic design processes until their model was acceptably met the problem constraints:

- Ask (What is the problem? What are the constraints)
- Imagine (What are some possible solutions?)
- Plan (What diagram can you draw?)
- Create (Follow your plan; create a model; test it out)
- Improve (Discuss what works; modify your design to make it better (Cunningham & Hester, 2007 as cited in English & Mousoulides, 2015, p. 534).

The researchers collaborated with the mathematics and science teachers of the sixth grade to implement this activity in their three classroom sessions. In the first session, the teachers introduced the problem through an article from newspapers and a video clip of the collapse. Individual students studied the problem descriptions with lists of questions, and the two data-tables including characteristics of four types of bridges (truss, arch, suspension, cable-stayed) and examples of these four bridges found in the United States. Second session, the students were assigned into mix mathematics ability groups of three or four to study given problem scenario and the data tables in (a) developing a model for calculating the cost for each bridge type, and (b) using the cost
model in conjunction with other bridges characteristics (e.g., safety, materials, design) (p. 536). In the last session, the students presented each group poster and provided supportive documents. At the end, a classroom discussion was conducted. The researcher showed that the final model created by students depended on the number of related model factors used. Importantly, the students demonstrated they could create the model and provide reasons for their results. For example, one group only used mathematics factors such a cost for decision making, creating the model based on cost estimation in terms of width and length of the bridge, while another group took both mathematics (cost) and engineering (types of bridges) domains into consideration.

Significantly, the researchers suggested that students’ learning experience and ability of problem solving can be motivated by the use of problems beyond the classroom. This was accomplished by combining complex factors in which a critical analysis process is required. English (2016) claimed that this modeling activity represented two highest forms of integration: interdisciplinary and transdisciplinary (Vasquez et al., 2013; Vasquez, 2015). Applying cyclic design processes promoted integration of STEM design-engineering and data-table searching related to mathematics problem solving. Overall, this activity honored the students’ reasoning and their way of thinking.

**STEM Education and Its Impacts on Thailand’s Education**

Thai education, like, other East Asian countries emphasizes mathematics, science, and engineering as disciplines for responding to global economic and social development. In addition to schooling for competitive market economies, East Asian education also promotes the students’ capabilities for innovative thinking (Postiglione & Tan, 2007).
Apparently, when the Western ideas of globalization, the 21st century skills, and STEM education have been shifted into international level (Dean et al., 2010; Mullis & Martin, 2013; NSEC, 2014), Thai educational stakeholders has immediately responded to these global trends. Consequently, the purpose of Thai education has been adjusted to fit in the global circumstances. However, the educational goals and curriculum decisions must align with the objectives of Thai schooling and Thai-ness context—language, cultural, religion, and politics (Bianco & Slaughter, 2016). Through school experiences, Thai students are encouraged to work and live happily and are equipped with important soft skills such as critical thinking and problem solving. Thai students are also taught how to live as flexible lifelong learners in the Thai democratic monarchy and global society (Office of the Education Council [OEC], 2013).

**STEM education in Thailand.** The Institute for the Promotion of Teaching Science and Technology (IPST) characterized the five components of what STEM education should enable learners to achieve—(1) to integrate STEM knowledge and skills, (2) to challenge with given problems or situations, (3) to be active in learning, (4) to develop the 21st century skills, and (5) to connect learned problems or situations in real life or future careers (IPST, n.d.). STEM is taught through project-based activities or problem-based activities employing ideas of engineering design (Bryan et al., 2016; Vasquez et al., 2013; Vasquez, 2015). The process of engineering design consists of *identifying a challenge, exploring ideas, planning and developing prototype, testing and evaluating prototype, and presenting the solution* (IPST, 2014). It is a cyclical and continual process until a problem is solved. The IPST also provides STEM curriculum including four grade levels (Level 1: Grades 1-3, Level 2: Grades 4-6, Level 3: Grades 7-
9, Level 4: Grades 10-12) of STEM activities, STEM assessment methods, and teacher handbooks to guide teachers for classroom implementation nationwide (IPST, 2014).

Although STEM education has been recently introduced to Thailand, the Thai national STEM policy with powerful authorities from the central government plans to propel the STEM action plan to implement it throughout the country (MOE, 2016). Therefore, with some guidelines for implementing from IPST STEM handbooks, the current studies of STEM in Thailand are heavily conducted to determine the impacts of new interventions on student learning outcomes. However, there are few research studies that address how Thai teachers have learned from and struggled with their STEM classroom implementation.

To achieve effective STEM integration in practices, the following guidelines aiming for changes at the national level were recommended (Senajuk, Sakorn, Sriwapee, & Trisupakitti, 2016; Siripatrachai, 2013). These guidelines will help to prepare STEM teachers and prevent raised concerns and misunderstandings about STEM implementation in classroom instructions. (1) Engineering curriculum must be developed to correspond with existing science, mathematics, and technology curriculum. The cutting-edge STEM curriculum plus ready-made educational lessons and medias, and clear-cut assessment and evaluation will facilitate the implementation of STEM effectively. (2) Teacher readiness is the next concern. STEM teachers should receive effective professional development (PD) programs in support of the collaborative IPST and higher educational institutes. Effective PD plans for in-service teachers are required. Coaching and mentoring system provides teachers secure place to freely discuss, share ideas and plan in STEM teaching. It seemingly creates STEM environmental talk among
the STEM teachers. (3) Not only are in-service teachers prepared for teaching STEM, but also student teachers. It is a responsibility of teacher education institutes to produce student teachers who possess confidence and knowledge, particularly, in scientific literacy and methods of teaching. A solid system of teacher production and teacher recruitment is needed and should be in accord with the national demand of STEM teaching workforce. (4) Education institute readiness is also important for successful STEM implementation. STEM education requires school administrators who have broad vision and look for opportunities to make changes. Professionally, school administrators act as a leader to bring school teachers into collaborative working environment and promote good relationship among parents, community and school. As well, good school administrators foster their teachers in professional development and provide opportunities for outside stakeholders to take part in school. And (5) research in STEM needs to be increasingly conducted. Then, the disseminated research findings are useful for teachers in updating new STEM strategies and innovations for classroom implementation.

Nevertheless, if Thai schools are more likely to be ready for change in traditional school norms and cultures (Hallinger & Kantamara, 2000), to bring effective change in STEM classroom practices, I strongly recommend that Thailand needs a robust policy regarding STEM curriculum development, STEM teacher professional development, and STEM research. Hallinger and Kantamara (2000) found that effective change-leading in Thai school context could be made through the following aspects: *leadership style, group orientation and teamwork, pressure and support for change, spirit and celebration, and accountability*. In order to lead school change in a Thai cultural context, powerful and authoritative leaders (e.g. principals and school administrators) must first initiate and
foster the change process in teachers. STEM guidelines as aforementioned share some similarities to Hallinger and Kantamara’s study that change in teachers’ leadership roles and classroom practices within Thai hierarchical social system (Kainzbauer & Hunt, 2016) will happen when teachers are fully supported by principals or other school leaders.
Chapter 3

Methods and Procedures

This study takes a phenomenological approach to examine the classroom instruction of mathematics teachers after participating in a STEM education workshop in Thailand. It was a multiple-case study of four teachers. According to Yin (2009), “a case study is an empirical [study] that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (p. 18). Thus, the research was designed as a multiple-case study analysis of four individual mathematics teachers in order to investigate the phenomenon in their classrooms resulting from the impact of a professional development program. The multiple-case study was subjected to the similarities and differences of school cultural and contextual elements. In doing a multiple-case study, I aimed to explain how the four mathematics teachers implement gained knowledge and skills from a STEM education workshop in their classrooms. This case study draws upon multiple sources of data—classroom observations, interviews, document, artifacts, and self-reflection reports—so that I was able to strengthen the trustworthiness of explanations. The research process was conducted under an active Penn State IRB in compliance with informed consents from Thailand.

Design of the Study

STEM education workshop is one model of teacher professional development programs. It was in the mainstream of the current Thai national PD plan for enriching teaching proficiencies in four main disciplines—science, technology, engineering, and
mathematics—aimed for change making in classroom instructions through project-based learning and inquiry-based-learning in real-world situations. My study focused on teachers as the key drivers of this educational change.

**Research Question and Purposes**

By focusing on a STEM education workshop taking place in the Upper Northern STEM Education Center (UNSEC), I examined how mathematics teachers uniquely integrated knowledge and skills in accordance with the local’s distinct sociocultural contexts, and school environments and policies, as well as the needs of communities and teachers. In doing so, the main research question was:

What aspects of a STEM education workshop in Thailand do mathematics teachers integrate into their classroom after participation?

The purpose of this study was to examine mathematics teachers’ classroom instruction. The study examines the knowledge and skills teachers integrated into their classrooms after participating in a STEM education workshop in Thailand. The study also investigates the extent to which teachers were able to implement what they learned during the STEM education workshop.

**Context of Study**

This section describes the research settings and the participants. I begin with the two main settings where I conducted the research. Then, I explain the process of participant selection and the participants’ profiles.

**Settings**

The study was conducted in public secondary schools in Thailand. The two main settings were the STEM education workshop organized by the Upper Northern STEM
Education Center (UNSEC). The UNSEC was funded by the Institute for the Promotion of Teaching Science and Technology (IPST). The other setting was the classrooms of four selected mathematics teachers; Tanwa, Kanya, Mena, and Mesa (pseudonyms) who participated in this STEM education workshop.

**Northern STEM Education Workshop**

The UNSEC is one of 13 regional STEM centers and located in a provincial secondary school in Chiang Mai, Thailand. Its function is to serve teachers and academic personnel from STEM networking schools in seven provinces of northern Thailand. The UNSEC acts as a coordinator to support academic cooperation among IPST, Office of Basic Education (OBEC), universities, and other public and private organizations. It serves as an interchangeable learning center, specifically in STEM disciplines by disseminating and promoting STEM learning and teaching in public schools. The National STEM Education Center (NSEC) empowers STEM ambassadors and core trainers who have expertise in STEM fields from universities, secondary schools, as well as public and private partnerships to assist UNSEC in organizing a wide variety of STEM activities. With this collaboration, UNSEC is able to provide opportunities for teachers and students to participate in several STEM teaching and learning activities, including STEM teacher seminars and workshops, student STEM clubs, STEM camps, STEM coaching and mentoring, and the Thailand STEM festival (National STEM Education Center: NSEC, 2014; STEM Network, n.d.). Overall, UNSEC is a key driver to inspire teachers to engage in multidimensional STEM teaching and learning. Ultimately, it aims to propel national education achievement into a global scale with high quality of science, technology, engineering and mathematics integration for 21st century skills development.
Information regarding STEM education in Thailand is provided on the official website, http://www.stemedthailand.org/, under the responsibility of the IPST.

Recently, in January 2016, UNSEC administered a 3-day workshop for dissemination of STEM education funded by the IPST. The workshop was organized to academically serve mathematics, science, and technology teachers. The UNSEC invited three teachers from each new STEM networking school in seven northern Thai provinces for a total of 139 teacher participants. From this workshop, my first research setting, I was able to select four mathematics teachers as my key research informants. The four selected teachers were from the same province in Thailand.

**School Classroom of Participants**

The classrooms of four selected teachers were my second setting. Figure 3-1 is the sketched geography of where the teachers’ schools are located and Table 3-1 is the summary of the teachers’ school location, and the number of classrooms and students I observed. The classroom and school contexts were also described as follows:

![Figure 3-1: The sketched geography of where the teachers’ schools are located.](image)
Table 3-1

The summary of observed schools and a number of classrooms and students.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>School/Location</th>
<th>Grade Observed</th>
<th>No. of Classes and Students Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanwa</td>
<td>A middle-sized secondary school (approx. 900 students) in town, Amphoe Mueang</td>
<td>G9</td>
<td>1 class with 30 students</td>
</tr>
<tr>
<td>Kanya</td>
<td>A large-sized secondary school (approx. 1501-2500 students) another district, (approx. 30 miles from Amphoe Mueang)</td>
<td>G9</td>
<td>4 classes (approx. 31-32 students/class)</td>
</tr>
<tr>
<td>Mena</td>
<td>A science boarding secondary school (approx. 720 students) in distant suburb, Amphoe Mueang</td>
<td>G8</td>
<td>1 class with 10 students</td>
</tr>
<tr>
<td>Mesa</td>
<td>An extra-large-sized secondary school (approx. 3000 students) in downtown, Amphoe Mueang</td>
<td>G8</td>
<td>6 classes (approx. 40 students/class)</td>
</tr>
</tbody>
</table>

**Tanwa’s school and classroom.** There were six classrooms of Grade 9 in Tanwa’s school, but only the “Math and Sci” classroom of 30 ninth graders was observed. Overall, these students were high-performing in academics. Tanwa’s school is a secondary school administering from Grade 7 to Grade 12. It is a middle-sized school of approximately 900 students located in a capital district (Amphoe Mueang) of the province. The school utilized a placement test to track students into classrooms since they first entered in Grade 7. Tanwa used the school’s mathematics lab to execute learning activities. It was full of mathematics books and videos, teachers’ artifacts, and visual aids for teaching such as an interactive whiteboard, overhead projector, handouts as well as other materials and tools for mathematics projects. There were six rectangular activity
tables at which students were seated groups of five. All students talked in northern Thai dialect with friends but communicated in central Thai dialect with the teacher.

**Kanya’s school and classroom.** There were 10 classrooms of Grade 9 in Kanya’s school; however, she taught four classrooms in two different mathematics courses: a fundamental course and a supplementary course. From the similar use of placement tests, students were placed into first and second classrooms based on their score rank since they first enrolled in secondary level. These two classrooms were also coined “Math-Sci” classrooms. I observed all four classrooms. There were approximately 31-32 students per classroom. It is a large-sized school (1501-2500 students) in another district in which a number of students are from hill tribes located in remote villages of Northern Thailand.

The mathematics department has its own building full with students’ mathematics projects, board games, student and teacher artifacts, and teaching materials. In mathematics classroom, students’ desks were arranged in four pairs in a row as a traditional classroom layout facing to the whiteboard and teacher’s desk. There was only an overhead projector with screen in the classroom. The wall was decorated with students’ mathematics works and assignment boards. Kanya allowed her students to choose their own seats in the classroom.

**Mena’s school and classroom.** The school had a different advanced curriculum from other public secondary schools (Grade 7- Grade 12). It is one of Thailand’s science boarding schools where students are academically admitted by several special placement tests. The school is filled with gifted and talented students who received full government scholarships plus food and accommodations. The school limits the class sizes in all grades to no more than 24 students. It is a middle-sized school and has approximately 720
students in the capital district (Amphoe Mueang). The students are also highly engaged in various hands-on learning, especially in mathematics and science from university and science-oriented experts. The school is expected to produce students who enter science and technology programs in postsecondary education and promote them in scientific professional arenas. I observed only one classroom of Grade 8 that Mena was teaching. It was a classroom of 10 eighth graders in Statistics. Statistics is an elective course according to the school mathematics curriculum. This group of students freely selected this course by themselves. There was no mathematics classroom for the students, so Mena taught them in any available classrooms at that time period. Although students had no fixed seats, they preferred to sit in a row facing the chalkboard and teacher’s desk. In need of teaching visual aids, she sometimes used the mathematics multimedia room.

**Mesa’s school and classroom.** Her school is situated in the heart of the capital district (Amphoe Mueang) and comprised of approximately 3000 students. It is an extra-large sized secondary school (more than 2500 students). There are 12 classrooms per grade level. I observed six different classrooms of the eighth graders. The students had fixed classrooms in the mathematics building. Therefore, classroom boards mostly displayed students’ works and mathematics news and information. The average number of students per classroom was 40. With a limit of classroom spaces, the desks were in the most common row arrangement facing the chalkboard and teacher’s desk. The students had fixed seats and were mostly in pairs. Due to limits of room space, students had to pile up their desks close to the wall when they had group activities and sat on the floor. There was only a flat screen TV above the chalkboard in each classroom. Sometimes, Mesa had to carry a small projector to set up and connect to the TV screen when PowerPoint
presentation was needed. Central Thai dialect was the medium of communication between teacher and students but northern Thai dialect was used among students. Since the school joined in the program called English for Integrated Studies (EIS) model, teaching mathematics by using English worksheets was included to some degree by Thai mathematics teachers. Only one classroom for each grade level will be taught by foreign teachers using English as a medium for teaching in mathematics, science, and English. It was called a Mini English Program (MEP) classroom under Thai curriculum.

Participants

The four participants (Tanwa, Kanya, Mena, and Mesa) were selected using purposeful selection as a typical method of selection in qualitative research (Maxwell, 2012). The participants were Thai mathematics teachers from public middle schools who attended a 3-day STEM education workshop provided by the UNSEC. The teacher selection was finalized on the last day of the workshop.

Teacher Selection. At first, I planned to select four teachers based on the following criteria: being an outstanding role model teacher in mathematics, teaching in middle school level, and teachers who strongly participated in the workshop. However, in the real setting, there were some unexpected challenges that occurred and I had to adjust the criteria. These following situations caused some adjustments of the selection process. Regarding the list of registration, there were 139 teachers of science, technology, and mathematics from K-12 level all together who attended the STEM workshop. Although I had the teacher list sheet in hand, it was difficult to keep track and follow only mathematics teachers because the teachers freely rotated their seats.
First, I randomly sat with some teachers in one table and introduced myself to the others. The teachers from the same school tended to sit together on the first day of workshop. During the workshop, I participated in every activity and built rapport with a number of participants by circulating to different groups of teachers. In a traditional way of group working, it allowed the members to know each other by icebreaking and self-introduction. Starting from trust building, I was able to know some teachers that I joined in the tables. If they were mathematics teachers, I marked that on my teacher list and observed them during participation. For teachers who I met but were not mathematics teachers, I asked them whether there were mathematics teachers from their school attending in this workshop. Because mathematics is a small community, once you know some mathematics teachers, they tended to introduce you to the others. I considered it as an applied method of using snowball sampling techniques for participant recruitments where one person referred you to the others. Nevertheless, not all teachers who I met were teaching middle school mathematics. Some of them were not willing to participate in the study because they were not ready to be observed. I believe that it was a feeling of fear of assessment and evaluation. Some teachers were also from rural areas that make for some difficulties of setting accessibility. At the end of the first day workshop, I was able to recruit only two teachers from different provinces who met the inclusion criteria.

The second day, I continued seating myself at different tables, joining in activities, and observing my prospective mathematics teachers. I spent time during every session break to search for mathematics teachers; however, it was difficult to approach all participants in a short period of time. During the activity sessions, I had no chance to talk to the teachers since we were concentrated on group work in order to finish on time.
Given advice and teacher information from the STEM workshop organizers and some teacher participants, I was able to select the mathematics teachers who met some inclusion criteria and were willing to participate in my study. In addition, I decided to call the mathematics teachers in person on phone to introduce myself and my research study after the second day. Fortunately, I had a chance to be a representative of the group to present group project and this presentation helped the teachers to recognize me. Once I had information of the potential mathematics teachers who agreed to participate in my study, I found that some teachers were from different provinces and some were from schools in remote areas. Importantly, there were only six weeks left in the school semester to follow these teachers in their schools. With the limitations on the convenience of field research access and school time, I decided to adjust my criteria. Eventually, I selected the teachers according to these criteria: *teaching in the same province, teaching in middle school mathematics, different years of teaching experiences,* and *different opportunities of PD participation.* Based on these criteria, I selected four mathematics teachers (Tanwa, Kanya, Mena, and Mesa). I found that two of them (Tanwa and Mesa) showed the outstanding characteristics during the workshop with high level of engagement and enthusiasm of learning. They sat together at the front row table, and often made more interaction with their team and the instructors.

On the last day of workshop, I talked to these four selected teachers and informed them about my research study, including the purposes, summary of procedures and duration of the research. In order to protect confidentiality of teachers, I assured to them that I would secure the collected data and keep the recorded audio and digital files in my computer for access only by myself. Additionally, I promised to remove their names or
other identifiable information (e.g., e-mail address, full face photos, and the name of school). Then, I provided them the teacher informed consent form for participating in my research study (Appendix A). Besides the request letter for school’s permission, I attached a cover letter written by my Thai scholarship sponsor to school directors in order to request permission for teachers’ classroom visits. The cover letter addressed that I am a Thai scholarship student and have government approval to collect data in Thai schools. The signed consent forms were photocopied and given to the teachers. In addition, I requested their class schedule and available time that I would be allowed to conduct the study in their schools and classrooms.

The four selected teachers taught mathematics in the same province but in different size schools. Three of them (Tanwa, Mena, and Mesa) taught in schools in the capital district while Kanya taught in a large-sized school in another district. The following section describes these four selected teachers’ career facts—on teaching experiences, professional development, current status of teaching, and other related school work—that can influence their classroom implementation. This information is also summarized in Table 3-2.
Table 3-2

Demographics of four selected teachers

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Years of Experience</th>
<th>Frequency/type of PD</th>
<th>Current Status/Academic Title</th>
<th>Other/Extra school work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanwa</td>
<td>15 years</td>
<td>At least 5 times/year from universities and UNSEC, self-directed PD via YouTube and social media</td>
<td>Government teacher/Professional Level (K-2)</td>
<td>Working at school supply unit</td>
</tr>
<tr>
<td>Kanya</td>
<td>8 years</td>
<td>3-4 times/year related to Gifted/PISA, self-directed PD via YouTube and Thai Distance Learning Programs</td>
<td>Government teacher/Practitioner Level (K-1)</td>
<td>Working at department of student affairs</td>
</tr>
<tr>
<td>Mena</td>
<td>5 years</td>
<td>Minimal (STEM workshop was the first one of this year), self-directed PD via mathematics book reading</td>
<td>Contract Teacher</td>
<td>Working on academic evening shift at school</td>
</tr>
<tr>
<td>Mesa</td>
<td>20 years</td>
<td>Very frequently attending PD programs from IPST</td>
<td>Government teacher/Senior Professional Level (K-3)</td>
<td>A mathematics mentor and a deputy head of EIS program</td>
</tr>
</tbody>
</table>

Tanwa has been teaching mathematics in every secondary school grade for 15 years. This academic year he taught Grade 9 to Grade 11 in both fundamental and supplementary mathematic courses. He holds a degree in mathematics. He is a government teacher with academic title “Professional Level (K-2)”. Tanwa attended at least five times mathematics PD programs provided by universities and UNSEC in northern Thailand this academic year. Basically, the PD programs he participated in took two to three days off-site. Besides outside school PD programs, he also continued learning his teaching techniques via internet channels such as YouTube and social media.
both in Thai and English. Tanwa also had extra work at the school supply unit to procure all school equipment and materials.

Kanya is a government teacher with academic title “Practitioner Level (K-1)”. She has been teaching mathematics for eight years. Before teaching in this school, she was a contract teacher in a specialized science boarding school. This year she taught only the ninth-grade mathematics both in fundamental and supplementary courses. She received a degree in mathematics with a master degree in curriculum and instruction. Kanya participated three to four times per year in PD programs mainly for teachers of students in talented education program such as PISA training. PD programs took at least two days. She continued to update herself in teaching skills and knowledge of mathematics from other Thai mathematics teachers through internet access such as YouTube and Thai Distance Learning Programs via satellite. Kanya also had extra school tasks at the department of student affairs in planning student activities, coordinating among teachers, and being a mentor to the gifted student group.

Mena is a school contract teacher. She has been teaching mathematics for five years in this boarding school. This year she was assigned to teach statistics as an elective course for Grade 7 to Grade 9 and Grade 11. She taught only eight periods per week in total; however, she was responsible for interested group tutoring in the evening from 16:30 to 20:30 pm. Her job was to schedule the intensive or tutoring courses, to facilitate students in library and computer room after school. She was selected to participate in the STEM education workshop since the other government teachers were not available. It was her first time joining PD programs this academic year. Although she had less
opportunity to attend PD programs, she tried to enhance her professional career by learning more techniques of teaching from a variety of mathematics handbooks.

Mesa is a government teacher with academic title “Senior Professional Level Teacher (K-3)”. She had 20 years teaching experiences in mathematics. She received both a bachelor and master degree in mathematics education. She is also a school academic mentor of beginning mathematics teachers who are in the program, Potential Teachers of Change in Science and Mathematics, sponsored by IPST. As a mentor, she was able to attend several mathematics PD programs provided by IPST. In addition, she is deputy head of English for Integrated Studies (EIS) which is the program of using English as a medium of teaching in mathematics, science, and computer science. She taught both fundamental and supplementary mathematics for Grade 8 this academic year.

**Data Collection**

The data was collected in Thailand from January to February of 2016. It was the last two months of the second semester in which the teachers were already in a rush to cover curriculum. The study started from the STEM education workshop as my first setting. First, I contacted the head of organizing team at the Upper Northern Regional STEM Education Center (UNRSEC) about two months in advance. I informed him of my research purposes and its process. I also requested to participate as one of the teacher participants in the STEM education workshop. The organizing head allowed me to participate in this workshop and provided me the prior report of first STEM workshop (The Upper Northern STEM Education Center [UNSEC], 2015). As a result, I was able to acquire some guidelines of the workshop organization. During the waiting period, I continued going to meet the organizing teams to check the progress of the workshop plan
until I could have the list of all teacher participants and workshop schedule beforehand. I participated in the entire STEM education workshop for three days with other teacher participants.

During the STEM education workshop, I observed and wrote down notes regarding what the instructors and teachers had been learning and working on, as well as what knowledge and skills in mathematics they were focused on. I participated in group activities with other teachers, however, I rotated to different groups when new activities started in order to build new relationship with others. I collected all hand-in workshop documents/ activity manuals. From workshop documents and my notes, I could summarize and reflect on what knowledge and skills were presented in the workshop. Overall, the obtained meaningful data from the workshop benefited me to carry out the process of teacher selection and research analysis afterwards. The next paragraph was the summary of characteristics of STEM education workshop according to given documents, workshop packets, and my reflection as one of the teacher participants.

**STEM Education Workshop**

The UNRSEC organized a 3-day workshop for dissemination of STEM education for teachers in the northern region who have not previously participated in any STEM workshops from IPST. The goals of this workshop were— *to enhance teachers understanding of goal setting in learner qualities consisting of knowledge, skills, process, competencies, and desired characteristics of STEM education, to promote teachers’ proficiencies in STEM learning and design in response to individual differences and learners’ cognitive development, and, to promote teachers’ use of appropriate media and technology as a tool of STEM integration by taking local context and wisdom into*
Characteristics of STEM Education Workshop

The organizers designed the STEM education workshop in two main sessions. First session was administered by an instructor from the USA on the first day of workshop. The instructor introduced STEM education, STEM lessons from the States, and STEM activities for 21st century classroom. To avoid the language barrier, STEM organizer provided an English-Thai translator to facilitate teachers when more clarifications were requested. The other session was about the dissemination of STEM education by two core trainers from a northern Thai university. They were selected and trained by IPST in order to facilitate schools in the region as a cooperation among IPST, schools, and universities. The core trainers demonstrated some examples of STEM activities designed by IPST to implement in the workshop. The teacher participants had to engage in hands-on STEM learning activities in groups, present group projects, and take part in in classroom discussions.

First Session: Introduction of STEM Education and Activity for 21st Century Classroom

The instructor from the USA introduced STEM education as an integrated approach of teaching and learning in science, technology, engineering, and mathematics. Students should acquire essential content knowledge and skills, namely critical thinking and real-life problem solving in order to integrate these four disciplines. Students for the 21st century also need to apply these two skills throughout college and career life. Thus, the instructor proposed Inquiry Learning as a significant process to develop student’s
critical thinking and problem solving skills. Importantly, emphasis was placed on asking effective questions that can prompt students in inquiry to discover the answers. The instructor illustrated the below example mathematics problems to explain the Inquiry Cycle and Level of Inquiry. He distributed PowerPoint handouts to the teacher participants. The problems were only displayed on a projector screen.

**Problem 1:** How many rectangles are there inside yellow box? (Figure 3-2)

![Figure 3-2: Problem 1: Asking about the numbers of rectangles.](image)

The instructor provided teacher participants time to work in groups. He asked how teachers solved the problem. He claimed that drawing a picture was the most logical way that teachers should encourage students to start with, but for most of the teachers a purely visual count was the method. Drawing out the partial figure allowed the students to identify patterns systemically and would be likely to result in a more precise answer. Then, he moved on to a more challenging problem as follows.
**Problem 2:** Design a toy box

![Image of Problem 2: Design a box](image)

**Figure 3-3:** Problem 2: Asking about the largest number of toy boxes.

This problem was more associated with real-life situations. The task was to design the box for a dragon with dimension of 22 x 9 x 22 cm that maximizes number of toy boxes able to be put in a 30 x 40 x 51 cm container. The instructor advocated that the teachers implement an Inquiry Cycle with four steps in the classroom including (1) Seeing a problem, (2) Planning, conducting experiment or activity, (3) Organization, collection, and analysis of data, and (4) Arrival at conclusion. According to the cycle, thinking time is provided to the students to identify the problem, to develop experiment, to determine whether the design really works, and what the facts mean, before moving forward to the conclusion and deciding if more problems need to be solved. When one problem was solved, teachers should bring more questions to students. Likewise, when the teachers finished solving Problem 2, the instructor gave more problems with some added conditions as shown in Figure 3-4.
The teachers worked in groups to redesign the box under given conditions. Later on, each group of teacher participants presented their solutions at the workshop as shown in Figure 3-5. Apparently, each group had different answers and ways of problem solving that led the instructor to discuss situations when students do not understand the questions with more than one possible answer. He suggested that if teachers plan to implement the Inquiry Cycle in the classroom, they should allow students time to think through every step.

Figure 3-5: A teacher presenting a solution of designing toy box for 2 animal toys.
**Problem 3:** How many triangles are there?

![Critical thinking and problem solving](image)

**Figure 3-6:** Problem asking about the numbers of triangles in a square.

The teacher participants started solving the problem by drawing and finally came up with different answers as one example shown in figure 3-6 and 3-7. The instructor used Problem 3 to guide them that sometimes in the classroom, teachers need to give students the correct answer. The main reason is the students will not be able to change their ways of thinking until they get the correct answer.

![Teacher drawing](image)

**Figure 3-7:** A teacher drawing the figure to find the answer of Problem 3.
After these three problems in the morning session, the instructor made three conclusions: (1) There is no one correct answer, (2) There is only one answer depending on students’ design, and (3) Students were able to think and justify their own thoughts. He emphasized that teachers should listen, value and accept students’ thinking because sometimes students have a better way to solve problems. Later, the instructor added on the 4-Level of Inquiry consisting of: Level 1: Structured, Level 2: Guided, Level 3: Challenge, and Level 4: Open, with the pros and cons lists of each level. The 4-Level of Inquiry moves from teacher doing to students working on their own. That means from teacher-centered to student-centered approach (Structured → Guided → Challenge → Open) dealing with the following three categories: (1) Problem of question identification, (2) Process of solving problem, and (3) Identification of tentative solution to the problem. He concluded that the more teachers practice using Inquiry Learning, the more progress they will make to shift from Structured to Open level instruction.

**Inquiry Learning in STEM education.** The instructor briefly explained how the 4-levels of Inquiry corresponds with the 4-levels of STEM education: *Structured ↔ Disciplinary, Guided ↔ Multi-Disciplinary, Challenge ↔ Inter-disciplinary, and Open ↔ Trans-disciplinary.* The teachers from four different disciplines can work together in development of a STEM lesson plan. He introduced the 5-E learning cycle to align in STEM lesson planning. The 5-E learning consisted of *Engage, Explore, Explain, Extend,* and *Evaluate.* The details of the 5-E learning for STEM lesson planning were included in the workshop packet; therefore, the instructor did not describe much in detail, but implemented it through STEM activities. One of the examples of designed STEM activities was called “Marble A-Maze-Ment”. The instructor distributed a one-page
assignment sheet to each group of teacher participants. It was an example of STEM lesson planning. The assignment sheet tasked each group to build a maze system in a shoebox. A condition of building the maze is a marble must travel from the top of the box to the bottom and exit in exactly 15 seconds. The assignment sheet included the specific rules, the request of data table for the experiment, and grading and point systems were also explained. After that, the instructor provided materials and time for the teachers to work on this assignment. The atmosphere of group working was shown on Figure 3-8.

![Figure 3-8: Group working on “Marble A-Maze-Ment” activity.](image)

At the end of the session, the instructor summarized what the teachers had learned that day and recommended teachers to be more creative, and prepare activities that inspire students to learn with fun and creative thought. These activities will help enable teachers to effectively integrate STEM lessons into the classroom to promote students’ high level of thinking.

**Second Session: Demonstration of STEM Classroom Activity**

This session was run similar to the co-teaching in which the two core trainers worked, planned, and shared their ideas together in the workshop. They are faculty members from a university who have expertise in physics and biochemistry. First, the
core trainers gave a lecture for about 1.5 hours on the topic “STEM education: Learning Innovation for 21st Century (สะเต็มศึกษา: นวัตกรรมเรียนรู้ในศตวรรษที่ 21). The PowerPoint handouts were distributed to the teacher participants. The content in the handouts was from IPST for the purpose of disseminating STEM education in Thailand. The lecture was about definitions and goals of STEM education, STEM integration and its level of integration, and needs of implementation of STEM education in Thailand. The core trainers showed some examples to guide teachers on how to challenge the students with STEM questions. For instance, STEM works for a ball point pen. The core trainers asked the teacher participants to observe its shape and its function. Then, they discussed the core mechanism of the ball point pen behind its working and the materials to make it workable. Besides manufacturing-related questions, the questions were extended to who else or which professional careers will take part in manufacturing, and what knowledge is applied to make the ‘click’ sound of the ball point pen. From this question, my conclusion was the core trainers tried to convince the teacher participants that “designing the questions” is the key to make classrooms equipped with more meaningful STEM implementation. Using questions associated with students’ everyday life is helpful to get them engaged in classroom discussion.

The core trainers then explained about the 4-level STEM integration and illustrated STEM in daily life with a bamboo rice container as an example of planning STEM lesson. The sticky rice containers are locally found in the northern and northeastern areas of Thailand where it has traditionally served as a staple food in every meal. Now it is consumed throughout Thailand. According to the providing STEM
handouts, the 4-level STEM integration is composed of disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary. The explanations of each level were appeared in Chapter 2, STEM education in Thailand. The following was the application of STEM in daily life with bamboo rice container at the multidisciplinary to transdisciplinary level presented in the STEM education workshop.

Figure 3-9: STEM in daily life with bamboo rice container at multidisciplinary level (IPST, n.d.).

From above Figure 3-9, after the students learned about content and gained the skills of STEM separately (disciplinary level), the teacher will use the theme (STEM in daily life: bamboo rice container) connecting to the content of each discipline (multidisciplinary level). For example, teacher will teach heat transfer in science, geometry and shape as well as surface area and volume in mathematics. Then, in computer class, the students will learn that bamboo rice container is one of simple technological innovations to keep sticky rice warm. In order to keep its heat longer, the
students must know that woven motifs and the size of containers can affect the effectiveness of heat insulation. Then, the teacher can let them plan, create the pattern of motifs, and design the features of the container in technology class. At the interdisciplinary level, students will learn knowledge and skills corresponding to STEM through activities as follows.

**Interdisciplinary: Sticky Rice Container**

**Science:** Study heat transfer  
**Mathematics:** Study surface areas and volume of solid figures  
**Science:** Do experiment to study about the factors affecting heat insulation of sticky rice container (experimenting and collecting data)  
**Mathematics:** Use experimental data to plot graph and interpret the data  
**Technology:** Design and create the patterns of motifs  
**Engineering:** Design the 3D-shape container that can keep the heat longer

(translated from STEM education workshop handouts on January 23-24, 2016)

The last level, transdisciplinary, the core trainers presented the problem related to a real-life situation as follows:

**Transdisciplinary: Sticky Rice Container**

ปัญหา  
ปัจจุบันในการทำอาหารร้านอาหารหรือหน่วยมีการใช้กระดิบข้าวเป็นภาชนะใส่ข้าวหน้าวิวและมักมีการบรรจุข้าวในถุงพลาสติกก่อนบรรจุในกระดิบข้าวเพื่อป้องกันข้าวหน้าวิวคัดด่างที่กระดิบมีผลให้เกิดความสะอาดจากรูบมดลูกการปริมาณถุงพลาสติกที่ถูกใช้ในการบรรจุข้าว และต้องการออกแบบกระดิบข้าวหรือวิธีการเพิ่มการระดับข้าวที่มีคุณสมบัติการดิบของข้าวหน้าวิวเพื่อลดการใช้ถุงพลาสติกถังกล้า

**Problem**

Nowadays, the north or northeastern restaurants often use the containers to keep sticky rice, however, the rice was first put into plastic bags for the sake of keeping the containers clean. Regarding the need of government to reduce the amount of plastic bags used, it needs to design a sticky rice container or seek for innovative ideas to make containers that will have less rice stuck to them. (translated from STEM education workshop handouts on January 23-24, UNSEC, 2016)
Examples of designing STEM learning activities

After lecturing, the core trainers demonstrated three STEM activities developed by IPST. In this paper, I chose only two distinct examples conducted in the workshop room and I was able to entirely participate in the activities. The other activity was about science experiment. The teacher participants were divided into two groups to do two different sets of experiment. The first activity was “tower model” with the given scenario—one northern province has decided to attract tourists with a new landmark, tower. Assuming that the teacher participants were in a construction team, their task was to design and build the tower. The core trainers emphasized that setting the goal was the most important step. Once the teacher participants had a clear goal, next step was planning. The last step was assessment. First, each group had to set and write down the goal of tower building. For example, my group set the goal to build a tower to represent the beauty of mixed northern Lanna and modern style architecture. Then we planned and designed the shape of the tower base, what type of materials would be used, and what is symbolic northern Lanna architecture. Besides, the assessment of its durability by architectural measurement, we decided to use surveys from the tourists or public opinions to assess its beauty. The last step was building the tower with the condition that the tower must be made of a bag of plastic straws and scotch tape. At the end, each group had to present its tower. The tower model was shown in Figure 3-10.
Figure 3-10: A group presenting Tower model.

In summary, the core trainers put an emphasis on the step of implementing STEM project-based-activities in which teachers must guide the students to (1) set goal, (2) plan/design, and (3) do assessment. In order to evaluate STEM lesson, project-based-activity in particular, the teachers should apply authentic assessment to measure students both in terms of performance (applying knowledge and skills) and practical assessment (working on task).

The second activity was “Mini-Helicopter”. First, the core trainer talked about Object’s Fall, and discussed with the teacher participants some questions. For instance, if we drop two solid objects such as a pen and a ruler from the same distance, whether or not the two object will reach the ground at the same time. Next, the core trainers introduced the Thai local trees called “Yang”, Dipterocapus Alatus as scientific name. The fruits of the trees were shown in the Figure 3-11.
The idea behind this activity was that Thai parents used them as a toy glider to play with their kids in the past. It showed Thai local wisdom of previous generations. IPST tried to connect STEM activities with situations or surroundings that occurred in students’ life. In this activity, the core trainers provided the paper with some traces for cutting in 4 sizes of mini-helicopter wings so that the teacher participants could design and perform experiment for each set of the wings. It was the activity imitating the fall of the Yang’s fruit from a paper helicopter. The core trainers advised the teacher participants to use scientific methods to study the factors affecting the fall of the mini-helicopter. Next, the core trainers set the scenario that the scientists and engineers need to explore one area on the space by using a robotic space probe controlled by a computer system. The exploring team found that the best distance to launch the space probe is at 2 meters above the ground within 2-3 seconds. From this situation, the core trainers assigned the teacher participants to conduct the experiment as shown in Figure 3-12.
Figure 3-12. A teacher launching mini-helicopter to a target.

The scoring criteria were varied based on the precision of its landing close to the mark point on the ground. At the end, the core trainers let the teachers reflect on the STEM activities and discuss about the guideline to implement STEM activities in the classroom. Based on the observation and analysis of workshop documents, as well as being one of teacher participants, I could provide the summary of this 3-day STEM education workshop as follows: the instructors used Inquiry-Based-Learning and Project-Based-Learning approach to engage the teacher participants in hands-on activities. The instructors also introduced inquiry learning as a tool for gaining more knowledge and skills from STEM integration. Therefore, the teacher participants gained knowledge and skills in STEM though the activities. The duration of each activity was about 1.5-2 hours, however, the teacher participants still requested more time to work on each activity. As a result, there was not enough time for discussion and presentation. Not all of group could present their group work because of time limits. The workshop helped to promote
teamwork through group activities. Mathematics and science teachers were more likely to show high level of engagement in group work, whereas the teachers from career and technology departments were less engaged in the activities. Although most teachers were active in doing activities, not many questions were asked during the workshop.

**Post STEM Education Workshop**

A week after the STEM education workshop, I received the four teachers’ schedules and available time to visit their schools. I attended their classrooms, observed, and interviewed them. Once I finished classroom observations and interviews, the teachers reported their teaching practices on the teacher self-reflection reports.

1. **Teacher observations** I categorized the observational units into three-main parts: introduction, teaching and learning process, and teacher learning according to my conceptual framework Part 2: effective mathematic teaching and Part 3: teacher change. At the beginning of the class, I observed classroom climate, teacher’s classroom management and lesson introduction. During the teaching and learning process, I focused on what the teacher was presenting in the classroom such as important elements of mathematics (e.g., goals and objectives, content, skills, problems), teaching methods, teaching materials and artifacts, activities and assignment, time for tasks and questions, assessment, and classroom summary. During the last part, I tried to look more closely at teacher-student interaction, classroom discussion, and teachers’ feedback on classroom teaching and learning. For instance, during the “Symbol Wheel: game-based-activity” Mesa wondered why a few groups of students did not move from the money word problem station to the other stations. After talking with the students, she figured it out that they had some troubles converting the money word problem into mathematical
equations with decimal points. She realized that it was her mistake that she did not teach
them about the value of some small coins used in the Thai currency system. Also, she
learned that nowadays, students have rarely seen these coins in their daily life. I noted
each teacher observation in four different notebooks. The field notes from classroom
observations were useful evidence that allowed me to conduct reflective conversations
with the teachers during the interview process. The number of classroom observations for
each teacher was varied. It depended on teachers’ schedule (Table 3-3).

Table 3-3
The summary of the number of teacher’s observations and interviews.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>No. of Observations</th>
<th>No. of Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunwa</td>
<td>3 (100 min each time for one class)</td>
<td>3 (3rd interview separated in 2 parts: follow up and member-check interview)</td>
</tr>
<tr>
<td>Kanya</td>
<td>17 (50 min/period for 4 classes)</td>
<td>3 (3rd interview separated in 2 parts: follow up and member-check interview)</td>
</tr>
<tr>
<td>Mena</td>
<td>3 (100 min each time for one class)</td>
<td>3</td>
</tr>
<tr>
<td>Mesa</td>
<td>15 (50 min/period for 6 classes)</td>
<td>4</td>
</tr>
</tbody>
</table>

I observed only one class of Tanwa’s and Mena’s for three times each. Each
observation took 100 minutes in two consecutive periods. After each observation, I
followed up with the interview. On the other hand, Kanya and Mesa allowed me to
observe them in more than one classroom on the day I visited. Each observation took 50
minutes. Both of them were observed more than 10 times during my study. When Kanya
and Mesa finished each topic of teaching for all classes, I interviewed them regarding
what I recorded on the notes, then they were able to clarify what I saw in their
classrooms. I audio recorded teacher’s instruction, however, students’ utterances were not
used in the analysis. I also collected some teachers’ artifacts. I saved examples of
classroom artifacts and innovations in digital files without the names of teachers on them. I photographed some classroom activities and saved them in electronic files with the teachers’ permission but their personally identifiable information was disclosed.

2. Teacher interviews I interviewed each teacher three to four times with audio-recorded by permission (see Table 3-3). I asked teachers to provide me with the available time and the place for interviews. I spent approximately 30-40 minutes in each interview. I developed the semi-structured interviews according to these following phases. The examples of each phase interview were attached in Appendix B.

First, an initial or baseline interview was used to receive basic information about how teachers plan to integrate and implement knowledge and skills in the classroom. Furthermore, this first interview allowed me to collect the teachers’ profiles such as level of education, teaching and PD experiences, classroom preparation, and initiated ideas and attitudes toward STEM education.

Second and third, follow-up interviews were important to create a more meaningful conversation after having memos and/or written notes from classroom observations. It was an in-depth interview to gain more understanding of the reasons why teachers implemented mathematics knowledge and skills in specific manner. The interpretations based on what I observed from actual practices and what teachers stated previously in the interviews will be discussed in depth. Each teacher was interviewed with different sets of interview questions resulting from teacher’s classroom observations.

For example, I asked Tanwa based on my previous observation: “Last two periods, you immediately applied a new activity from STEM education workshop after
your returned to school, how did you prepare this activity plan? And why did you decide to use “Tower Model” activity?” While Kanya was asked about how to help the students in mathematical calculation: “Some students in Class 9/5 still struggled with basic mathematical calculation such as square root in Trigonometry lesson, how do you help them to solve this problem?” Mesa, on the contrary, was asked to clarify the classroom interactions: “I observed that the students with high academic performance from Class 8/1 had less engagement in the classroom but they tended to work on their own assignment, when comparing to the students from Class 8/10 who are weak in mathematics. Could you clarify the differences of these two classroom contexts?”

The last is member-check interview that constructed the tentative claim in which I was able to ask the teachers to give feedback or confirm the accuracy and the validity from his/her interviews versus actual practices. I tended to ask teachers similar interview questions. For example, “Can you recap the process/ method of your classroom instruction? In summary, in what ways do you think that you have been enhancing your students’ thinking process and their ongoing skill development?” I added more questions to the flow of conversation when the teachers brought up specific topics.

3. Classroom artifacts The classroom artifacts were empirical evidence that represented teachers’ process of teaching and learning. I asked permission to save examples of artifacts and assignments in electronic forms without any personally identifiable information. I collected some examples of classroom worksheets, assignment tasks, quizzes and tests. Then, I converted them to electronic files (PDF files). Some documents and student work were photographed.
4. **Teacher self-reflection reports** I developed a 5-point Likert Type scale form of teacher self-reflection with open-ended statements. I adopted the questions from Teacher Self-Assessment Guide (Strong, 2011) for self-assessing the teachers’ effectiveness of classroom practices which related to the Framework Part 2. There were two parts of Teacher Self-Reflection Report (Appendix C). Part 1 consisted of 30 statements of teachers’ self-evaluation on their classroom practices. It was a 5-point scale that allowed the teachers to evaluate the frequency of each statement from never to very frequently. A numerical value was given to each of the five responses in order to be used for measuring the frequency (Never = 1 / Rarely = 2 / Occasionally = 3 / Frequently = 4 / Very Frequently = 5). The 30 statements were categorized into three stages of the classroom practices comprising of 8 statements of classroom preparation stage, 17 statements of teaching and learning stage, and 5 statements of classroom assessment and evaluation stage. Part 2 consisted of five open-ended statements that allowed the teachers to complete the statements on STEM relatedness. The teachers wrote self-reports to determine the benefits obtained from STEM education workshop, their understanding of STEM education, STEM classroom integration, their changes of behaviors, beliefs and attitudes, and their evaluations of teaching practices at the end of semester.

**Data Analysis**

I used a phenomenological analysis approach (Moustakas, 1994) to analyze the data for this study. The analysis process from the field research was continually developed throughout the study, both at STEM education workshop and post-STEM education workshop. All individuals’ interviews were audio-recorded and transcribed verbatim. Field notes from the STEM education workshop, classroom observations,
interview transcripts and data from teachers’ self-reflection reports as well as STEM education workshop documents/activity manuals were dealt with as three forms of data analyses: (1) memos, (2) categorizing strategies such as coding and thematic analysis, and (3) connecting strategies such as narrative analysis (Maxwell, 2012, p.105). The steps of data analysis started in the two main settings: STEM workshop and the four teachers’ classrooms as shown in the following section.

**STEM education workshop analysis** I used the conceptual framework of mathematics PD (as shown in Chapter 1) as an analytical tool to analyze the characteristics of STEM education workshop and teacher learning. I placed the explanations of STEM education workshop characteristics as a part of data collection in Chapter 3 instead of the findings because it was not my main research emphasis. The results of teacher learning from the STEM education workshop were analyzed and presented in Chapter 4 as my findings. From the conceptual framework, I modified the core features of PD program of Desimone (2009): content focus, active learning, coherence, duration, and collective participation— to analyze the model of this STEM workshop. The analysis was therefore based on what activities or models the instructors implemented in the workshop, how long each activity lasted and what were the objectives of each activity. Moreover, I analyzed the knowledge and skills the instructors tried to increase in teacher learning from the workshop. The level of participation or teachers’ engagement was captured and the interactions between the instructors and teacher participants during the workshop were examined as well. In addition to analysis from my observation notes and memos, the secondary data such as STEM workshop documents,
STEM activity packets and the other related materials used in the workshop were analyzed to support my assertions.

**Teachers’ classroom analysis** Due to my focal interest in teacher learning, the classroom of the four selected teachers was the second step of data analysis. The data was collected from multiple sources in which I employed the tools. Interview transcripts served as the primary data source of analysis. Then I continued analyzing my observation notes, classroom artifacts, and teacher self-reflection reports.

I conducted the interviews with the four teachers in our first language, Thai. After interviewing, I transcribed all audio-recorded interviews verbatim in Thai. Verbatim transcriptions were used to prepare the interview questions for other rounds. Once all interviews were conducted and transcribed, I started reading each teacher’s interview transcripts. I coined the pseudonyms for the teachers based on the Thai months (Tanwa = December, Kanya = September, Mena = March, and Mesa = April). They are quite common names in Thailand. According to what I found in the field settings, each teacher had differing background in professional experiences and teaching, and school and classroom context, which permitted me to construct a multiple-case study analysis (Yin, 2009).

Next, I reviewed the set of interview transcripts of each teacher in order to analyze them case by case. First I started with Tanwa case, followed with Kanya, Mena and Mesa case analysis. I conducted a similar coding process for all four teachers. I considered myself as the key analytic tool, thus I started coding in the transcripts when I discovered the relevance to my research question. I initially created the codes derived from my conceptual framework Part 2 (key component and characteristics of effective
mathematics instructions) and Part 3 (teacher change) (see Figure 3-13). When I found some interesting evidence that emerged from follow-up interviews or extra conversations, I added them as emergent codes (see Figure 3-14). I wrote all the codes at the margins of the interview transcripts. I also marked or underlined some statements which later on I quoted in my paper. In the finding chapter, the excerpts of the teachers’ quotes in Thai were juxtaposed with English translations.

Figure 3-13: An example of initial coding derived from the framework Part 2 and 3.

Figure 3-14: An example of emergent coding based on evidence from interviews.
When I finished the first round of coding, I read through the transcripts again and tried to recode and combine the similar codes. I collapsed the codes and categorized them in the table and filled in excerpts from the supportive quotes as shown in Figure 3-15. Lastly, I attempted to create themes which emerged from the collapsed common codes for each teacher.

**Figure 3-15:** A tabulation of collective codes and supported quotes.

I analyzed my observation field notes by recognizing and highlighting key behaviors such as teacher-student interactions and discussions or specific events that happened during the instructions in support or contrast to the interview transcript analysis. The observation field notes were first used to develop the questions for the follow-up interviews to gain more clarification. Likewise, the field notes analysis benefited me for determining whether there were some contradictory events that might cause some misunderstanding or lead to misinterpretation at the end. Classroom artifacts were then analyzed to understand the expected outcomes that teachers were willing to
have in their students. Classroom artifacts were used as the tools to develop student learning in terms of knowledge and skills. At the same time, they could reflect the teachers’ beliefs, attitudes, and pedagogies, so that is why the analysis of classroom artifacts was counted in my study.

Lastly, analysis was on teacher self-reflection reports. Although I gave numerical values from 1 to 5 to each scale, the average value of frequency would not explain much without additional descriptive explanations. I calculated the scores that the teachers evaluated themselves on with regards to classroom preparations, classroom teaching, and classroom assessment on the basis of the frequencies of acting in particular repertoire (Part 1). I compared the scores, interpreted, and linked them with the other descriptive results to determine the effectiveness of classroom implementation presented in Chapter 5. The analysis of the reports allowed me to investigate the teachers’ classroom instruction in general and the phenomena of STEM integration in the teachers’ classroom.

Overall, the case study of each teacher was investigated and the findings were represented in two themes in Chapter 4. Additionally, there were some common themes that emerged with sufficient evidences during the analysis process of these four cases. As a result, I continued a cross-case study from these four individual cases in order to possibly explain new findings pertaining to the commonalities and differences of phenomena under specific circumstances. The findings are shown in Chapter 5.

Trustworthiness

I applied the four criteria of Guba’s constructs: credibility, transferability, dependability, and confirmability in establishing the trustworthiness of my research study
To achieve credibility or internal validity, I immersed myself in the settings with the teachers both in STEM education workshop and in their classrooms. I built up relationship with STEM organizers and the teachers to gain trust. As a result, I was able to understand the characteristics of STEM education workshop as well as the differences in school cultures and classroom atmospheres. With the prolonged engagement in teachers’ actual classroom practices, I was able to receive detailed and in-depth information from the teachers’ perspectives based on their responses. Although my qualitative research did not aim for generalizability, to ensure transferability or external validity I deliberately explained the context of STEM education workshop and school setting where the phenomena were presenting. I presented the process of selecting teacher participants and provided the selected teachers’ profiles. I anticipated that information of my study context and participant selections and profiles were sufficient to benefit other researchers to replicate the study in a similar context or apply in other settings. In addition, the reliability (dependability) and validity of my findings were strengthened through the research design of data collection and data analysis. I utilized multiple tools to gather the data. The data was triangulated from the following data sources: memo and field notes from classroom observations, transcripts of teachers’ interviews, classroom artifacts, and teacher self-reflection reports. The multiple sources of data gathering and triangulation helped to promote the confirmability or objectivity of the research in which its findings resulted from participants’ responses. In summary, triangulation was designed to eliminate or at least reduce bias as well as deal with validity threats in this qualitative research (Maxwell, 2012, Lichtman, 2013).
Limitations and Delimitations of the Study

Limitations of the current study were that the timing of the STEM education workshop was organized toward the end of the Thai school calendar year limiting the ability of the teachers to implement what they gained in the workshop. In addition to that, the workshop ultimately attempted to promote changes in classroom practices through STEM integration but did not realize how the rigid Thai school curriculum and examination system significantly affected teachers’ abilities to start new practices. The process of teacher selection also affected my methodology. Based on the total of 139 teacher participants from different STEM disciplines in the workshop, it was challenging to select the four mathematics teachers by my proposed criteria for teacher selection. As a result, I had to adjust the criteria of teacher selection and employ a convenience sampling method. Additionally, there were some unexpected school events occurring during my classroom observations that interrupted the teachers’ plan for implementation. As the observations were conducted under the teachers’ permission only, it was out of my control to specify the exact numbers of classroom observations. Thus, the numbers of my classroom observations largely varied among the four teachers. The delimitations of the study presented from my professional background as a mathematics teacher in Thailand and having experience in Thai school and student contexts in the northern region. These explicit characteristics may have caused some biases in the scopes of my study focus, research designs, justifications of explanations or conclusions of these four Thai mathematics teachers.
Chapter 4

Findings

In this chapter, I respond to my research question: What aspects of a STEM education workshop in Thailand do mathematics teachers integrate into their classroom after participation? I observed the classroom instruction of four Thai mathematics teachers, with attention to the knowledge and skills they integrated into the classroom after participating in a STEM education workshop. I also investigated the extent to which teachers were able to implement what they learned during the STEM education workshop. This study is a multiple-case study of four teachers: Tanwa, Kanya, Mena, and Mesa, respectively. I begin each case with a characterization of the teacher’s classroom phenomenon. Then, I present themes that emerged as assertions from the multiple sources of data.

A Case Study of Tanwa

Tanwa’s Classroom Phenomenon

Tanwa has been teaching mathematics in every secondary school grade for 15 years. He holds a degree in mathematics. He is a government teacher with the academic title “Professional Level (K-2).” This academic year he taught Grade 9 to Grade 11 in both fundamental and supplementary mathematics courses. I observed only the “Math and Sci” classroom of 30 ninth graders. A week after attending the STEM education workshop, Tanwa returned to the school and implemented two STEM activities: Tower Model and Yang Fruit as a Glider. Based on his previous teaching plan, he would prepare the students for O-NET (The Ordinary National Education Test) after covering all
mathematics content areas for this semester but he changed the plan to introduce STEM in the classroom. As Tanwa explained, “Prior to attending the STEM education workshop, I had connected a few STEM content areas, for instance, when learning parabola, students would only learn about its applications in telecommunication via video clip but would not learn through activities.” Thus, this was his first time to set STEM experiences as a classroom activity for the entire class period.

With an aim to effectively integrate STEM for the next academic year, this STEM classroom implementation served as an experimental site for Tanwa to learn more about STEM practices in the classroom. He decided to implement STEM in the high-performing classroom of Grade 9, although a few students are weak in mathematics. “Some of them [Group 1] failed my tests but they were pretty good in group work assignment,” Tanwa said. He also confirmed that the students are enthusiastic and have confidence to discuss and explain their thinking in the classroom. As Tanwa mentioned in the first interview, he developed flexible activity plan that allowed him to adjust if needed. He adopted learning activities from what he learned at the STEM education workshop. In doing so, he added some conditions to the project design, materials to develop the tower model, created a student worksheet, and searched some video clips about the tower exercise. Tanwa said, “I mainly use step [-by-step] teaching, namely students will work, learn, help, compete and be assessed in a group.” He claimed to use authentic assessment (e.g., ability of group participations and interactions while doing activities) for this STEM activity because it was only a supplemental activity to enhance students’ mathematics skills. On the other hand, he used paper-tests for mathematics content assessment in the regular classroom. Tanwa expected that this STEM activity
would cultivate students’ learning motivation, understanding the importance of mathematics and its real-life relevance. The significant goal is students would learn more easily and be able to maximize their capabilities of thinking, designing, and practicing by themselves.

Tanwa conducted the STEM learning activities in the school’s mathematics lab. He used group work to run activities and create competition among groups. First, he assigned students to groups of five with some conditions. When I first observed, the students were already seated. Tanwa explained that weak mathematics students would choose to sit in these six groups first, and later the rest of students who are higher performing would disperse in different groups. Interestingly, the students who are weak in mathematics tended to sit together in one group. After that, Tanwa started his first STEM activity with assistance from a science teacher who participated in the same STEM education workshop. The descriptions of his STEM instructions are shown as follows:

**The description of Tower Model activity.** Before the class began, Tanwa set up the projector screen and computer. He opened a YouTube video link of the sky towers in Asia. He prepared project materials (plastic straws, clear adhesive tapes, plastic and nylon ropes, and disposable bamboo chopsticks) and other school supplies (marker pens, newsprint papers, scissors, utility knives, cutting mats, measurement tapes, and stainless steel rulers) on the table in the back of the classroom (a supply unit) (Figure 4-1). The science teacher assisted Tanwa at the supply unit where students would make a purchase during the activity. The school’s Department of Mathematics budget provided funds for all project materials, tools, and other supplies.
In the classroom, Tanwa turned the music on until the students settled down in their groups. Using music was one technique he used to tune his teenage students in a better learning mood, motivate them to engage in activity, and improve the teacher-student relationship. When the class was ready, Tanwa introduced me to the students and the science teacher. The students greeted me with Thai respect gesture, Wai (Palm together at the chest and bow the head). He arranged a seat for me at the back corner of the classroom and allowed me to closely observe in-group activities. He reminded the students what they were going to do in this class. He began to ask the students about the purposes of building the tower in the past comparing with its functions in the present. The students shared a variety of ideas. For instance, it was used for watching enemies’ deployment during the war, as a clock tower, or observing in a long distance, like lighthouse and observatory tower. Tanwa noted that nowadays, towers functionalize in digital telecommunication. Beyond their functions, they also represent the country’s
architectural potential. Consequently, it becomes a competition among countries to construct a sky tower to achieve at least these criteria—the most attractive, tallest, strongest and functional tower.

To gain more students’ attention, Tanwa used video clips of sky towers in Asia, including in Thailand as a visual introductory activity. Then, he introduced the Tower Model activity and distributed the handouts to the students. The activity required the students to design the tallest and the most functional tower and develop the model. As a competition, each group needed to minimize the cost of purchasing project materials, however, the other school supplies have no cost. When each group purchased project materials from the science teacher, the students had to record the budget they spent. In case of over-purchase, the students could later return the unused items and receive the money credit back.

In order to carry on the project activity within 2 periods (100 minutes), Tanwa set a defined time for each step: 20 minutes for design planning, 50 minutes for developing the model, and 3-5 minutes for each group presentation, and 10 minutes for classroom discussion. The time was set and displayed on the projector screen. “If I let them work for 2 hours [2 periods] without displayed time, they might think they can get it done in time. In fact, they may or may not, so I would like them to check if their progress associated with elapsed time or between products and time. It helps them to plan their work and ensure that they can finish work on time or whether they need to speed up their thinking and working,” Tanwa explained.

The first session was a design planning in 20 minutes. Tanwa encouraged the students to study the handouts in order to have some initial ideas for their own models
It was during the brainstorming time that Tanwa engaged the students to share their ideas and imagination as well as share responsibility in group. During time on task, Tanwa and the science teacher walked around to monitor the students engaging in work but they did not interfere with students’ working unless the students had questions.

**Figure 4-2:** Students studying the handouts and brainstorming on a tower design.

After brainstorming, each group sketched the tower design on the newsprint paper with its functional detail. As I observed, the students actively engaged in-group work and shared the responsibilities. One or two students sketched the tower; one calculated the cost of the materials purchase list, whereas the other was writing about what STEM knowledge that was integrated in the tower model construction (Figure 4-3 and 4-4). Although, each group member had their own tasks, they also consulted each other for comments and shared ideas (Figure 4-5).
Figure 4-3: One student sketching the tower whereas the other was calculating the cost of model construction.

Figure 4-4: Students listing what STEM knowledge was integrated in this Tower Model activity.
Tanwa reminded the students that each group had to present the tower design to the class before moving to the next session, model developing. When time was over, Tanwa used “draw number from a hat technique” to order six group presentations. Each group presented the ideas of tower design, its functions and opened question-and-answer session to the classmates (Figure 4-6). Tanwa did not ask any questions. He said, “I want the students to pose and answer questions as much as possible because their learning occurred from questioning…. [Also] if they think and ask their own questions, they will more actively listen to the answers.” The students had more questions to ask their friends, but due to time limitations, Tanwa decided to move on to the next session and encouraged the students to continue their discussion after class.
In the model developing session (50 minutes), each group was requested to calculate, purchase, and record the project materials at the supply unit. “Keep in mind, purchased materials must be judiciously used to minimize the cost,” Tanwa emphasized. Each group received the copy of purchase list while the original one was collected at the supply unit. After purchasing, each group carried on model developing. Tanwa told the students to share group task and manage time on task in 50 minutes. The students started working; some groups worked on the floor while Tanwa and the science teacher were walking around and providing advice when needed. The music was on during the session to increase students’ motivation in working. Although the students made many noises and talked quite loudly, the topics of conversation were on-task. Figure 4-7 displays the classroom atmosphere during model constructions.

**Figure 4-6:** Group 2 and Group 4 presenting their ideas of tower design.
Although the class was over, the students continued working in their group. They were reluctant to leave and negotiated to stay another half an hour even though it was the last class of the school day. Instead of giving extra time after school, Tanwa promised them that he would allow an extra 20 minutes to work in class the next week. He asked the students to keep their unfinished models on the top of the book shelves. Tanwa realized that 50 minutes for developing the model was not sufficient. At the second observation, Tanwa had only one period (less than 40 minutes) left because there was an unexpected school activity that took his students out of the classroom. When the students were back, Tanwa let them continue developing the model until they finished. The students returned the unused project materials and calculated the final cost of model construction. During the next class (my third observation), each group presented their models and explained about the integrated STEM knowledge with question-and-answer session. However, there were few questions from students. Tanwa criticized, “The students had less interest because it [the Tower Model activity] was not new for them anymore so now they became bored.” The last session was project assessment. From the
handouts, the assessment lists and scores were provided—product (30 points), time spent on task (10 points), cost (10 points), presentation (15 points), engineering design (15 points), and STEM knowledge integration (20 points). In fact, all groups received the same scores on the other assessment domains except product and cost assessment. As the competition was set, each student received a sticky card to vote for only one model of the other groups that they liked the most. Tanwa also had to vote. The model with the highest counted votes got the full points of 30, the rest would be deducted one point down respectively. Likewise, the group that spent the least expenses got the total score of 10 points while the other would be deducted one point each. At the end, Tanwa categorized and displayed the results on the projector screen. He and the students discussed and reflected on the Tower Model activity. For instance, what are the differences between created tower design (imagination) and actual developed model (actuality) and what causes these differences?

**The description of Yang Fruit as a Glider.** Tanwa implemented the second activity from one of the ideas he learned at the STEM education workshop (paper helicopter). At the beginning, Tanwa talked about the Yang fruit that kids in previous generations used to play as a glider toy. Some students recognized and have seen its tree, but many of them did not. Next, Tanwa posed the questions about an object falling, “If we drop the two equal weight objects from the same height whether or not they will reach the ground at the same time.” Then, he illustrated two experiments and let the student observe and discuss about the following: (1) when dropping two sheets of paper, versus (2) when dropping a sheet of paper and a paper ball (a sheet of paper crumpled in a ball shape) at the same time and height. The students noticed that the paper ball first hit the
ground, however, many students misunderstood that it was because of differences in mass or gravitational force. In contrast, there were some students who argued that it was the effect of force related to the paper shape since its mass is equal and the force of gravity is a constant value. Tanwa had to correct them that scientifically, it was about the air resistance in relevance of surface area. The sheet of paper had larger surface area, therefore, it encountered more air resistance force which caused it to fall slower than the paper ball. The other question, “If we drop a bowling ball and a bird feather from the same height, which one will first reach the ground. Do they reach the ground at the same time?” Tanwa asked. The students replied “No” with different answers such as, unequal weight, density, and drag force in the air. To visually and clearly understand these scientific facts, he opened a YouTube link about a NASA experiment for the students to watch before introducing them to the new activity.

Tanwa created a scenario in which the students as NASA scientists are inventing a space probe equipped with the relay to orbit and land on the specific target. In applying the scenario, this activity challenged the students to create a paper glider that can stay longer in the air, and accurately reach the target on the ground. It was a group competition. The group whose glider was the slowest falling and the most accurate landing to the bullseye (the round target) on the ground would be the winner. The students had to build the glider and change its design to determine how it affects the accuracy of falling on the ground target. Because the students would explore the length of a glider’s wings plus the weight of the glider that affect the falling, Tanwa recommended each group create a data table to record the experimental outcomes. He prepared materials and supplies: paper templates of glider’s wings, cardstock paper, modeling clay,
scissors, measurement tape, and the paper round-bullseye target. Tanwa required each
group to design, build and test for the best glider with aforementioned conditions. Then,
each group had to demonstrate the glider falling at the end of the class (2 periods). In the
competition, each group would have only two trials.

At first stage, the students used only the given templates to build the gliders and
test their performance. They found that the gliders landed far from the round target
because they were too light. Tanwa gave them a hint to think about the shape of Yang
fruit. The students figured that the Yang fruit is a centric round ball shape with two
leaves and it has weight. Tanwa concluded, “That is why we need to add some weight
[for the paper glider] in order to increase the accuracy [of its falling].” Later, the students
added some modeling clay on their gliders and worked on falling trials (Figure 4-8).
Using only the glider template, the students were also able to design their own glider
from cardstock paper (Figure 4-9).

Figure 4-8: Students putting some modeling clay to add more weights on the gliders.
Tanwa asked the students to record the dimensions of the wings in each trial.

Tanwa provided each group 20 minutes on the trial session. When the session was over, each group demonstrated and presented the dimension of the gliders (Figure 4-10). The class completed with teacher-student discussion about factors or variables that created the slowest and the most accurate falling of the glider.

Figure 4-9: Students designing the glider’s wings from the cardstock paper.

Figure 4-10: Each group demonstrating the glider falling with glider dimension.
Theme 1: New Instructional Challenges When Implementing PBL Activities

According to the observational field notes, the interview transcripts and the other sources of my data collection, there was evidence supporting Tanwa’s unique classroom practices and what he learned from implementing the PBL activities. Drawing from the sets of coding, I identified Tanwa’s instructional challenges as my first theme. These challenges consisting of classroom climate, increased student autonomy, and time constraints and curriculum coverage are described with supportive evidence as follows.

First, I asked Tanwa about his prior understanding of STEM, STEM integration, and the new set of gained knowledge he learned from the STEM education workshop, he replied:

ส่วนใหญ่ที่ผมรู้ส่วนมากถึง การบูรณาการวิทยาพื้นฐาน วิทยาการและคณิตศาสตร์ รวมถึง ผมรู้ว่า

Mainly, what I know the most is that [STEM] is an integration of science, technology, engineering, and mathematics. However, from what I have seen [at the STEM education workshop], [STEM] has its level of integration. Stand-alone teaching [of one STEM discipline] could be one of its levels but it should integrate the other disciplines in the teaching course. Thus, I got some teaching ideas that if we teach our subject, it can be STEM and it is not necessary to teach all [STEM disciplines]. We teach our subject and insert the others in. Overall, for the best outcome, it must help students to be capable of self-thinking and develop their thoughts for excellence in all domains. I will try to enhance them according to this (Tanwa, Interview 1).

Tanwa engaged in STEM with engineering design practices in his mathematics classroom. He chose two PBL activities from the STEM education workshop and directly implemented them in the classroom: (1) Tower Model Activity and (2) Yang Fruit as a Glider Activity. It was nearly the end of the school semester, Tanwa nonetheless viewed
that it was well-timed for him to learn and prepare himself for further STEM classroom implementation. He created the collaborative group project because he knew that his students like group work and being in competitions.

**Creating positive classroom climate.** From what I observed during PBL activities, Tanwa and his students had frequent classroom interactions although most of the time the students engaged more in group work than interaction with Tanwa. In addition to the meaningful interactions, the way the students approached Tanwa and their comfortable feelings when communicating or asking him questions presented a positive relationship between Tanwa and his students. I noticed that this relationship was developed over time when Tanwa mentioned that he has been teaching this group of students for three semesters, therefore the students were familiar with his style of teaching.

Tanwa understood the importance of the classroom atmosphere. He built student engagement by creating a positive learning environment. Tanwa was friendly to his students. He provided the students autonomy to think, discuss, and make decisions in group work independently. Tanwa’s personal characteristics—a calm, kind and supportive teacher, plus a relaxed classroom atmosphere encouraged the students to ask questions and express their thoughts with confidence. He viewed that teaching should have a two-way communication. “If we [teachers] are very strict, they [students] might not dare to think, to practice, to ask, to get out of our fixed frame, and to create….”, Tanwa insisted.

In terms of classroom management, Tanwa described how he dealt with the students when they made too much noise:
Assessing and reflecting on classroom practices. After the first PBL activity (Tower Model), I asked Tanwa to summarize and reflect on his practice. The four steps I concluded from his interview responses are: (1) introduction of towers from the past to the present, (2) planning and design, (3) model development, and (4) project reflection and problem analysis. The details are described as follows:

During PBL activities, Tanwa was less strict on his students. He allowed the students to work and talk on-task with quiet music. Tanwa walked around to monitor the students’ group work and often stopped for their questions. Tanwa’s classroom was not similar to a Thai traditional classroom. It was loud with students’ talking and challenging across the groups. Overall, it was a dynamic classroom with students’ talking and moving. The floor was messy and full of project materials and supplies while working but it was clean after class. The students sometimes shouted to call teacher attention while Tanwa was talking to the other groups. Although he seemed too kind to the students, they respected his authority and classroom leadership. While Tanwa was talking, they all were quiet and listened attentively.

Assessing and reflecting on classroom practices. After the first PBL activity (Tower Model), I asked Tanwa to summarize and reflect on his practice. The four steps I concluded from his interview responses are: (1) introduction of towers from the past to the present, (2) planning and design, (3) model development, and (4) project reflection and problem analysis. The details are described as follows:
The first step was to introduce to them that the towers have been built since the ancient times. I showed some examples of the tallest towers… and their functions. Then, [I] introduced the importance of Thailand [with regard to exercise]. [We] also have one of the tallest buildings ranked in the world records. To present to them the importance of the activity would awake their inspiration… in creativity.

Next was step 2, students brainstormed and planned on how to design, and what kinds of materials were needed if given conditions. [They] had to collaboratively think, present the design, and purchase the project materials regarding to the design.

Then, [they] started developing the model until it was finished. This step was a slow process because [the tower models] might not go as designed. [I] let them modify [the design if needed]. Some groups could develop the models similarly to their designs while the other completely built them differently. Eventually, they realized that the real work might not be as it was expected. It leads to the situation where problem solving is needed.

At the last step, the students reflected on their final product and determined the STEM relevance. They identified the problems and provided some solutions for future improvement. [The last step] is applicable to real-life work where students have to find the ways to solve the problem when it occurred (Tanwa, Interview 2).

At the planning and design stage, Tanwa encouraged the students’ creative thinking and ideal imagination, while defining the real-world working conditions that the model development stage involved. In doing so, he set time and budget as conditions to the learning activity in order to promote students’ analytical thinking and understanding of the real-work context.
Tanwa designed flexible lesson plans for both activities. Therefore, when unexpected events happened he was able to adjust his plans. He modified the time for the student assignment, but the consequences of extending project time to the next day left him feeling less satisfied with the exercise. The students could finish their project, but they were no longer interested in the Tower Model activity. In addition, he considered that the students overspent both time and cost on project materials. He identified the problems and came up with some solutions for future implementation as follows:

I have too many choices of project materials. I might cut the disposable bamboo chopsticks out, then only plastic straws will be used. [So, they will] spend less time on it. In addition, plastic ropes will not be needed. Now I also think they wasted the materials thus it should be changed (Tanwa, Interview 2).

As I noticed, some students had fewer opportunities to ask questions during Q&A session. Often time, a certain number of students controlled the discussion and had more chances to ask questions. Tanwa insisted that he was not willing to manipulate individual students to ask questions, however, next time he might step in and engage the students who might have less interaction to ask questions.

Learning the lessons and mistakes from the first activity, Tanwa was later able to execute the second activity in the fixed time. His teaching procedure was smoothly run. Instead of directly telling the students the learning objectives, Tanwa illustrated some basic experiments related to force and motion as a body of scientific knowledge that the students would apply in the activity. He engaged the students in learning through the trial
and error method. This method promoted the students with fun experiments. Tanwa also observed his students and commented that.

Some students were active. They tried to creatively think of the ways to make it stay longer and accurately land on the target…. All students had fun…. (Tanwa, Interview 3).

As Tanwa mentioned about student participation in group work as a criterion of authentic assessment, he indicated that he was satisfied with the students’ group work and their cooperative learning. “Obviously, the students with high mathematics ability seemed to be a group leader who assigned tasks and distributed handouts among group members. Although, individual group members had their own thought, they all helped each other”, Tanwa claimed. Based on my observation of both activities, Tanwa only assigned the students into groups but the other responsibilities in group work such as assigning the roles or sharing tasks were fully on the case of the students. It could be said that the students had teamwork skills. Tanwa believed that the students’ readiness when it came to group work was a byproduct of the science project classes.

Perhaps, it was a result of [doing] science projects. Owing to being in mathematics and science program, they started learning in science project classes from Grade 7. They might work and present their science projects quite often, thus it was beneficial [to their mathematics group work] (Tanwa, Interview 2).

However, when asking about what he struggled with and needed to improve in further implementation, he answered:
Tanwa also assessed the STEM activity implementation and the satisfaction of his practices.

In addition, Tanwa demonstrated strong ambition and shared some ideas how to practice and improve his STEM teaching in the future classrooms.

Next semester STEM activities, I will establish [the STEM] Club and continue improving it. However, I will not fully implement in the classroom, I have to teach the [mathematics] contents first. It might not have sufficient time for STEM. If there is time left from completing content, like this Grade 9, I will arrange the [STEM] activity. I will focus on activities relevant to the learned contents. If I have more expertise [in STEM], I will design my own activities related to my teaching content. It might take long time to work on it (Tanwa laughing).... Instead of directly implement the activities from others [IPST], I will create my own. But it might be quite difficult.... (Tanwa, Interview 3).
Tanwa wrote a Teacher self-reflection report in corresponding to his interview to reveal that mathematics curriculum was packed with so much content and took a larger proportion of teaching time. Additionally, STEM activities were solely implemented in some mathematics topics. Implementing STEM in the classroom was time consuming as well. Thus, Tanwa viewed that time and a packed content curriculum were the barriers of STEM integration. Although Tanwa had passion about integrating STEM in his classroom, in real practice, it was an inevitable situation that covering curriculum was his teaching priority.

**Theme 2: Strong Intentions toward Changes**

Despite being his first time participating in the STEM education workshop, Tanwa recognized the significance of STEM learning activities in his teaching practices. The observed outcomes supported his strong intention toward implementing changes in his classroom. I use my Framework Part 3 to outline Tanwa’s idea of teacher change in classroom practice, student learning outcomes, and teacher’s beliefs and attitudes. The explanations are described as follows:

**Change in classroom practice.** To implement STEM in the classroom, Tanwa deliberately designed the new lesson plans with the ideas of integrating STEM knowledge and skills in the two activities. He set the learning goals, learning objectives and the set of integrated knowledge and skills as well as activity assessments. He created the hands-on activities and handouts based on what he learned from the STEM education workshop. Tanwa would not have made the changes in the classroom without the support from the school and his mathematics department. The school fostered Tanwa in terms of technology aids, school resources, and teaching materials in every learning activity.
Tanwa was able to make autonomous decision on adjusting teaching plans and designing classroom activities.

In accordance with the new activity plans, Tanwa changed his teaching approach. Instead of assigning the seatwork for students to work alone, he preferred group work to create interactive and collaborative learning activities. He first explained how he planned to implement STEM innovations in his classroom after participating in the STEM education workshop:

I will adjust [it] by leading the students to do some activities. [I will] start with simple one, like object building in order to promote students to think, have fun, and self-improve…. Now, I am applying Yang Fruit and Tower Model Activity. Also, I learned from internet that, I probably engage the students on bridge building. It relates to STEM learning as well, like learning about structure (Tanwa, Interview 1).

Tanwa created group competition to drive the students’ engagement and motivate them to work in teams. “The kids like it. They like doing experiment. The kids from this classroom, they are competitive in learning, doing homework but they help each other,” he said.

Due to implementation of the STEM activities at the end of semester, Tanwa did not have a chance to develop a STEM activity assessment form. However, he shared a plan to assess the activity by students.
After conducting a STEM activity, there will be an assessment form to assess whether students like or dislike this type of STEM activity and what they need for improvement. [I] would like the students to write the feedback. Normally, in regular classrooms, at the end of semester, there is also assessment of what the students need teachers to improve in teaching. So, I think probably a STEM assessment is needed as well (Tanwa, Interview 2).

Overall, Tanwa expected that his first STEM implementation would create a new STEM atmosphere for students to enjoy and have fun learning. In addition, the students would be familiar with his teaching approach in applying to their real-life situations. In this regard, Tanwa assigned the students to identify the STEM knowledge implemented in the project because it would help the students to understand the key elements of knowledge applications through their invented products. In terms of acquired skillsets from active learning through STEM activities, Tanwa anticipated that the students were able to master some essential skills such as exploration, presentation, mathematical process, and problem-solving skills in particular.

**Change in student learning and behavior.** Tanwa was impressed with the student outcomes. He valued group learning as an opportunity to improve student performances, especially, when the students were grouped under mixed-ability performance criteria. He noticed some positive changes while applying group work in the practical STEM activities.

Every time, I saw the development of their group work. If letting them work individually, only the high-mathematics performing students would finish work.
But working in group, they would help the other students who has less intentions. They will lead and assign work to each individual. Relatively, group work enhances [teamwork and] solidarity (Tanwa, Interview 2).

As a result of implementing the STEM activities, Tanwa reported some changes in his students’ learning and behavior. For instances, he was surprised by the work of Group 1 students specifically. As Tanwa mentioned, the students from Group 1 were less engaged in the regular mathematics classroom. They did not score well in mathematics content paper tests. In addition, they were frequently absent from the class. In spite of having first opportunity of group selection, they decided to be seated together in Group 1. Consequently, their group was labeled as “a weak group” of the classroom. Surprisingly, their group work was impressive, as Tanwa commented:

My most favorite one is this group (Group 1) who do not quite pay attention in the [regular] classroom. At first, I thought they might not work indeed. On the other hand, they did work, created work quite well, and paid attention all the time. Unlike in the regular class that [I] had to repeatedly tell them to work on assignment or to do this or do that, I had said nothing. They knew their roles, wrote, and worked by themselves. This group had only 3 students as the rest were sick or absent. That was them who don’t like to learn that much. During the activities, however, they did not evade the responsibilities, they were able to present, to work, or do everything like other groups. I really like the group work of these weak students who are not good at mathematics but are able to create and work like the other friends (Tanwa, Interview 2).

Tanwa seemed to pay more attention in Group 1’s work in activity 2 (Yang Fruit as a Glider). He also noticed that the students dared to think differently. During the trials, two of them were testing the paper gliders whereas the other was jotting down the results.
They repeated the experiments and recorded the dimensional changes of paper wings systematically. As I observed, Group 1 students worked step by step as planned while the other groups were determined to better develop their glider invention instead of writing anything down. At the end, all groups were able to accomplish every assignment in time before class presentation and discussion.

In short, Tanwa perceived that the students achieved positive learning outcomes from the STEM activities. At the same time, Tanwa regained the inspiration to continue implementing STEM and make an effort to create an effective classroom. He said, “I feel very impressed. They all helped each other. Nobody did nothing.” What I observed in Tanwa’s STEM implementation, it was not about the scores, but the student engagement in group work and their participation in classroom discussion as well. The students worked with self-motivation. Eventually, they were happy in the learning activities. These were all outcomes that Tanwa attempted to achieve in his students’ learning.

**Change in attitudes and beliefs.** Tanwa understood that the nature of mathematics is more abstract. He explained that the students felt mathematics was not related to their daily life. Not too many students would easily comprehend the importance of mathematics and its applications. Therefore, to help the students make more sense of the practical implementations of mathematics learning, Tanwa led the students to be involved with some STEM integration activities. Thus, he viewed that the learning innovation from the STEM education workshop he participated in could benefit students more than the traditional classroom activity.
I think STEM learning could lead the students to understand the systematical working of knowledge and its applications. Thus, their understanding would last longer than only [content] classroom learning which is easily forgotten. At least, for instance, they know how to adapt or modify and rationalize things. It is the experiment and being able to apply in reality (Tanwa, Interview 3).

Tanwa also pointed out that teaching through STEM activities benefits the students in the long run. It is because integrated learning of both content and STEM practices will enhance the students to be equipped with the skillsets necessary to be ready for the workforce in the future. Regarding the teacher self-reflection report, Tanwa concluded that STEM education learning is the best way to promote individual students’ ability of applying mathematics knowledge. In so doing, unlike in mathematics content teaching, Tanwa did not master the STEM classroom. Instead, the students were more likely to be the center of the classroom. In fact, his role as a direct teacher was faded out. He became a project advisor when students needed him and served as a significant facilitator of student learning.

A Case Study of Kanya

Kanya’s Classroom Phenomenon

Kanya is a government teacher with academic title “Practitioner Level (K-1).” She has been teaching mathematics for eight years. This year she taught only the ninth-grade mathematics both in fundamental and supplementary courses for 18 periods per week. I observed four different classrooms from these two courses. There were approximately 31-32 students in each classroom. Only two classrooms were math-sci
classrooms whose students studied more mathematics topics than the other two classrooms. They were the top students, mostly female, from elementary schools in the villages who passed the school placement test with high scores when they first entered in Grade 7. The other two classrooms were a cluster group of students, mostly male, with lower academic performances and tended to study more vocational subjects such as agriculture and have less mathematics and science classes. To clearly explain their differences regarding learning and classroom atmosphere, I name the students from these two groups of classrooms as math-sci students and non-math-sci students.

**Student characteristics.** Unlike the other teachers I observed, a portion of the students in Kanya’s classes are ethnic minorities in Thailand. Most of the minority students were non-math-sci-students. They come from the hill tribes along the borders of Thailand and Myanmar. Thai is not typically their first language but they are capable of communicating in Thai. Thus, language barrier is not a concern for their learning. These students are generally from the lower socioeconomic background. They have less motivation because education is not traditional part of their culture as most of them come from rural agricultural-based communities and their families have little education. They have high level of truancy and increase levels of behavioral issues in the classroom that are often rooted in their cultures. One example I observed, a high level of absenteeism is due to tribal tradition related to celebration of Chinese New Year. In my observation, this leads to Kanya spending a significant amount of time on classroom management and it impacts her ability to implement new innovation in the classroom. In addition to the hill-tribe students, a number of the ethnic Thai students were demonstrated disruptive
behavior as well. I did not observe behavioral issues to be nearly as large an issue in the other teachers’ classrooms I visited as I did in Kanya’s school.

Kanya’s classroom preparation. Kanya prepared lesson plans guided by IPST curriculum and standards. As she has been teaching Grade 9 mathematics for 4 years, Kanya is familiar with the contents and skills taught in this grade. She mainly used the IPST mathematics book, in the meantime, she added more challenging problems from other sources to help students articulate mathematical process skills. Instead of teaching from the book, Kanya created the PowerPoint slides as a visual tool to aid students’ learning. She showed her interest in using technology in mathematics related to STEM integration in the first interview. As she knew that the students nowadays are more likely interested in technology, she started using computer aids to increase student engagement and interaction during the lessons.

At the beginning of the classrooms, Kanya had to deal with student attendance. Often times, the students were late for class due to the long distance walk from the other buildings. Some of them skipped the classes. She carried her own computer to connect to the projector screen in the mathematics classrooms. She tried to cover the last two topics in the curriculum before preparing the students for O-NET test. I observed her teaching in two topics: mathematical skills and process and trigonometry. Most of my observational time was spent on first topic, mathematical skills and process. Kanya mentioned that this topic is broadly related to STEM integration as a crucial part of basic skill improvement. Next paragraph is the lesson learning through activities to develop mathematical process skills adapted from the IPST curriculum. Kanya claimed that she was able to integrate STEM knowledge in this topic more than the other mathematics topics.
**Mathematical skills and process teaching.** According to the IPST middle school mathematics curriculum B.E. 2556 (2013), the learning standards of this topic indicated that the students are able to demonstrate mathematical process skills to solve the problems in different situations and in appropriate ways. The mathematical process skills consist of problem solving, mathematical communication and representation, reasoning, connection, and creative thinking. The mathematical communication and representation skill was where Kanya placed emphasis in her teaching. “Once the students are able to communicate their mathematical thinking, express the ideas, and represent them with the use of mathematical language or expression, then, they will be able to continue solving the problems or creating new solution pathways by themselves”, Kanya explained.

From my observation in four classes, after introducing the use of activities for developing mathematical process skills and the learning objectives, Kanya posted the questions on PowerPoint slides to the classrooms and let the students work in groups of four, in pairs, or individually to solve. Kanya provided time for the students to work on tasks, however, Kanya took a greater control to lead problem-solving activities. Apparently, she used a “chalk and talk” approach in the classroom. This approach was explained by Kanya’s classroom situation in which she started asking for the answers from the students then writing down the solutions based on students’ talks and thoughts. When the students had no clues to begin solving a question, Kanya suddenly directed the class in problem solving because of time limitations. Kanya utilized a variety of different types of questions in the classrooms. Below questions are the examples from Kanya’s activity plans on the slideshows.
Activity Set 1: How many are there?
Baworn has some pencils to give to the children. If he gives 3 pencils for the first group of children, 1 pencil is left. If he gives 4 pencils for the second group, 3 pencils are left. And, if he gives 5 pencils for the third group, 4 pencils are left. At least, how many pencils does Baworn have?

**Figure 4-11:** An arithmetic word problem with number of pencils Kanya asked in class.

Kanya first asked the students to look for the first number to start with from the word problem (Figure 4-11). Number 9 was the students’ answer, then she suggested the students to set a table (Table 4-1) to carry out in the number corresponding to given conditions.

**Table 4-1:** The experiment table Kanya suggested to the class for problem solving.

<table>
<thead>
<tr>
<th>Number</th>
<th>3 R 1</th>
<th>4 R 3</th>
<th>5 R 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

The math-sci students spent more time to solve by themselves while the non-math-sci students were more directed by Kanya. In the math-sci classrooms, Kanya encouraged the students to work on more numbers in the table until they figured out
mathematics facts such as an application of divisibility rules. From the table, Kanya hinted that a number ending in 0 or 5 is impossible. Eventually, the students discovered that the possible answer must not be divisible by 3, 4, and 5. Next slide was the second question (Figure 4-12) about counting the numbers of squares in 4 by 4 grid.

![Activity Set 2: How many numbers of squares?](image)

*Figure 4-12: A 4-by-4 square posted for finding the numbers of squares.*

When the question was posted, the students visually counted and mentally added them up instead of writing it down in their notebooks. From my observation, Kanya preferred students to participate in verbal classroom interaction than note taking. In this question, Kanya encouraged the students to draw the partial figure in order to discover the patterns. First, she exemplified the 2-by-2 square and led the students to continue with 3-by-3, and finally work on 4-by-4 square (Figure 4.13). Kanya displayed the steps of counting on the whiteboard as follows:

<table>
<thead>
<tr>
<th>Step 1:</th>
<th>1. Count number of 1-by-1 squares</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. Count number of 2-by-2 squares</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3. Sum up the numbers of squares</td>
<td>5</td>
</tr>
</tbody>
</table>

Kanya presented the shortcut way of writing as

\[
1 \times 1 = 4 \\
2 \times 2 = 1 \\
\text{Total} = 5
\]
Step 2

1. Count number of 1-by-1 squares = 9
2. Count number of 2-by-2 squares = 4
3. Count number of 3-by-3 squares = 1
4. Sum up the numbers of squares = 14

Finally, most of the students were able to conceptualize that it is the sum of the first n-by-n squares, where n is the size of a square. For example, the numbers of squares in 4-by-4 square are $1^2 + 2^2 + 3^2 + 4^2 = 30$ squares.

Nevertheless, some students continued using mental counting to find the answer, Kanya supported them in any ways they were comfortable with to practice. In addition, Kanya engaged the math-sci students to continue working on 5-by-5 and 6-by-6.

Although, she motivated them to identify the number patterns and sequences as well as write down basic counting principles, she did not move forward on calculating with formula for arbitrary n of n-by-n squares.

Figure 4-13: Kanya working on counting patterns of numbers of squares.

Besides counting the numbers of squares, Kanya posted more challenging questions in counting the number of rectangles and triangles from the given figures
(Figure 4-14). She prompted the math-sci students to find the answer on their own while the non-math-sci students were given hints. Due to time constraints, to make sure that all students were able to learn on the same page from prepared lesson, Kanya always demonstrated the solutions in the classrooms.

**Question 3: How many rectangles are there?**

Given a rectangular formed of 7 1-by-1 square grids, how many rectangles are hidden in this figure?

**Hints:** counting numbers of rectangle in pattern 1x1, 1x2, 1x3…, 1x7, and sum up.

**Question 4: How many triangles are there?**

**Hints:** Counting the number of each following shape of triangles

**Figure 4-14:** Kanya posting questions with hints to find the numbers of rectangles and triangles.
In addition to the questions regarding visual counting and patterns, Kanya added more variety of word problems to develop mathematical communication and representation skills. The highlighted practice is to improve the students’ skills in solving a system of linear equations from the real-world problems. For instance, the students were required to solve the following problems and show step-by-step solutions.

**Problem 1: Chickens and rabbits**

**Situation:** Nittaya’s father has some chickens and rabbits. Normally, he keeps the chickens in a coop and the rabbits in the hutch separately. One day, he let all chickens and rabbits out at the yard. Nittaya walked out and asked her father the following question.

Nittaya: How many chickens and rabbits do you have?
Father: You have to figure it out by yourself. There are 30 chickens and rabbits in total with 86 legs all together.
Nittaya: It is not that difficult, father.

In one of the classrooms of math-sci students, Kanya assigned them to work individually in class while the other class was assigned the problem as a homework due at the end of period. No matter whether it was a classroom or a homework assignment, Kanya always illustrated all possible methods to the classes (1. Guess and Check, 2. Solving equation with one variable, 3. Solving equation with two variables). At the time of her writing on the whiteboard, she asked the students in every step of solving the problem questions to assure their understanding through the whole process.

Kanya started “when defining x is the number of chickens,” “then, 30-x is the number of rabbits,” the students added. Kanya asked, “why is that?” The students replied, “If we combine x and 30-x, the result is 30.” “Are you sure that x is the number of chickens, not the number of chickens’ legs,” Kanya further asked. “Yes,” all students
clearly replied. Next, she continued, “So, now we know that 2x is the number of chickens’ legs and,” “4(30-x) is the number of rabbits’ legs,” the students answered.

The reason is that Kanya was determining if the students might be confused with all unknown quantities. After that, Kanya and the students proceeded on writing two equations, solving, and checking for the right answers. By contrast, in the classrooms of non-math-sci students, Kanya seemed to lecture them by going through all methods of problem-solving procedures without providing time for practice. “In fact, I would like to assign them homework, however, I really know that they would not get it done. It is better to teach them and let them understand in class,” Kanya concerned. After that, Kanya moved on to more complicated but fun real-life problems such as Problem 2 and 3. The problems allowed the students to use any methods which are meaningful to them and make sense of answering questions.

**Problem 2: How many ice-cream bars?**

An ice-cream parlor has offered a promotion for the customers to give away free ice-cream bars. Once they hand over any 5 ice cream bar bags, they can receive 1 free bar. Tan collected all 29 ice cream bar bags including her friends’ bags. How many free ice cream bars will she possibly receive?

The question promoted students’ engagement and classroom discussion. First, a lot of students promptly answered 5. Kanya reacted with silent response to signal that they have to rethink it logically. The class started sharing their opinions and finally came up with the answer 6 which was the correct answer. Kanya asked the class to explain their thinking and she would write it down as a written diagram shown in Figure 4-15.
Figure 4-15: Kanya’s written diagram based on students’ explanations.

Kanya presented the written diagram from the students’ explanations. In the following statement is the students described their rationale to solve the problem step-by-step, “From 29 ice cream bar bags, and you take 25 of them to trade for 5 ice cream bars. Then you use those 5-ice cream-bar bags to receive one more free bar. Now you have one more ice cream bar bag to combine with the other 4 bags to receive the last one bar. Therefore, Tan can possibly have 6 free ice-cream bars in total.” The class ended with fun time and funny conversation to extend the situation, for example, whether Tan will share the ice cream to her friends since she collected some bags from them or she will eat all by herself. Some students mentioned about the deadlines for promotion and limits of giving away ice cream bars per person to make more sense in the real-business marketing plans.

Problems 3: How many minutes for boat rowing?

Somsak is rowing the boat at an amusement park. The ticket person charges him 20 Baht for the first 10 minutes. And every 5-minute excess will be charged 5 Baht. If he pays 40 Baht, how long can he row the boat?
Although, the math-sci students immediately answered 30 verbally, Kanya attempted to teach them how to show the written work. With her approach of “a chalk talk”, she created and completed the two-variable (money and time) relationship table on the whiteboard with the students. In additional to Problem 3, Kanya further asked 2 additional questions (3.1) if rowing a boat for an hour, how much should we pay? and (3.2) if paying 100 Baht, how long can we row? A lot of students quickly answered 80 but one student answered 70. Later on, they changed to 70 as the answer of Problem 3.1. Next, the problem 3.2 was answered correctly. Interestingly, when Kanya asked them to explain, they were reluctant to clarify their own thinking. Therefore, Kanya used the questions to elicit the student’s thinking illustrated as the following conversation:

“As you see in the table, we paid 40 Baht for half an hour, but given that every 5-minute excess costs 5 Baht, what is the average? Kanya asked. The students replied, “1 Baht per minute.” “So, how much do we have to pay for the other half an hour,” Kanya continued. The students rapidly answered, “30 Baht.” “Therefore, how much do we have to pay if rowing for an hour,” Kanya asked. “40+30 is 70 Baht,” the students answered. “Then, if spending 100 Baht, how long can we row the boat,” Kanya further asked. Some students said, “one and a half hour,” while some said, “90 minutes.” “Do you add another 30 Baht to 70?” Kanya implied. The students said, “Yes.” Kanya concluded, “So, for 100 Baht, we can row for one and a half hour.”

Overall, Kanya aimed to achieve that the students are able to apply basic mathematical skills and prior knowledge as well as express their critical and creative thinking either via verbal or written communication to solve the word problems in any methods. To demonstrate student learning by having written evidence of their work,
Kanya encouraged the students to represent their work by rewriting them in the form of mathematical symbols and statements, selecting appropriate methods of solving, and justifying the solving procedure. Finally, they show an ability to determine the possible results in responding to the given conditions of the real-life problems presented.

**Theme 1: Challenges of Implementing Activities for Developing Mathematical Process Skills to Non-Math-Sci Students**

Due to the differences of students’ academic abilities in the four classrooms, Kanya had to employ different strategies to gain student engagement, for non-math-sci students in particular. From my observation and interview with Kanya, classroom management seemed to be the most challenging problem that Kanya had to cope with. Although, she had sufficient management skills to handle the disruptive students, their inattention and poor behavior remained an issue in the classrooms.

**Classroom management.** Kanya spent a significant amount of time to establish students’ attention. She had to coax the students into a learning mode by casual conversation aimed at building a positive rapport with them. Sometimes, she used body language to convey messages to stop them from talking such as using eye contact and walking close to the students who were chatting. She moved around the classrooms to observe their behavior. She used a wooden stick (typically used as a whiteboard pointer) to gently hit on the table when the class was in utter chaos.
If the students made loud noise, I walked to them and asked if they had any problems. First, I friendly talked off topics a bit then tried to get them back to the lesson. Mostly, each classroom required different techniques. I had to overlook on how to manage the classroom. Normally, problems occurred at the day one (beginning of semester) because I had not really known the students, their classroom atmosphere, or their interests. Therefore, teaching in these four classes was totally different (Kanya, Interview 2).

From my observation, Kanya sometimes warned the students who distracted their friends during class by telling them that she will report their behavior to the student affairs department. Occasionally, she seated the talkative students away from each other.

“The talkative students were most likely to sit in groups, I moved the noisemaker to the other side of the classroom. He was quiet. Definitely, the noise making was reduced, but in terms of their classroom attention, it remained unsolved because somehow, it depended on individual student, too” Kanya described during the interview. Although the classrooms of non-math-sci students were loud and less likely had long-term intention in learning, Kanya never gave up her attempt at including them into the lessons. For example, Kanya created the friendly atmosphere to help the students feel safe and supported in the classroom.

I encouraged a friendly teacher-student relationship, but not to the point that they do not respect me as a teacher. The reason for being friendly with them is to let the students comfortably interact with me. However, the students in some classrooms were likely disobedient thus I need to set the tone for them [e.g., classroom behavior], sometimes giving them a warning (Kanya, Interview 3).

Kanya made a meaningful conversation with the students when they had some questions and engaged other students to participate in the discussion. She encouraged the students to ask any questions even if they were off-topic questions.
Getting the students engaged in learning. In the non-math-sci classrooms, the students had less active academic interaction. Kanya made an effort to gain students’ attention. Although Kanya applied mixed-teaching methods, she employed lecture as a dominant use of classroom teaching, in non-math-sci classrooms, particularly.

[My teaching styles] are mixed, including giving a lecture. After lecturing, I will divide the students into groups for collaborative work. Mostly, if it is new content that they have never learned, I prefer lecturing…. The proportional teaching time by lecture is about 60 [percent] (Kanya, Interview 1).
Kanya attempted to deliver the maximum content coverage to every class. She utilized the problem slides as a task to orient the students to learn. The math-sci students had five periods per week in both fundamental and supplementary mathematics, whereas the non-math-sci had only three fundamental mathematics periods per week. In the math-sci classrooms, the students had more chances to practice additional complex problems for solving as time permitted. In fact, the non-math-sci students engaged in less task materials because Kanya overspent time on classroom control. In order to maintain equal learning opportunities, however, Kanya provided an option for the non-math-sci students to choose the questions based on their interest developed from the classroom conversation.

Sometimes, when I continued talking with the students, they responded, they added on some stories that fit my PowerPoint slides, then I was able to bring it up to learn at first…. It depended on the students’ classroom context, and how much they were interested in…. depended on the students (Kanya, Interview 2).

During lecture time, she applied several strategies to capture the students’ interest in learning. The most useful strategy Kanya often used in class was drawing a diagram to represent word problems. She confirmed that drawing a diagram was a visual representation to help the students easily understand the problems. Kanya used a diagram drawing for all students. In math-sci classrooms, Kanya drew the diagram to guide students and they were able to solve the problem presented by Kanya. Later, she required the students to draw a diagram and solve on their own. The non-math-sci students, on the contrary, were guided on organizing their thoughts before further moving to
mathematical manipulation together in class. For example, after learning about trigonometric ratios, she used diagram drawing to represent the trigonometric word problems. Besides drawing a diagram as a solving strategy, she also showed the left-hand trick to help students memorize the unit-circle values (Figure 4-16).

Figure 4-16: Kanya drawing a diagram, using left-hand trick, and solving the problems.

She explained the left-hand trick step-by-step on the whiteboard while the students enjoyed counting the fingers and responding to Kanya’s questions (Figure 4-17).

Figure 4-17: The students writing numbers on the fingers representing the basic angles while Kanya teaching the left-hand trick to the class.
Even though, Kanya preferred the students to participate in classroom discussion, unlike the math-sci students who proved they were accountable for their learning the classroom contents, Kanya adhered to writing out the work for non-math-sci students with minimal classroom discussion.

In fact, [I] want them to take notes, or write some concepts down, but they did not. Sometimes I had to enforce them to write…. For instance, if not taking notes, [I] wouldn’t let them out when the class was over. Thus, when they saw their friends had been taking notes, once their friends finished and got the teacher signed and moved out, they needed to go out as well. So, they would hurry to jot it down (Kanya, Interview 2).

When I asked Kanya if she can engage the non-math-sci students to participate only in asking and answering without writing down in notebook, she reasoned, “Using only questioning techniques is not replaceable. Taking notes would provide learning evidence in which they were able to recall and read over later on. Unlike questioning, when their questions were answered, it’s done. Probably, they might not extend further their thoughts anymore.”

As I mentioned earlier, Kanya had been trying several teaching approaches to enhance students’ learning. She also tried to create a group assignment. She divided the students to work into groups of four and in pairs, however, the group work was not effective due to off-task talking.
The reason for assigning them to work in groups of four was to promote thinking process skills, so the students would be able to ask and discuss critical information with each other. It turned out that they were grouped but did not think, or sometimes talked off-task. Then, I decided to group them in pairs, again, chitchatting was still existed. Thus, I would rather them to think individually (Kanya, Interview 2).

In addition, Kanya encouraged and provided opportunities for the non-math-sci students to express their thinking. As I observed, there were few students who dared to present their ideas in front of the class. “In this topic relating to process skills, the students had several ways of thinking, when I let one student present in front of class, the other classmates who had different ideas would disagree and be confident that only their own way was correct. They started to shout and embarrass their friend who was presenting,” Kanya described. Since Kanya understood the nature of her classrooms and students that they felt comfortable not to share ideas in front of the whole class, therefore, she accommodated them by walking close to the student who had ideas to share and listened to him/her. Then, Kanya would convey his/her messages to the classmates.

It is unfortunate situation that Kanya had limited amount of time to promote positive classroom atmosphere for building up students’ confidence. Apparently, Kanya devoted her time and energy to promote the non-math-sci students’ process skills. Even though she mastered all the classes in learning process, mainly in problem solving, these students were independently and actively involved in lesson by Kanya-directed questioning strategies. Although Kanya might not have been able to get all the students
engaged in classroom learning, she did her best to shift them from passive learners to become active receptive participants in class work.

**Theme 2: Kanya’s STEM Learning, Implementation, and Expectations for Future Change in the Classroom**

From her teacher self-reflection report, Kanya understood that STEM education is a learning activity in which four disciplines—science, technology, engineering, and mathematics are integrated, aiming to enhance the process skills of learners. She heard about STEM information from several sources, however, to integrate mathematics with the other disciplines in actual practice was a new idea for her. She positively viewed that teaching through STEM integration promoted student-centered learning. It is an interactive teaching method to get the students engaged in learning. Therefore, it is different and more effective than traditional approaches.

[I] think it is different because in the past, [we] put emphasis on lecture…so, students had less learning by practice. But, STEM is like integrating multiple subjects in which individual students are more likely to participate and practice on their own (Kanya, Interview 1).

Kanya claimed that at that moment, the mathematics topic she was teaching was similar to the idea of STEM taught in the STEM education workshop. As a consequence, she comfortably connected the STEM knowledge and skills from the workshop with five mathematics process skills as aforementioned. Particularly, she linked the inquiry-based learning taught in the first session of STEM education workshop with the problem-solving skills in mathematics. As previously mentioned, she focused on mathematical communication and representation because she strongly believed that once the students
were capable of mathematically translating from word problems, they would be able to solve the problems. In accordance with her response from the interview, she noted that mathematical problem-solving skills aligned with STEM learning and it is one of crucial soft skills in the 21st century.

**Significant factors that affected STEM classroom implementation.** According to the final interview and self-reflection report, Kanya was concerned about time limitations and a number of contents for curriculum coverage. When I asked how she applied the STEM innovations from the workshop into her classrooms, she thought for a moment and replied to me that she was not sure whether or not her plan of STEM implementation was in the same direction from what it should be. She reported that it would be better if there were some guidelines of STEM implementation that existed from the previous group of participants in STEM education workshop. For her classroom, she implemented STEM based on her understanding. Thus, she preferred to adapt STEM learning from the workshop by enhancing the students’ thinking process skills instead of assigning the students to work on the group project. “Group project requires a lot of time, but I teach each class only 50 minutes per period. As well, I have a lot of mathematics contents to cover, so I can partially insert STEM knowledge in the class but not for the whole period,” Kanya claimed. Besides time constraints resulting from overloaded curriculum, the extra school activities without advanced notice to the teachers affected Kanya’s classroom practices. Kanya exemplified that due to a tight schedule, she got the students to study in one period of consolidated 2-period-lesson plan and assigned them some extra exercises.
In conclusion, Kanya pointed out that it takes a longer period of time to improve the thinking process in learners and the duration of time for STEM learning is limited. Regarding the matter of content covering, the Thai mathematics curriculum is overloaded with content which needs to be taught, and some topics are not easily integrated with STEM. Moreover, As Kanya experienced with different academic groups of students in classroom learning, Kanya viewed that not only teacher but also students are key for successful implementing STEM in the classroom. Students’ academic readiness matters for the levels of participation in STEM activities. Lastly, too many unexpected school events also affected Kanya’s teaching time and had impacts on students learning eventually.

**Kanya’s perceptions of implementing STEM in future classrooms.** Kanya realized the essences of STEM learning and its relevance of future skills needed in the 21st century. She viewed that implementing the four distinct STEM disciplines in the classroom will promote process skills in students. As a mathematics teacher, Kanya had a plan to develop her students to achieve the five-components of mathematical skills—problem solving, mathematical communication and representation, reasoning, connection, and creative thinking. Unfortunately, she might not be able to fully engage the students in learning by practice based on time constraints. Kanya discussed some ideas on how she planned to implement STEM in the classrooms. For instance, in trigonometry classroom, she planned to assign the students to practice using the mirror and the set of 30/60 and 45/90-angle-triangle rulers to find the height of the objects such as school flag pole, trees, and school buildings, find the width of school pond as well as the distance between the buildings. In addition to trigonometric applications, Kanya
further thought about topics of inequalities, probabilities, and statistics for which she could integrate mathematics with other STEM subjects by applying daily-life problems. Despite facing inevitable challenges (e.g., time, students’ readiness, and curriculum coverage), Kanya is willing to improve and make some changes in her teaching practice toward the STEM guidelines as she perceived that in the end it helped to increase her students’ classroom engagement and their learning.

A Case Study of Mena

Mena’s Classroom Phenomenon

Whereas the majority of school teachers are government teachers with professional titles, Mena is a school-contract teacher. She has been teaching mathematics for five years in this boarding school. It was her first teaching position after her graduation from university. This year she was assigned to teach only statistics as an elective course for different grade levels. I observed only a classroom of Grade 8 that Mena was teaching. It was a classroom of 10 eighth graders in statistics including seven boys and three girls. This group of students freely selected this course by themselves.

Before I observed Mena’s classroom, I was introduced to the head of the mathematics department and a retired school director who visited the school on that day. I was able to gain important details from insiders about the distinctive characteristics of the school and students. As mentioned in Chapter 3, Mena’s school context is different from the other teachers’ schools in several aspects. It is a special free-public boarding school for only talented mathematics and science students. The school selected the students who achieved the highest (top 3%) academic performance in mathematics and science in their cohort and passed a special entrance test from IPST and also received
high scores in the regional level placement test. The school provided only 96 seats in a total of 4 classrooms (24 students/class) each year for the entering Grade 7 class based on the number of provided science-laboratory-equipment sets. All of these students received academic merit aids covering books, school supplies, and free accommodation from the government from Grade 7 to Grade 12.

**Academic support and requirements for Gifted-Grade 8 students.** It was obvious that all students had been screened for their academic readiness level prior to entering the program. Besides, first-year placement test, the students were evaluated for their academic abilities again in order to continue studying in the high school level (Grade 10-12) at the end of Grade 9. The students have to compete with outside school students who are focusing on science and mathematics in the high school level as well. It is a very competitive situation that all students have to maintain their academic performances and qualify with certain grade levels in each semester. Additionally, to graduate the middle school level, the students have to read 50 additional books with reading notes recorded by school librarians. The required number of books will be less if the students read other foreign books (e.g., English books). Significantly, the students are required to start working on either mathematics or science projects and present proposals in their first year of school. At the end of Grade 9, the students must present their projects as a compulsory graduation requirement.

In addition to regular school time, the school provides evening study time from 6:30 – 8:00 pm for students to work on homework assignments, read books, or get extra tutorials under the care of on-duty teachers. The school sets a schedule for the teachers to stay overnight with the students, especially teachers who live on site. Mena is one of the
teachers who was responsible for managing time and evening academic programs. During
weekends, the school offers advanced tutorials for students as well, however, the students
are allowed to go home with parents or guardians every three weeks according to the
school academic calendar.

In terms of curriculum management, the school’s customized curriculum is
adopted from the national curriculum to be more concentrated in mathematics and
science. Thus, the students are required to have more extra hours of mathematics and
science studies. In the middle school mathematics program as an example, the students
study in fundamental and supplementary mathematics similar to the other public schools
but more in-depth and focus on more advanced content. The supplementary mathematics
are divided into two groups. Supplementary mathematics group 2 differs from group 1
because it provides elective courses in which the students are able to select based on their
interest. This is a unique academic model compared to the other public schools based on
the intense content and pragmatic teaching elements. To complete the middle school
curriculum, the students must study at least four courses of supplementary mathematics
group 2 in addition to other mathematics requirements. Elementary statistics which Mena
taught is one of the courses in supplementary mathematics group 2.

**Gifted-Grade 8 students in Mena’s statistics classroom.** According to the
national mathematics curriculum, elementary statistics will be first introduced in the
second semester of Grade 9 and applied statistics will be taught in Grade 11. Unlike the
normal curriculum, Mena’s school mathematics department created the statistics topics to
teach for Grade 8 in the measures of central tendency and the distribution of data in—
quartiles, deciles, and percentiles for ungrouped and grouped data. It required the
students to comprehend the descriptions of —mean, median, mode and specified-ile positions, and be able to find the values corresponding to them. The class started every Friday afternoon for 2 periods in 100 minutes. I observed Mena’s classroom three times, however, one time was used for the chapter test.

Mena prepared a statistics-learning packet including content sheets and worksheets covering both topics. Mainly she designed the lesson plans by herself with some guidance from experienced colleagues and the department. Mena reasoned that providing the packet was convenient for the students to write-up notes or a summary and practice different types of exercises combined from several sources. The classroom projector was normally used to facilitate her in leading the students to learn content and practice examples together. Mena explained that her teaching style was interactive learning in which she and her students would learn and discuss as the lessons progressed. She also used multi-color pens to pinpoint important content while delivering the lessons through the projector. The students’ relationship among friends and with Mena was impressive resulting from their time spent together in the boarding school. The students actively engaged in classroom learning and discussions. It was a friendly academic atmosphere where the students were fully prepared and ready to learn in the classroom. Thus, classroom management was not an issue for Mena.

**Theme 1: Implementing Independent Learning as Inquiry-Based-Learning (IBL) in the Gifted Classrooms**

Mena accepted that being newly experienced to STEM it was too late for her to make changes in the lesson plan during this semester. This semester, she was overwhelmed with a handful responsibilities, however, she aimed that for the next
academic year, she will be able to make a few changes in the statistics classroom by implementing some STEM activities.

As mentioned previously, Mena’s students were well-prepared academically so that enhancing their abilities to learn independently was what Mena aimed for in her classroom. Mena described her teaching strategy,

I mainly play the role of leading them in introducing the lesson, but will make connections and review what we had been learned in previous class by asking them or letting them talk through their thinking…. [I] will explain to the students, then let them work on skill practices on given exercises. That is to let the students do first, follow with explanations, and provide them the answers later. Let them justify whether their answer is correct or not (Mena, Interview 1).

Regarding the interview, Mena led the class in content explanations but the students were the key practitioners to engage in learning activities. My observations followed her interview, I found that all students in her class were eager to learn. In the first class I observed, Mena checked class attendance and reviewed the previous lesson with the students. She also gave them a few exercises to complete before moving further to the lesson of the day on finding the values of mean, median, and mode in grouped data. Despite not permitting the use of calculators, mathematical calculation was not the students’ concern. Mena claimed that since the students are skillful at basic calculations it would be better for them to focus on concept-based-learning and statistical process. Mena did not expect the students to memorize the statistics formulas but she emphasized understanding the formulas as pivotal learning.
Today’s class was an example scenario of Mena’s teaching process. First, she reviewed the formula to find the value of mean, median, and mode from the distributive frequency table. For instance, given the formula of median, Mena connected the prior knowledge concepts of median and the process of finding its value of ungrouped data. The students replied with three consecutive steps by arranging the set of data in either ascending or descending number, finding the midpoint in the sorted list, and calculating the median. There was one interesting aspect regarding Thai language used in statistics that created confusion for the students. The students misunderstood between the midpoint of the number of data set which was translated in Thai as the position of median (ตั้งหน่วยของมัธยฐาน), and the value of median (ค่ามัธยฐาน). Thus, the students sometimes answered the value of a midpoint as a median value of a data set. Mena assisted the students to reconceptualize the differences between these two values. She explained that the midpoint is the location with equidistance from left and right side of ordered data, whereas the median is the value located at the midpoint or it is the mean of two central numbers, given the total frequency number (N) is odd and even respectively. “Therefore, to find the value of the median, you have to find where the median is located first,” Mena concluded.

Mena explained that once the students had clear concepts of the measures of central tendency of ungrouped data, then the students were able to extend the ideas to grouped data. She encouraged the students to further study from other textbooks on how the formulas were derived and how to apply them in calculating the values of mean,
median, and mode. Instead of memorizing the formulas, Mena engaged the students in learning the statistics formulas. For instance, given the median formula:

\[ \text{Median} = L + I \left( \frac{\sum f_i}{\sum f_m} \right) \]

and a frequency table. Mena prompted the students to describe each single letter found in the formula and perform its calculation together. To ensure that the students were able to comprehend the formulas, she assigned the students to work on a five-question classroom worksheet. The questions were more challenging than the prior worksheet and required the skills of formula applications. The students had to show the step-by-step process of calculations and explain the solutions to Mena when she approached to ask. Six boys sat in pairs, the other boy sat in front of the three girls who were sitting together in a row. However, the students preferred to work individually. They were concentrated on their own working (Figure 4-18). When they struggled with some questions, they were likely to figure it out by themselves or by discussing with friends. Even though Mena opened opportunities for the students to discuss with her anytime, she became the last person the students preferred to ask for advice. Based on my observation, students did not seem to fear talking with the teacher, but seemed to have a lot of pride as independent learners. Their learning characteristics expressed their perseverance in learning and enthusiasm as problem solvers.
Individual students preferred working on their own. Although individual learning was the students’ preference, Mena convinced the students who struggled to work in groups with other friends. Often times, she recommended for them to brainstorm with friends to gather new ideas about problem solving. The students persisted in finding their own ways of solving when possible. Towards the end of class the students started to walk around and find groups to work with and shared ideas among friends as shown in Figure 4-19.

Figure 4-19: The students brainstorming the ideas of problem solving on a classroom worksheet.
It is interesting that the students asked Mena only for the correct answer. If their answers were not correct, they continued solving with some discussions with friends and Mena. Mena occasionally offered her students some hints when she saw them spending a long time on a certain question. Mena guided the students on techniques of problem solving—starting from formula, writing down what was known and unknown, what was given and what else should be added. She reflected on her current teaching as a strategy to enrich the students’ ability of thinking to become the inquiry learners.

... ให้กระบวนการคิดกับตัว โดยที่ไม่ต้องพึ่งกลับรู ถึงถึงพึ่งจากคำของอาจารย์ แล้วถ้าไม่ได้จริงๆ ถูกต้องอะไรแล้วคอยตรวจดูอีกทีนึงถ้าไม่ถูก ชั้นเด็กก็จะกลัวถาม กลัวตอบผู้คึกครึง [My teaching style] supported them in the thinking process without relying on the teacher but with self-reliance. Unless they do not really solve the problem or not sure whether is correct, [we] can recheck together. Overall, the students dared to ask and answer (Mena, Interview 2).

In the second observation, Mena provided an in-class chapter test as a formative assessment. She informed the students one week in advance to review for the test. The time for test was 90 minutes and the total score was 20 points. The chapter test was an open-ended question consisting of two parts—short answers (9 items) and showing solutions (4 items). The test was designed to assess the students content knowledge and concepts of descriptive statistics—such as classifying types of data, constructing frequency table and histogram, finding the values of mean, median, mode, range, and standard deviation, and finding the missing values. The questions derived from the statistical data set applied to a variety of real-life situations—such as the weight record of guinea pigs, the number of cars per hours of a road, the midterm scores of a group of students, the height record of a sample group of population, the income of employees in a company, and the time record of a student to commute from home to school. Mena set the
addition to that, the school had to organize a test center for administering an admission test. In order to examine their understanding (Mena, Interview 2).

In terms of assessment, I set the criteria, for example, if total score is 20 points, passing score will be 70% [of 20]. For the students who did not pass, he/she will retake and explain [the work]. Using the same paper test? Yes, by using the same test. Like the first-time test of Grade 9 class, the students who did not pass, they had to explain about the reason why to use the set of data, where is it from [as an example]. Verbally explain? Yes. Let the students show their work, and explain verbally. (Individually?). Yes, but there are not many students who failed. (Any additional work for those who failed?) No, but they had to do all questions on the test. Assumed that they did five questions wrong but still need to do all of them by showing the work and explaining it. At this point, I will ask them [to explain the answers] in order to examine their understanding (Mena, Interview 2).

It showed that Mena made every effort to assure her students were able to comprehend the concepts, correct their misunderstanding and mistakes from their work.

Nevertheless, Mena also accepted that there was some minor confusion that remained resulting from the intense content that she tried to cover within a tight schedule. Time constraints as a result of the extra school activities and the official assignment to the teachers for out-of-school tasks caused the classroom time management including Mena’s statistics class.

My last observation at the school was shortened due to a class delay. It was the week in the schedule that the school would grant the students to leave campus, and in addition to that, the school had to organize a test center for administering an admission
test during that weekend. Therefore, the students were allowed to leave school earlier on Thursday if needed. In consequence of this school event, only four male students attended the Friday class but the other six students were absent. They were reluctant to attend the class. Since it was the last class of the semester, Mena had to cover the lessons so she did not cancel the class. She would schedule a make-up class for the absent students in evening study-time when they returned. Finally, four of them presented in the multimedia room where Mena continued teaching the new lesson about the distribution of data in—quartiles, deciles, and percentiles for ungrouped and grouped data. According to time limitations, to speed up a pace of the classroom learning, Mena mainly gave the content lecture from the statistics packet via projector screen. She explained to the students about data distribution as the learning extension from the measures of center (mean, median, mode). In doing so, she presented that when the N number of a dataset was split into 4, 10, and 100 equal-sized groups and given to the concept introduction of quartiles, deciles, and percentiles respectively. She exemplified the calculation of the 2\textsuperscript{nd} quartile of a data set while the students were assigned to determine the value of mean. She asked the students to justify why the value of the 2\textsuperscript{nd} quartile is equal to the value of the median. After that, she led the students to further investigate the relationship among quartiles, deciles, and percentiles. For the grouped data, she guided the students to compare between the median formula and the quartile formula of grouped data.

\[
\text{Med.} = L + \left[ \frac{N - \sum f_i}{\frac{f_m}{f}} \right] \quad \text{versus} \quad Q_r = L + \left[ \frac{N - \sum f_i}{\frac{f_r}{f}} \right]
\]
Collectively, the students comprehended the concepts of quartiles, deciles, and percentiles distribution from extending the median formula. In terms of using the above formula, Mena asked the questions with the purpose of checking their understanding as per the following conversation.

Mena: To find the quartile, let’s say quartile \( r \). What do you do first?
Students: Finding the position of quartile.
Mena: In order to find its position, what should we have in hands?
Students: The cumulative frequency.
Mena: How to find it?
Students: Adding up all frequencies.
Mena: What is a difference between \( \sum f_i \) or \( F_i \), and \( f_r \)?
Students: \( \sum f_i \) or \( F_i \) is the summation of frequencies of preceding quartile group while \( f_r \) is the frequency of quartile group (Mena, Classroom Observation 3).

Besides the concept teaching, Mena led the students to solve a few example questions. Mainly, by using questions to interact with the students she wrote down based on what the students said on the packet sheet via projector. (Figure 4-20).

**Figure 4-20:** Mena and the students finding the 3\(^{rd}\) quartile shown on the projector.
Later on, Mena assigned the students to work on the classroom assignment. They did the work independently. The classroom was quiet as the students concentrated on their work. Mena thoroughly observed each student while completing the task. When she realized the sign of struggle shown by one of the students, she was active in helping him. She sat beside and worked with him step-by-step. She assisted him to find out the mistake but let him correct it by himself. Overall, Mena’s students were active in learning and classroom discussions. Mena claimed that she did not have a high learning expectation for this class because it was only an introductory of statistics. The students will fully learn statistics again next year and in Grade 11.

By setting the expectation, that is the students are able to calculate, understand the rationales, and apply in science, such as, conducting IS [Independent Study] or research…. The point is to understand where is the data collected from and its rationales. In short, being able to apply and integrate beyond what has been learned in the classroom. At the beginning of the class, the students were told that they are able to apply [statistics] in several subjects such as IS…. Because IS mostly connects to statistics in comparing the data, data collection, and finding the values [of descriptive statistics] (Mena, Interview 2).

Although Mena realized that time constraints in classroom teaching was a major concern to cover all the lessons, she also reflected that she has less lesson preparation time for class. As I mentioned earlier, Mena is a contract teacher hired to additionally fill government-teacher positions. She was assigned to be responsible for several related-school works in the school. Likewise, she was recently assigned to teach statistics and had to prepare the lesson plans for different grade levels.
Theme 2: A New Mindset of Mena toward STEM Classroom Implementation

Mena is a young mathematics teacher in the department. She had less opportunities to attend the professional development programs, however, she pursued self-development through a variety of mathematics books. Attending the recent STEM education workshop was an important academic pathway for her in shaping ideas of the four-STEM-discipline integrations.

As reference to Mena’s first interview, her understanding of STEM education is an application of a body of scientific knowledge to re-create or invent new solid outcomes or products, known as innovations. STEM was a continual improvement that required clear sets of goals and objectives. “Thus, in order to completely implement STEM in the classroom, we need a significant amount of time to plan the lessons. What I learned from the workshop, I could not apply directly because I had to determine if the lessons could be integrated with STEM.” Mena pointed out. Her written teacher self-reflection was in accordance with her interview response. Mena reflected that the nature...
of the subject (statistics) was one of obstacles affecting STEM implementation. As a consequence, it is necessary to fully understand the scope of work or characteristics of the disciplines that need statistics to be applied. In addition to planning, Mena considered that using mathematics as the scaffolding discipline of the integration was quite difficult. 

It is easier to integrate mathematics with other disciplines, such as collaborating with science. Mena shared her idea for integrating statistics as follows:

To integrate statistics, [I] could have a meeting with [science teachers] to discuss the content of scientific inquiry. Statistics can be used in [2] parts of the inquiry: (1) searching and collecting data, (2) finding the research results such as mean, and standard deviation…. Because statistics is involved in research and project initiatives. The school emphasizes doing research, like IS as well (Mena, Interview 3).

Based on her interview, Mena associated statistics with ideas of conducting a research project or creating innovation. “Thus, I have to organize the hands-on activity that students will initiate on their own. Whatever they learn by doing, will be more interesting and challenging to them. It will create their enthusiasm to accomplish the work even if it is a time-consuming effort,” Mena said. Mena presented her ideas of applying statistics, however, she doubted it would be considered as a STEM implementation activity. At the beginning of semester, she assigned the students to work on a group project by doing a survey on the topics they were interested in. In doing so, the students will employ inquiry skills to search for proper data sets. Next, the students will represent the data in a frequency table, construct a histogram and display the
frequency polygons. After that, the students will determine the descriptive statistics used for analyzing and interpreting the data. Finally, the students will discuss the project results. Mena had a potential project design, unfortunately, she was not able to complete her entire idea due to time constraints.

Mena gained confidence in establishing inquiry learning in the classroom, resulting from her participation in the STEM education workshop. The workshop also enhanced her self-development by increasing her awareness of STEM research in seeking effective teaching practices. She foresaw the benefits of STEM learning as a support of building the students’ inquiry skills through investigation and research procedures. According to the conversation and self-reflection, Mena appreciated ideas of STEM integration and created her new mindset of STEM learning stemming from receiving the professional opportunity in STEM engagement. As a result, she became aware of novel methods for applying STEM in her future classroom.

**A Case Study of Mesa**

**Mesa’s Classroom Phenomenon**

Mesa is a government teacher with academic title “Senior Professional Level Teacher (K-3),” She had 20 years of teaching experience in mathematics. This academic year, she was assigned to teach Grade 8 and Grade 11. Mesa taught 8th grade both fundamental and supplementary mathematics for 20 years. I observed each of her six different 8th grade classrooms (from 12 classrooms in total and 40 students per class) in the last two weeks of the school semester. Due to a tight schedule for covering lessons before final exams, Mesa was able to organize a game-based-activity at the end of the chapter for only one classroom. This classroom was the top performing class among 12
classrooms of Grade 8. Therefore, Mesa was able to teach the content for this class faster than the other five classrooms resulting in extra available time for a special classroom activity. The game-based-activity was a lesson implementation on the topic one-variable linear equations. The other lessons Mesa taught during my observation were quadratic equations and parallel lines.

**Preparing hands-on classroom lesson plans and artifacts.** Despite her two decades of teaching grade 8 continuously, Mesa always kept her lesson plans updated. She showed her two sets of lesson plans. The first one was a year-round lesson plan for school assessments. She recorded the problems of implementation of the lesson plan in order to adjust it for following years. It was two-inches thick and consisted of well-organized typed documents. The other one was a daily-lesson plan in which she wrote the self-reflections on what was going on during the time of implementing the plan. Unlike the one-year lesson plan, the daily-lesson plan was handwritten by Mesa with a lot of inserted comments on pieces of paper that later she collected and put in a customized bound file. However, Mesa preferred using the daily-lesson plan as it was more dynamic and convenient for adding new ideas while teaching. Furthermore, Mesa created several hands-on activities and invented new artifacts to facilitate students in mathematics learning and process skills development. For instance, Mesa designed a colored
mathematics word-problem book with some help from one of her former students in drawing illustrated cartoons (Figure 4-21).

**Figure 4-21:** A cartoon comic book representing the mathematics word problems Mesa designed.

Mesa also utilized interesting comic strips and pictorial worksheets in both English and Thai to gain student involvement in classroom learning (Figure 4-22).

**Figure 4-22:** English-Thai cartoon strips and pictorial worksheets used in Mesa’s classrooms

Teaching by applying a variety of techniques to increase student engagement.

Mesa implemented several teaching methods to gain student engagement in the classroom. For example, she used game-based-activities, mathematics storytelling from cartoon comic strips, and jigsaws as hands-on learning activities to challenge the
students. Mesa implemented these activities in varied practices according to the classroom differences in level of academic abilities and teaching topics.

In terms of content teaching in general, Mesa summarized the phases of her classroom teaching in a 50-minute period. She spent 10 minutes in introducing the lessons and 40 minutes in teaching the daily lesson. In the teaching phase, she first examined students’ prior knowledge by using a questioning technique. She then reviewed some basic content knowledge and skills that were necessary for connecting it to the lesson at hand. For example, for translating word problems into mathematical expressions and equations in a topic of quadratic equation, Mesa reviewed some written algebraic expressions with variables of—the product of any two-consecutive odd or even numbers (e.g., if x is first odd number, x + 2 is second odd number), the square of the sum of an unknown number and a constant, and the product of two consecutive integers. After that, she routinely gave a lecture for 20 minutes and interacted with the students by questioning while solving some examples on a chalkboard (Figure 4-23). The other 20 minutes, Mesa assigned the students to work on a classroom assignment. The students might work individually, in pairs or in groups of four depending on the level of difficulty and the amount of work assignment.
Figure 4-23: Mesa teaching and interacting with students in a quadratic equation on chalkboard.

If we arranged activity, each time at the end of period, I would have some small pieces of paper for the students to ask what else have they learned today? Let them write what did they think they still did not understand and what did they need me to adjust or teach more. Sometimes, they told me that I taught too fast. They wrote it down but I wouldn’t let them write their name otherwise they did not dare to do it. So, I told them that there was not any impact. I only wanted to know that perhaps, they didn’t understand part of a lesson (Mesa, Interview 1).
In addition to formative and summative assessment by paper test, Mesa also assessed the students through activity participation and classroom engagement. In doing so, she used a reward system for classroom motivation (Figure 4-24). She would offer some star stickers to reward students for achievement on activities or classroom assignments. At the end of semester, the students would present their star sticker collection book to gain desirable characteristic credit points.

**Figure 4-24:** The star stickers collected in the collection book by Mesa’s students.

**Discussing and reflecting on content knowledge teaching.** For the topic of quadratic equations, Mesa focused on solving word problems involving numbers and geometric figures. Mesa claimed that even though she mainly directed the classroom learning by lecture, she posed several questions to ensure that the students were engaged and comprehended the lessons.

I thought my [teaching style] is sort of lecturing but using a questioning process. I would use an asking and answering technique with students. It was dependent on the types of questions to check whether they understand or not. It depended on the way we [I] asked them questions. Hence, we [I] must prepare the questions for each period. We [I] must prepare the questions which encourage them in thinking development. We [I] would not ask yes/no questions (Mesa, Interview 3).
For deeper understanding, Mesa activated students’ prior knowledge to make connections to what they were about to learn such as the properties of real numbers, number factorization, perimeter, area, and volume formulas of geometric figures, and Pythagoras theorem. In essence, before beginning a new topic, she used a questioning technique to assess the students pre-existing knowledge. If they remained silent and were not able to recall content, Mesa spent the first 10 minutes to cover some pre-requisite knowledge and skills which would be critical in the new topic of study.

Based on my observation, Mesa followed the four steps of Polya’s (1945) problem-solving process—understanding the problem, devising a plan, carrying out the plan, and looking back. Mesa underlined the written solutions in a step-by-step manner. Except for the short-answer questions, Mesa required the students to show detailed solutions in order to check their problem-solving process. Drawing figures and diagrams was another technique Mesa used to make word problems more visually understandable for the students. She stated that sometimes some questions could be accurately solved by drawing any kinds of visual representations.

Some simple questions were not necessary for equation solving. We only drew a picture to let the students connect, look, and make it more concrete. It was easier than seeing as variables such x and y…. If we draw a picture, we would see where and how to get started. It is easier [better] than if we have nothing only imagination (Mesa, interview 3).
At the same time, to prevent misunderstanding and confusions of the unscaled pictorial drawing, Mesa had to remind the students to justify the picture/diagram with properties of geometric figures and given condition of word problems. Practically, Mesa’s teaching strategies varied across different classrooms according to level of mathematics competencies of the students. Basically, she encouraged all students to freely initiate their individual ideas of solving problems. Nevertheless, some classrooms of students with lower-mathematics competencies relied on her assistance to some degree at the first and second step of problem solving. After that the students were able to demonstrate mathematical computations on their own. Mesa mentioned that the key elements of solving quadratic word problems were writing quadratic equations and determining accurate answers. During her lecture delivery, Mesa interacted with the students with a number of questions for almost every step before she wrote on the board.

She described her purpose of frequent questioning as follows.

To check whether or not the students understood in every step. [I] would ask, and let them respond. Otherwise, it would be only teacher’s lecture which is meaningless because some students listened [carefully] but [some of them] might not. Once I asked, I checked, I pointed, and I saw some students started murmuring, then I pointed to them. Also, it is used for checking the students [attention] and getting control of the classroom as well (Mesa, Interview 3).

Although there were some students with disruptive behavior in a few classrooms, Mesa did not appear concerned over the issue of classroom management. She mentioned that at the beginning of the semester, she talked with students and had common
agreements on the classroom rules and regulations. For instance, during a 20-minute period of teaching, the students had to be quiet, pay attention, interact with teacher by questioning, and listen carefully to the teacher talk. After getting lesson concepts, the students were allowed to move around the classroom and have some discussions with friends regarding assigned work.

As I mentioned previously, questioning was one of Mesa’s technique to examine students’ lesson comprehension during the period of teaching. Checking on students’ classroom and homework assignments was the other method that Mesa normally used while the students were working on tasks or assigned some homework. Regarding what I observed, Mesa was the key leader in the classroom in terms of posing the questions and prompting the students to answer. The students rarely asked her questions in the classrooms regardless of the friendly atmosphere or Mesa’s generosity and support.

When I asked Mesa to clarify the situation. Mesa was not surprised but explained it with no clues on how to increase the students’ confidence of asking questions.

There might be two parts. First, they did not understand thoroughly. So, whatever the teacher told, they accepted it. They did not ask [me] back. In short, they did not understand [the lesson]. Second, they did not dare to ask. This is a typical behavior of Thai students. If the teacher did not probe to ask, they didn’t dare to ask the teacher…. This is a normality [of Thai classroom culture] …. [I] don’t know what caused it. Or maybe, because of our Thai [classroom learning]. It’s like whoever asked the question, he/she was looked as a stupid [student]. Or [the student] might feel like [a loser] when asking question…. [Students would wonder why] others understand but he/she doesn’t (Mesa, Interview 3).
In her point of view, she thought the students had discomfort to ask questions in the public setting. Typically, for the students who had some questions, they would be more likely to ask her after class or met her in the teachers’ room for private academic advice. Therefore, rather than awaiting the students’ questions, it was better to frequently pose the questions for them instead due to time limitations. In addition to that, at the end of each chapter, Mesa asked the students to write down feedback and questions that remained unclear for them. Mesa, however, remained open for any suggestions to establish new approaches for enhancing two-way classroom communications.

Overall, Mesa flexibly designed her classroom practices and teaching approaches in content knowledge. She adjusted her practices based on what she had experienced in classrooms of students with diverse abilities. As she recognized that a “one size fits all” description does not work. However, she tried her best to differentiate her pedagogy and new idea of teaching through hands-on activities and artifacts to fulfill the students’ potential of both knowledge and skills in mathematics.

**Theme 1: Implementing Game-Based-Activity for Developing Students’ Mathematics Problem-Solving Skills**

Mesa acquired the technique of using games in classroom learning from her prior IPST training. She explained that it was used as an activity for a formative assessment. Recently, she implemented a game-based-activity in a Grade 8 classroom on the topic of fundamental real numbers. During my observation, Mesa implemented a game-based-activity in problem solving of one-variable linear equations topic. She designed the game activity with the aim to primarily promote group work among the students with mixed-mathematics abilities.
The game was called “วงล้อสัญลักษณ์ (Symbol Wheel).” Mesa assigned the students to eight groups with five students per group. Before starting the game, the students were asked to pile up the desks for working space on the classroom floor. Mesa prepared the game materials and distributed the worksheets to the students. Once the students sat in groups, she started explaining the game instructions and opened the discussion for any questions. It was a 50-minute-game period.

**The description of the “Symbol Wheel” game conducted in Mesa’s classroom.** The materials used in the game consisted of a wheel board, geometric shape cards, wheel sheets, word-problems cards, and word-problem worksheets as shown in Figure 4-25. Mesa used a variety of geometric shapes representing the symbols. Therefore, the students would easily draw them on the given wheel sheets once the questions were correctly solved and matched with the answer on the next question cards.
Figure 4-25: Example of materials used in the “Symbol Wheel” game.

The eight word-problem cards were dispersed and placed around the classroom wall. The eight groups were seated according to these cards. Then, each group started solving the first question from where they were seated. Everyone had to show their work on the given worksheet (Figure 4-26).

Figure 4-26: The group members solving the word problems and writing down the solutions.
After that, they had to look for the answer of the first question which would be shown on one of the other seven word-problem cards. When they found it, they would have seen the geometric shape as a symbol and drew it on their wheel worksheets. At the same time, they had to start solving the second question, and move on to find the second answer from the other six cards. The symbols were placed in the wheel worksheet clockwise. The students continued playing the game until completing the wheel as much as possible in the 50-minute period. At the end, the teacher and the students would place the geometric shape cards in correct order on the wheel board and have a discussion about the game (Figure 4-27).

Figure 4-27: The students completing the wheel and teacher giving the correct order at the end.

The questions were adopted from the content study in six different topics—*numbers, age, area and perimeter, speed, distance, and time, mixtures,* and *money.* Mesa set passing criteria that at least four questions need to be correctly solved. According to the rules of the game, the students were not able to skip the questions when struggling otherwise the geometric shapes would be misarranged in the wheel. Therefore, this game was a challenging task for the students. Literally, the group members had to brainstorm
and go over their previous exercises to find some similarities as solving guidelines to the given questions. It was clear that the groups were not allowed to move to the next question unless all the members finished the written solutions. Significantly, these conditions enhanced the skills of team work or collaborative working among the group members. In fact, Mesa planned to implement the “Symbol Wheel” game on the topic, one-variable linear equations, only for the high-performing classroom owing to aforementioned conditions and the period of time for the game.

In this topic, [the game] will be played in the high-performing classroom only. Because if using it in the weak-performing classroom, when they unsolved a question, they can’t complete the symbol wheel. Also, they can’t skip the question, once one group got stuck, it caused the other groups to become stuck as well. Let’s say, in the weak-performing classroom, there might be 3-4 students who are good at mathematics, but the others are not. Thus, using this game might not be successful (Mesa, Interview 2).

Based on her success with game-based-learning, Mesa placed students with mixed-mathematics abilities in groups so that the high-performing students could lead the team in problem solving and be able to move forward to the next questions faster. Mesa explained the instructional goal and the three-domain objectives of learning: cognitive, affective, and behavioral as follows:

In Thai: เรื่องนี้ จะใช้ในห้องที่จะแบ่งนักเรียน เพราะว่าถ้าเป็นห้องที่ดึงดูด เริ่มทำไม่ออกได้เนื่อง คำถามจะต้องสู้ สิ่งที่นักเรียนทำไม่ได้ เท่านั้นจะขย้ำข้อแยกต่างๆ  pov ที่นักเรียนทีละกลุ่มที่มีก่อนก็ต้องติด กัน อย่างเช่นว่า ห้อง ต้องวิ่ง เท่านั้นถ้า 3 คน 4 คะแนนต่อเมื่อไม่ได้เลย เราใช้ย้อนนั้นคิดว่า มันจะไม่ประสบความสุขจริง
My first expectation is the students comprehend six types of word problems about one-variable linear equations. Whenever, they see similar questions to what they have learned in class, they are able to solve them. That is, they gained content knowledge. In terms of behavioral learning, I want them to learn about teamwork, because sooner [in the future] if they work, they will not work alone. They need to learn to interact with others, support each other, and work in groups. That is what I expected. Also, I would like them to maintain positive attitudes toward mathematics understanding that mathematics is not abstract [concepts] for just practicing exercises but indeed, it has several [real world applications] (Mesa, Interview 2).

Mesa’s teaching and learning experience from the game exercise. During the time students engaged in the group work, Mesa walked around to check on their work and encourage some groups to speed up their problem solving. When she spotted a group overspending time on the questions, she assisted and provided some hints until they got ideas to reach a solution. Based on Mesa’s observation while students were on tasks, she reported that all students participated in group activity very well. They helped each other. Mesa also noticed that the bright students in the group would more quickly solve the questions whereas the others were waiting for the explanations. “Because I told them that they have to move together. If all in group has not finished, I would not have allowed them to go. Thus, they have to teach and learn from each other. Eventually, they would learn that this is the way how to live together in the future society by helping and supporting each other,” Mesa reasoned.

Additionally, Mesa believed that using positive reinforcement is an important strategy to improve student motivation. Thus, Mesa rewarded the students with some star stickers. Each student was given a star collection book at the beginning of the semester. Mesa used the star stickers to motivate the students to participate in classroom activities.
At the end of each chapter, Mesa assessed students’ behavioral learning scores based on the number of the stars in their collection books. In “Symbol Wheel” game, Mesa would give two star stickers to every member of the group who first completed solving all eight questions, and one star sticker for the other groups who finished the questions as well (Figure 4-28).

![Image](image.jpg)

**Figure 4-28:** The students who completed all questions lining to receive the star stickers.

According to the first interview, Mesa appreciated reflective teaching because she often practiced it as a mentor with beginning mathematics teachers. Mesa viewed that classroom reflection results in improvement of her classroom practices. She and her colleagues normally took turns for classroom observations in responding to school policy of teaching improvement by peer evaluation. In my second interview, I brought up some concerns based on what I observed to Mesa and asked her to clarify and share her feedback. Mesa and I had a discussion after conducting the game in the classroom. Both of us found that many groups of students overspent time in two types of questions about speed, distance, and time, and value of money. Mesa reflected that the question about speed, distance, and time was not a new problem and she has been trying to apply the technique to make it more understandable for the students.
Actually, the confusing topic that occurred for years is speed, distance, and time. I think because it is quite beyond the kids’ life routine. It is difficult for them to imagine about it. In the previous years, I used lecturing as a way to explain it. The recent years, I found a foreign website suggesting the use of a table to understand about speed, distance, and time. At first, I introduced the relations of these three variables, then fill in the table, and finally set an equation. Some students thoroughly understood but the others might not because [we] had only one period to learn about it. In this topic, the students struggled and I know that it remained the problem (Mesa, Interview 2).

Unlike the above question regarding concept comprehension, Mesa was surprised that the students were confused with the monetary value of the Thai smallest coin. It is called a saleung or the 25-satang coin of Thai baht currency (1 baht = 100 satang, 4 saleung = 1 baht). Due to the rare use of the coin in nowadays in daily-life, the students had no idea about its value. As the result, the students had some troubles converting the money word problems into symbolic expression with decimal points. Mesa recognized that it was also her mistake that when she taught them previously, she used only the exact amount of money without decimal points.
saleung and a 50-satang coins. But now we rarely used them, so that is why the students were stuck on this question. (Isn’t it new to us?) Yes, knowing that they don’t know saleung coins. Next time I will improve by bringing some to show them that this is a saleung coin, and four coins are equal to one baht. (Also, your assignment exercises were in baht unit only.) Yes, because I’ve never thought about it. When the kids got some change from the supermarket cashiers, they only just kept them but, literally, they never used them (Mesa, Interview 2).

In summary, Mesa learned that the students more likely comprehended, wrote the mathematics equations, and solved the problems when they are able to associate the word problems with their real-life or daily situations. This was not always the case with mathematics, however, with science aspects of STEM the students experienced several hands-on experiments in the classroom, therefore, they were able to solve the question about solution mixtures even it was not directly related to their life routines.

Moreover, we found that the students delayed in shifting from one question to the others due to spending too much time for discussion and waiting for all the group members’ work to be completed. Mesa admitted that at the beginning she had a concern about the potential of students’ collaborating on their work and brainstorming. Also, she was concerned that some students would not be actively engaged in group brainstorming until they finished their own worksheet. During the game activity, Mesa noticed that some students might work slowly since they really deliberated over written solutions. As a result, some groups were not able to solve all eight questions even though Mesa rushed them to rotate. Therefore, she anticipated to implement some changes for her next game-based-activity including assigning each group to complete only one worksheet. At the same time, she will focus on developing team-work by encouraging sharing work among the members, brainstorming and exercising creative ideas for problem solving.
Overall, Mesa was satisfied with the outcomes of implementing the “Symbol Wheel” in the classroom. According to her observation, the students actively participated in group work, shared ideas, had discussions, and supported other members to complete the worksheets. Most of the groups completed solving all questions. A few groups had one or two questions which remained unsolved. Learning from her previous experiences, Mesa also pointed out that there were two key factors affecting successful implementation of the game-based-activities. The first factor was the appropriate amount of time to carry out the game. For this reason, she decided to implement this game in a high-performing classroom, manage the group assignment in advance, and motivate students to stay focused on group work as much as possible. The other factor was students’ readiness in content knowledge of the topics. In addition to that, to achieve the goal of the game activity, students must possess some essential skills.

The students must have thinking skills and collaborative working skills in order to accomplish [the game], as well as mathematical process skills such as problem solving and creative thinking. Sometimes, for one question, each student might not think in the same way but gets the same answer (Mesa Interview 2).

Mesa considered experiencing the “Symbol Wheel” game as a hands-on activity would promote students’ mathematical process skills. It resulted from the frequent practice of solving problems by connecting the content knowledge with real-life applications. As she perceived positive benefits of using game-based-activities, she will continue implementing the game-based-activity to the other classrooms, however, she will adapt the “Symbol Wheel” wheel to a five-question group work without rotation for
the low-performing classrooms. In the end, Mesa expressed strong intentions that she would make significant efforts to create challenging learning activities to benefit her students with diverse mathematics proficiencies. At the same time, she would keep herself updated in new innovations related to STEM that she could introduce in the future to her students.

**Theme 2: Perspectives on STEM implementation through the Lens of an Enthusiastic Senior Experienced Teacher**

Being a school mathematics mentor for beginning mathematics teachers from the IPST program over three years, Mesa regularly attended several professional development programs provided by IPST. Mesa viewed that it was a great opportunity to professionally develop her teaching capabilities of bringing new techniques and mathematics processes to implement in the classroom. Based on the aforementioned gains from PD programs, Mesa continually kept up with the latest teaching innovations like STEM learning. Mesa looked forward to participating in the workshop since STEM was first initiated in Thailand, however, she did not receive any training until the recent STEM education workshop provided by the regional STEM center. She and one of her science colleagues had been waiting for this workshop for a long period of time.

I would love to attend [the workshop] because when [we] got training [from one university] we would like to learn more. We applied for [STEM trainings] but they were full, full, and full., never got in. Finally, able to be in this [STEM education workshop] since the school established the MOU [with UNSEC]. They
sent the application letters for one mathematics and one science teacher. So, I volunteered, and I wanted to go. Because whatever we saw, we learned, we would be able to disseminate to our school’s teachers. We expected that we would start applying gained knowledge first to see the results. If it works, we can disseminate to science and computer teachers (Mesa, Interview 1).

Mesa showed her interest in STEM training and her efforts to become a participant paid off. She reflected on what she gained from the workshop: “The workshop provided us training about what is the actual [STEM] model. In the past, I had no clues how to implement it but now after participation, I know where to start.” Before participating in the STEM education workshop, Mesa learned STEM integration by self-study through public informative media channels. Even though, STEM was not a new idea to her, she admitted that her understanding about STEM was superficial. Mesa also noted that the process of STEM and the levels of STEM integration were the new knowledge she gained from the workshop.

I think that the new topic I learned was the process of integrating STEM by each level. First, I thought only having the related content was already a completed STEM [integration]. In fact, it was just a STEM integration to a certain level but was not the terminal level or the so called the supreme level. Hence, I know that if we implement like this, we are in this level. Now we are implementing at the second level. If we continue implementing and set the indicators of [STEM Club] (as collaborating with science and computer teachers), we can achieve the third level of STEM [integration]. As they [in the workshop] mentioned, if the students had applied to reach the fourth level, it might have been difficult. So, for now, our aim is to achieve the third level of STEM integration. As they said, wow! (even the third level), it is a full STEM integration (Mesa, Interview 1).
Mesa evaluated her current classroom teaching and determined it was related to STEM implementation in the second level out of the four-levels of STEM integration addressed in the workshop.

In the STEM system, my recent teaching is at the second level. That is being able to integrate the (mathematics) lesson content with other subject content, but it is not yet combined with the other three groups to do the [STEM] activity. Thus, it was only at the level 2 by integrating within the subject from applying content or problems of other subjects (Mesa, Interview1).

The “Symbol Wheel” game is an example of how Mesa tried to implement the STEM content into mathematics lesson. She applied the real-life situations in mathematics word problems to boost the students’ thinking process skills including analytical, critical, and creative thinking. At the same time, the students would be able to develop their social skills stemming from group work through interaction and communication with each other. She also reflected that the overall process of mathematics learning could foster STEM skills. For example, systematically solving mathematics word problems would promote problem-solving skills. Justifying how to prove lines are parallel lines and determining the missing values would strengthen logical reasoning skills. Furthermore, Mesa attempted to create her classroom activities which encouraged the students to approach problems in different aspects. Consequently, the students would be challenged to think outside the box and rationalize the problems with single or multiple solutions. Likewise, Mesa perceived that any learning activities associated with the mathematical process could be counted as one of STEM learning
activities. However, it would benefit the students to be more capable by integrating knowledge and skills across the four-STEM disciplines.

As Mesa applied several teaching techniques in her classroom practices, she was able to address some changes in the roles of teacher, classroom practices, students, and classroom atmosphere.

First, implementing these kinds of activities is a change, changing the teaching methods. Rather than using chalk and talk, and teacher [I] changed my teaching style and learning management. Instead of being a teller, I became an advisor, let students be doers to more utilize their problem-solving skills. The students would have some changes of classroom atmosphere. Instead of being seated in learning [as traditional way], they would have some movements. Since they could move around, they would have fun to work together with friends. So, it is considered as a positive atmosphere (Mesa, Interview 2).

Mesa viewed that changes in her teaching methods and implementing new innovations supported the students to be productive in learning by doing. Engaging the students with hands-on activities and challenging them with complex real-world problems would enhance the students’ essential skills. “Whenever we have to choose an activity for implementation, we had to make sure that it is applicable, appropriate, as well as whether or not it benefits the students in learning development,” Mesa suggested.

She strongly believed that in the long run, the students would be able to earn maximum benefits from STEM learning activities. Being involved in STEM activities required students to plan, think, and work in teams. In the long term, being engaged in different kinds of STEM activities would be gradually instilled the STEM process
elements into the students’ manner and shape up their capabilities of thinking and performing systematically. They would become skillful students and be able to design or make a significant contribution in the future scientific arena when entering professional life.

Additionally, Mesa viewed that collaboration among STEM teachers was a significant factor to create a concrete STEM integration plan. However, the amount of time for meeting up amongst the science, mathematics and computer teachers was limited. Based on her written self-reflection report, Mesa considered that time constraints for both teacher collaboration and activity implementation in the classroom were major obstacles for successful STEM learning management.

[The obstacle] was [short] existing time for learning. Because implementing STEM activities was time consuming. According to what we were trained from [the STEM education workshop], we saw that the amount of time for STEM activities must be at least half a day. Hence, only one period of implementing [STEM] activity was not enough. At the same time, during the period for activity, we have to cover all lesson content as well. Since there were time limitations, implementing this kind of [STEM] activities would be difficult (Mesa, Interview 4).

Although it was unfortunate in terms of school time allocations, Mesa and her colleagues had a strong intention to move forward to implementing STEM in their discipline learning. Mesa was not the only teacher who shared innovative ideas of STEM integration; her science and computer teacher colleagues were also enthusiastic to establish the STEM Club next semester.
Next [academic] year, I would establish a [STEM] Club in collaboration with at least 3 teachers of science, mathematics, and computer. [We] would recruit students who are interested in [STEM]. We would try to conduct these kinds of activities [from STEM education workshop] together, creating a theme [of activity]. Or, [allowing them to do whatever], if they [the students] were more likely to design a new innovation similar to the prototype or better than an existing one (Mesa, Interview 4).

Mesa also reflected that the well-designed STEM learning activities would be able to unlock students’ hidden potential and build up creative inspirations which would positively elevate student learning outcomes both in knowledge and necessary skills. Lastly, Mesa aimed that her ideals of STEM implementations would be continually embraced and ultimately conducted across the STEM disciplines in her school.
Chapter 5
Looking Across the Cases

In Chapter 4, I presented the results of four teachers’ STEM integration in the classroom after participating in a STEM education workshop. According to the findings of the individual study cases, the four mathematics teachers shared significant commonalities and differences related to their teaching practices. This chapter explores these commonalities and differences across the four case studies regarding the particular characteristics of activities the teachers implemented, the supportive conditions for implementation and the obstacles the teachers encountered, and the teachers’ visions and plans for STEM implementation in their future classrooms.

Characteristics of Implemented Classroom Activities

Two of the teachers (Tanwa and Mesa) designed the group project activities in additional to their mathematics content teaching, whereas, two other teachers (Kanya and Mena) attempted to integrate some gained knowledge and skills in their typical classroom teaching. Tanwa directly integrated gained knowledge from the STEM education workshop and used a project-based-learning (PBL) approach to design his classroom activities. He chose two activities from the workshop (Towel Model and Yang Fruit as a Glider) to implement in his top-performing classroom of Grade 9 students. Tanwa was able to manage the STEM activities separately from the regular classroom study without interfering with content coverage in his mathematics instruction. The STEM activities served as an extra activity to enhance mathematical skills for his students in addition to
content knowledge. It was a starting point at which he introduced students to the ideas of integrating mathematics with other STEM disciplines.

Mesa’s aims of conducting game-based activities differed from Tanwa’s aims. Her purpose was to examine student understanding of word-problem solving for a top-academic achievement classroom of Grade 8 after she finished her mathematics chapter. Basically, Mesa arranged different kinds of activities as a part of her content teaching or used as a formative assessment for chapter tests. She challenged the students with real-world word problems at different levels of difficulty. Tanwa and Mesa implemented the activities in the selected classrooms according to the students’ academic readiness and the levels of activities. Both of them shared the same expectations that providing students experiences with hands-on activities within groups could promote student potential of team work and collaboration. To meet their expectations, Tanwa and Mesa purposely assigned the students to groups with mixed-academic abilities so that the group members had to share and interact with each other. Moreover, they created group competition to challenge the students to be more engaged in the activities. Thus, the teachers believed that engaging in the learning activities, students gradually developed both mathematical skills and social skills through brainstorming and group discussions.

Unlike Tanwa and Mesa, Kanya and Mena did not organize any extra STEM activities due to time limitations. However, Kanya claimed that the knowledge and ideas she acquired from the STEM education workshop corresponded to the current lessons about mathematics skills and process that she was teaching in her Grade 9 classrooms. Her teaching emphasized a development of mathematical process skills in terms of problem solving as well as mathematical communication and representation. Practically,
she applied a variety of word problems from real-life situations and assorted mathematics puzzles to empower students with the skills of thinking and reasoning. Kanya posted the questions on PowerPoint slides as in-class aids. She led the students by having them follow her solution methods, particularly in the non-math-sci classrooms where the students had poor performance in mathematics. Differently, in the math-sci-classroom, although Kanya held control of classroom learning, the students were more engaged in the process of thinking and problem solving. Through my observation, the whole-class discussion was the main strategy Kanya effectively used to interact with the students instead of group-work assignment.

Mena, on the other hand, taught in a unique school, highly selective school. She was assigned to teach statistics as a supplementary course of her school’s mathematics curriculum. It was not like the other three teachers’ mathematics curriculum as it was adopted to be more advanced in content and included additional courses. Furthermore, Mena’s students differed significantly from those in Kanya’s school. Her students had high academic achievement in mathematics and science in particular. They were attentive individual learners. Consequently, independent learning was an approach Mena used with her Gifted-Grade 8 students in the elementary statistics classroom. With this approach, as active learners, Mena’s students spent most of the study time individually practicing problem solving even though Mena encouraged them to collaborate with friends on ideas for solving questions. Mena played a role as a supportive teacher if assistance was needed. She designed the statistics packet to facilitate students’ individual learning. Although she did not make any changes to integrate STEM activity in her statistics classroom during this semester, she represented the idea of inquiry-based-learning in her
classroom. She promoted the students’ academic strengths by challenging them to work on complicated statistical problems. However, Mena ensured that her students truly comprehended the fundamental concepts of statistics before presenting exercises on its applications. Rather than learning formulas through memorization, Mena deliberately taught them to understand the applications of statistics formulas in the problem-solving process.

It was concluded that because of available time, Tanwa was able to create STEM projects for his students in addition to covering the mathematics content he needed to teach, whereas Mesa conducted game-based-activities to assess her students’ abilities to solve word problems. On the contrary, Kanya and Mena made their typical content classroom learning to be more associated with STEM principles in regard to inquiry-based learning and necessary skills for the 21st century such as critical thinking, problem solving, and the processes of doing mathematics and statistics. Characteristics of their activities and learning practices varied according to several factors influencing the four teachers in decision-making of STEM implementation. Overall, the four case studies showed the teachers’ attempts at change-making and connecting STEM with their typical classroom teaching after participating in the STEM education workshop.

**Supportive Conditions and Obstacles for STEM Implementation**

Among these four teachers, STEM was viewed and applied differently based on several factors which either led to supportive conditions or presented obstacles for classroom implementation. Tanwa, Kanya, Mena, and Mesa all were faced with time constraints in classroom practices. As well, the four of them experienced unexpected school events or situations out of their control which delayed their plan or caused them to
rush to cover lessons in a tight schedule. Thus, they were overwhelmed in covering the lesson plans by the existing content curriculum. As a result, they had less time to manage new hands-on activities for the students. There was agreement across the four teachers that implementing STEM learning activities is time-consuming. The STEM activity might not fit in one or two periods of a typical mathematics class. Hence, Tanwa and Mesa shared the ideas of a STEM Club to avoid the constraints of time for content teaching.

Additionally, in order to implement new innovations into the classroom, the teachers required a significant amount of time for designing their activity plans and preparing materials. In terms of carrying out the activity, Tanwa and Mesa as experienced teachers could handle the challenging problems that emerged during engaging in STEM activities and impacted progress. While Kanya had more concerns on motivating less-attentive students to be engaged in mathematics learning, Mena as a quite new teacher in statistics struggled with creating a challenging STEM activity that related to STEM integration for gifted students.

The students’ academic readiness was one of the main factors that all four teachers considered at first when they had to decide to choose appropriate activities to meet their students’ interest and abilities. At the same time, it was necessary to activate or assess the students’ prior content knowledge and essential skills before introducing new innovations in the classroom. All four teachers indicated that building prior knowledge at the beginning of a new lesson study or innovation implementation helped the students to make learning connections which leads to sustainable development of knowledge and produces long-lasting gained knowledge.
Classroom atmosphere and its management was also an important concern among the four teachers. Tanwa developed positive teacher-student relationships overtime since he taught his students for a few years. Likewise, Mena spent time with her students on boarding sites regularly. Thus, the teacher-student relationships were well-established for these teachers. Mesa and her students set the classroom rules and regulations together at the beginning of the semester. She also positively reinforced the students with a reward system to increase student engagement. In contrast to the other three teachers, Kanya encountered issues with non-math-sci students in classroom management as they were less interested in mathematics learning and demonstrated some disruptive behaviors. However, there was no conflict in their relationship because Kanya was very supportive and had friendly talks with her students in order to engage them in learning.

**Teachers’ Visions and Plans for STEM Implementation**

Tanwa decided to conduct STEM activities to evaluate the outcomes of its implementation as he anticipated establishing a STEM Club next semester. Mesa shared the same idea as Tanwa for STEM Club establishment but she intends to collaborate with science and computer teachers. Based on her plan, she will engage student club members in STEM group-project activities. The students will be able to systematically work on planning, designing, and creating distinguished artifacts in response to given scenarios. With the requirement of Mena’s school that students have to conduct a research project as an independent study, Mena had a future plan to assign the students in applying statistical procedures in the research study such as determining the types of data, collecting, and analyzing the data with descriptive statistics. Similarly, Kanya expressed her ideas of integrating the other disciplines’ content knowledge to some chapters of mathematics
such as applications of science in speed and volume capacity, and graphic designing of containers’ packaging. For instance, if it is implemented in the trigonometry lesson, she will offer the students to practice on angle-measurement applications to estimate the distances or the heights of actual buildings or any places.

The STEM implementation allows the students to play significant roles as active learners, thus, the role of teachers is supposed to be changed. Instead of directive instruction, the teachers should be opened-minded and supportive to the students in their own ways of thinking. As observed, Tanwa, Mena, and Mesa reduced their role as a directive teacher and became an advisor while the students were engaged in group work. On the other hand, Kanya seemed to be a key character to lead her students to solve the problems as her students remained unprepared in individual learning.

All four of them characterized integrating STEM learning as a new teaching trend that challenges teachers to make significant changes in the classrooms. From their perspectives, STEM integration through project-based-activities demanded a long period of preparation time for teachers’ planning, materials designing, and students’ readiness both in knowledge and skills applications. The teachers recognized that initially practicing STEM implementation could seem challenging but believed its outcomes will benefit the students in the long run if STEM activities are practiced on a continuous basis. Importantly, the teachers viewed maximizing student learning as their goal of teaching, therefore, they would make every effort to help their students become knowledgeable and skillful in the STEM disciplines.
Effectiveness of STEM Implementation in Teachers’ Classroom

As teacher learning is my study focus, it is important to determine the effectiveness of STEM implementation among the four teachers. In doing so, I apply the key components (mathematics teachers, out/in school supports, mathematics classroom instructions) and four-domains of characteristics of effective teaching (classroom climate, teacher preparation, teaching and learning process, and teacher and student learning), from my Framework Part 2 developed in the review of literature. Since the process of teacher learning from the STEM education workshop and classroom implementation was covered in-depth in previous sections, below is a summary of each key component.

The STEM education workshop served as an outside PD program where their schools showed the support by granting a budget and time allocation for the teachers to attend the workshop. In terms of teacher background, all four teachers had at least a college degree in mathematics and teaching experience ranging from 5 to 20 years. Based on the number of year of teaching experience and my classroom observations, I concluded that all of them possess the necessary mathematics content knowledge and pedagogy, knowledge of learners, as well as curriculum and assessment. This set of knowledge is the first requirement of teaching and learning guided in Principles to Actions by NCTM (2014). Tanwa, Kanya, and Mesa participated in outside PD programs at least three times a year. Unfortunately, as a school contract teacher, Mesa rarely had the opportunity to attend PD programs compared to the others from her school who are government teachers. All teachers adopted school mathematics curriculum from a national curriculum developed by the IPST to purposely implement in their schools. They had been teaching in different grade levels, therefore, they all fully comprehended Thai
mathematics curriculum and its assessment system. They believed that it is important that mathematics be taught by actively and consistently engaging students, specifically in the process of problem-solving. Consequently, the students will be instilled with the skillsets of mathematics, critical and creative thinking skills, and problem-solving skills in particular. Ultimately, the students will be able to transition the mathematics knowledge and skills across disciplines and further apply its essence of knowledge and necessary skills in their future careers.

In terms of *classroom climate*, the first domain of characteristics of effective teaching, the four teachers understood the importance of establishing a positive classroom atmosphere to make students feel secure in classroom involvement. Teacher-student relationships were developed overtime from their teaching. Like the others, Kanya also created a friendly classroom environment, at the same time, she had to set the tone by warning her students who demonstrated disruptive behaviors. Tanwa showed concern that sometimes he was not able to control the whole classroom while the students were working on the group project because they had so much fun in peer-discussions. Mena had a highly selective classroom whose students were individual learners, thus she had no issue of classroom management. Furthermore, to deal with these gifted students, she engaged the students with challenging tasks. While Mesa set the star-stickers reward as a positive reinforcement to challenge her students in achieving the goal of learning. The four teachers acknowledged STEM focuses on students integrative learning, therefore, they tried to maximize student engagement and encourage them to freely demonstrate their own thoughts while respecting the students’ voices.
Second domain: *teaching preparation*, from a 5-point Likert Type scale form of teacher self-reflection reports, all of them designed their lesson plans corresponding to national and school curriculum (scored as 5, very frequently). They all reflected that their lesson plans were mainly content-based. However, the three female teachers frequently created some extra worksheets and tasks in addition to content learning (averaged response as 4.7), whereas, Tanwa responded “occasionally (scored as 3)” as a frequency level of developing additional worksheets for his students. In terms of STEM planning after workshop participation, Mena reflected that she had not planned to implement STEM activities in her classroom (never =1, others’ averaged response as 3.3), but all four responded that they often applied gained knowledge and skills in their classrooms. Kanya and Mesa reflected that they set agreements with their students about classroom rules and regulations at the beginning of semester (scored as 5, very frequently).

Third domain, *teaching and learning process*, the four teachers demonstrated their teaching in different degrees of STEM implementations. According to P.S. Wilson et al.’s (2005) recommendations for teacher to enhance student understanding, Tanwa created PBL activities to connect and transition the knowledge of mathematics and other STEM disciplines from theory to applications. He responded in the self-reflection report that he used various forms of media and technological aids to motivate students’ learning (scored as 5, very frequently). Kanya visualized mathematics via technological aids and visual presentations such as pictorials, patterns, and equation formations. Her attempt of helping students to formulate appropriate mathematical strategies to solve the problems is identified as promoting students’ *strategic competence* which is one of five components of mathematical proficiency presented by NRC & the Mathematics Learning Study.
Committee (2001). As Kanya claimed that she taught the students with significantly different academic background, she scored 5 (very frequently) on the self-reflection report about teaching the students emphasizing the difference of students’ abilities. Based on five-strands of mathematical proficiency, Mena placed individual learning ahead of a specific approach as her students showed high interest and positive attitudes in mathematics and science (*productive disposition*). They were fluent in performing mathematical procedures (*procedural fluency*) and were able to appropriately use mathematical strategies (*strategic competence*) in problem solving. Thus, Mena enhanced them in the other two-strands: *conceptual understanding* and *adaptive reasoning*. From my observation, Mena listened to her students’ meaningful justifications on problem solving and provided them the opportunity to discuss among friends in the classroom. She also reflected with the high level (scored as 5, very frequently) of frequency on placing values of students’ shared thoughts in the classroom. Mena’s classroom is student-centered orientated where students are individually provided academic support. Moreover, Kanya, Mena, and Mesa assessed their students’ understanding by using frequent and quick questions during lessons. Mesa employed several activities such as game-based-activities, word-problem solving from her own artifacts such cartoon books and cartoon strips to motivate students to learn about real-life applications rather than rote memorization. Mesa’s process of teaching also corresponded to the recommendations of Reynold and Muijs (1999). Her classroom’s evidence illustrated that she helped the students to recall existing knowledge and skills to the new lesson by questioning. After about 20-minutes of lecture, she assigned the students to work in pairs or groups and ended the lesson with the whole class summary and discussion. For
classroom assessment, Tanwa used authentic assessment with rigid criteria to assess the students’ group work. Mesa designed “Symbol Wheel” game-based-activity to assess the students’ word problem-solving skills in groups at the end of chapter. Classroom participation was also one of the criteria the four teachers used to assess student engagement. Paper-tests and completed worksheets were mostly used to assess students’ content knowledge among the four teachers throughout the semester according to their responses.

Lastly, teacher and student learning domain, from teacher’s self-reflection reports and my interviews and classroom observations, the teachers learned the STEM principles and gained ideas and techniques of implementing STEM in the classroom. As empirical evidence shown in their cases, they all attempted to involve real-life situations in mathematics lessons for challenging the students in mathematical thinking and problem-solving process. Reasonably, they made an effort to choose and adapt the STEM lessons from the workshop to suit their students’ interests and abilities even under the stress of time for content-curriculum coverage. At the same time, the four teachers tried to assess their student learning both in cognitive knowledge, and behavioral changes in the classrooms to reflect the classroom learning and determine the effectiveness of their teaching.
Chapter 6
Discussions, Conclusions, and Recommendations

This research study examined Thai mathematics teachers’ classroom instruction of STEM integration and investigated the extent to which teachers were able to implement what they learned during a STEM education workshop. The first part of this chapter is a brief summary of the STEM education workshop, teacher learning from the STEM education workshop, and teacher classroom implementation after participation. In the second part, I conclude my critical research findings and discuss the findings in relation to the previous research and research literature from Chapter 2. The last part is the professional recommendations for future action and research.

Brief Summary

The brief summary comprises three main parts. The first part is an account of the STEM education workshop organized by the Upper Northern STEM Education Center (UNSEC) in the northern Thailand as my first setting where I selected the four teachers (Tanwa, Kanya, Mena, and Mesa) to be my key research informants. The second part is the overview of their learning from the STEM education workshop. The last part is the synopsis of their classroom implementation after participating in the STEM education workshop.

The STEM Education Workshop

A 3-day STEM education workshop was provided by the upper northern STEM center with support from the Institute for the Promotion of Teaching Science and Technology (IPST). Only the teachers of science, mathematics, vocational career and
technology from the upper northern STEM networking schools were invited to participate in this workshop. The STEM education workshop engaged the teachers with critical innovative ideas of inquiry-based-learning (IBL), and project-based-learning (PBL). The first session of the workshop was an introduction to STEM and its relatedness for 21st century skills, critical thinking and problem solving skills, in particular. The instructor posed a variety of real-world and mathematical problems to involve the teacher participants in inquiry learning. The process and technique of inquiry learning was introduced throughout the course by teacher’s engaging in problem solving. The other session allowed the teacher participants to actively engage in group work through the designed hands-on STEM learning activities by the IPST core trainers. The group project was dominantly applied to initiate PBL approaches for demonstrating STEM integration in the classroom. The overviews of STEM learning, levels of its integration, and essence and urgency of STEM implementation in Thailand were also stressed in the STEM education workshop.

**Teacher Learning from the STEM Education Workshop**

From teacher interviews and self-reflection reports, the four teachers shared positive responses about what they learned from the STEM education workshop. The findings of my study regarding each teacher’s observed grade level, classroom implementation, obstacles or challenges, and visions or future plans are summarized in Table 6-1.
Table 6-1

The summary of the findings

<table>
<thead>
<tr>
<th>Observed Grades</th>
<th>Tanwa</th>
<th>Kanya</th>
<th>Mena</th>
<th>Mesa</th>
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<tbody>
<tr>
<td></td>
<td>1 Class of G9</td>
<td>4 Classes of G9</td>
<td>1 Class of G8</td>
<td>6 Classes of G8</td>
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| Classroom Implementation | Project-based-activities (group projects) | Whole class study on topic: mathematical skills and process | Independent learning in statistics | Game-based-activity, whole class study and group work |

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<td></td>
<td>2. Unexpected school events</td>
<td>2. Unexpected school events</td>
<td>2. Unexpected school events</td>
<td>2. Unexpected school events</td>
</tr>
</tbody>
</table>

| Visions/Plans | A STEM Club | Increase of integration other STEM disciplines’ content in math lessons | Integrating statistics in independent study/research project | A STEM Club |

Tanwa and Mesa who experienced several professional development (PD) programs seemed to have basic STEM principles before attending the STEM education workshop. Both teachers were willing to make some changes in their classroom practices by implementing STEM through group activities. Kanya related her current content teaching on mathematics skills and process to STEM-inquiry-learning. After being trained in the STEM education workshop on engaging students with a variety of techniques of mathematical problem solving, Kanya recognized that it was associated
with what she was attempting to practice in order to increase the level of student engagement in her classrooms. Mena was new to STEM learning and had the least opportunities to participate in mathematics PD programs. However, she was excited and became more interested in self-study and STEM initiatives and innovations after her first participation in the STEM education workshop. Mena presented future ideas of integrating statistics in student research study and continued promoting her students to acquire knowledge and statistical skills independently. In summary, the four teachers comprehended that STEM is an integration of science, technology, engineering, and mathematics. They acknowledged that STEM learning was an innovative approach to highly elevate students’ academic abilities both in discipline content knowledge and career skillsets.

**Teachers’ Classroom Implementation**

I observed these four teachers’ classroom instruction after they participated in a STEM education workshop for three days and I conducted interviews with them near the end of the second semester of the Thai school system. The following is the synopsis of each teacher’s classroom implementation in his or her specific school culture and student contexts.

Tanwa implemented two project-based-learning (PBL) including Tower Model and Yang Fruit as a Glider from the workshop in his top-performing Grade 9 classroom. The two activities were organized in extra hours separate from the regular classroom where normal mathematics content was mainly taught. Tanwa carried out the activities according to the guidelines provided by the workshop’s core trainers. He designed the activity plans, created additional conditions for project designs, and prepared worksheets
and materials. Tanwa employed mixed-academic grouping and group competition to encourage peer collaboration and team-work among his students. He adjusted STEM learning activities in order to suit his students as much as possible. Importantly, Tanwa provided opportunities for his students to lead group discussions and motivated student question-and-answer sessions without his interruption.

Kanya did not implement any STEM group projects from the STEM education workshop but she continued teaching based on her planned lessons of mathematical skills and process. Similar to the ideas of inquiry-based-learning introduced by the instructor from the workshop, Kanya challenged the students with several types of mathematical problems to promote students’ critical thinking skills and mathematical expressions. In math-sci-classrooms, she encouraged the students to express their own ways of thinking and represent mathematical solutions systematically. On the other hand, in the non-math-sci classrooms where the students were less motivated in mathematics learning, Kanya directed them in the process of problem solving and mainly lectured in a step-by-step process of written solutions.

Although Mena did not integrate STEM learning activities into her statistics classroom, she strived to build up the students’ greatest academic potential through an individual learning approach. In doing so, Mena facilitated students’ learning by managing a well-organized statistical packet with the applications of real-life situations. Her typical teaching practice was aligned with STEM as part of inquiry-based-learning where her students played the key role of classroom learning. In teaching for talented and curious learners, Mena demanded a high-level of engagement in which the students
meaningfully learned and fully understood statistics concepts and applications through problem solving.

Mesa associated her game-based-learning activity with the level 2 (multidisciplinary level) of STEM integration (Vasquez et al., 2013). She organized a “Symbol Wheel” group activity to assess the students’ ability of real-life word problem solving in the top-performing Grade 8 classroom. The game-based-activity was one of Mesa’s learning designs to create a dynamic classroom where the students were able to learn mathematics with fun, an interchange of thoughts, and group collaboration. In her typical mathematics content teaching, Mesa tended to use a questioning technique to elucidate students’ understanding of mathematical ideas and made them explicitly use the technique throughout the process of problem solving during the whole class discussion.

Using the Eight (0-7) Levels of Use ((LoU), one of three diagnostic dimensions of CBAM (Concerns-Based Adoption Model) for assessment of new innovation implementation (Hall, Dirksen, & George, 2006), I determined the extent these four teachers implemented what they learned from the STEM education workshop in their classrooms. Tanwa and Mesa were in the third level of Mechanical Use. As an early implementer, Tanwa mastered the STEM activities from the workshop in his classroom with a short period of preparation time. Mesa also attempted to adopt the STEM inquiry-based-learning to create her own learning group activity. Although both of them made efforts to implement STEM innovation in their classroom, it was carried-out over a relatively short period of time and it is not possible to determine if they will continue their practices. Kanya was in the second level of use, Preparation. It was the state in which she was beginning to approach implementing the STEM learning activity. She
recognized the relevance of STEM knowledge and skills with her topic of teaching and planned to further develop her STEM knowledge base. Mena was in the early state, *Orientation*, the first level of use. She was seeking more information about STEM innovation and exploring related-innovative ideas of STEM integration with statistics before implementing what she learned from the workshop in her future classroom.

In summary, by looking across the cases, I found these four teachers shared some commonalities and differences in classroom implementation after participating in the STEM education workshop. Tanwa and Mesa implemented group project activities to challenge their top-academic performing students with different activities. Tanwa adopted the STEM PBL activities in order to introduce his students to the ideas of integrating STEM in mathematics, while Mesa used game-based activity to assess her students in real-life word problem-solving skills. Kanya and Mena did not directly integrate STEM learning activities in their classrooms because of time limitations for content teaching and STEM lesson planning. They both attempted to associate the acquired STEM knowledge and skills with the topics they were teaching in their typical classrooms. According to the difference of students’ academic readiness and class size, Kanya mainly used the whole-class discussions for classroom discourse and led the students in the problem-solving process while Mena tended to personally interact with her students and encouraged them to work on tasks individually or in groups. All four teachers faced time constraints for content classroom teaching as a result of overloaded mathematics content curriculum and unexpected extra school events. Nevertheless, the four teachers shared visions and future plans to implement STEM during the next academic year. Tanwa and Mesa had a plan for STEM Club establishment. Kanya
planned to increase integrated STEM knowledge in her content teaching while Mena foresaw her students integrating elementary statistics in research projects or independent study. For success of STEM implementation, they all agreed that the amount of time for planning and conducting STEM learning activities should be properly and significantly allocated.

**Discussions and Conclusions**

To the best of my knowledge, this is the first study to evaluate Thai mathematics teachers’ implementation of STEM learning in their classrooms after attending a STEM education workshop. Based on my interviews, none of the teachers demonstrated resistance to implementation of the STEM activities that they learned in the STEM education workshop. Although the results of my study cannot be generalized to the entire Thai educational system, it does suggest that there is interest among teachers in STEM professional development which aligns with the Thai Ministry of Education’s plan to develop a formalized STEM curriculum (MOE, 2016). In this section, I discuss the results of my study by connecting them with the literature I reviewed in Chapter 2.

**Teachers’ aspects of STEM integration in the classroom.** The findings of my research were that teachers shared wide aspects of STEM integration. The teachers shared the ways they viewed, practiced, and struggled with challenges and determined influential factors or problems that had impacts on their classroom teaching after participating in the STEM education workshop. First, all four of them viewed that to advance STEM learning, they had to increase more real-life applications in the form of either mathematics word problem solving or engineering project designs. Their perspectives represent the key elements of the STEM learning approach and its core
concepts of integration which are consistent with STEM educators. For instance, their perspectives are specifically in line with those of researchers such as Vanquez (2015) with regards to the idea of engaging the students in real-life application as the heart of STEM education and Bryan et al.’s (2016) ideas of learning mathematics and science through an integration of engineering design practices and technology relatedness.

Second, the four teachers reflected that the main challenge of STEM implementation was time constraints owing to overloaded content curriculum. This challenge is associated with Bryan et al.’s (2016) claim in which to bring effective change in the classroom, teachers must implicitly demand that curriculum change be more focused in STEM integration. That means a comprehensive STEM curriculum is urgently required to facilitate teachers in planning sustainable STEM lessons. Even though the teachers recognized that learning through STEM activity benefits students in knowledge and skill applications, practically, it is time consuming. Thus, they first preferred to cover the mathematics contents as guided by school-curriculum requirements. Later, if time permitted, they would implement STEM in the classroom such as in the case of Tanwa and Mesa. The teachers’ priority is similar to Wang et al.’s (2011) assumption that teachers were more concerned about content teaching than knowledge applications. Lastly, in addition to content teaching, all four teachers pointed out that students’ academic readiness affected their level of STEM integration, thus teaching students first the subject content as important background knowledge for them to apply in STEM activities.

**Teachers’ change after workshop participation.** According to Guskey’s (2002) alternative model described in Chapter 2, the processes of teachers’ learning resulted
from their experiences in PD programs. In my study, I focused on only two forms of teacher change based on Guskey’s ideas: change in teachers’ classroom practices and change in teachers’ beliefs and attitudes. The results showed that the four teachers had positive attitudes toward STEM learning and had future plans for implementing STEM in their classrooms. Tanwa’s belief of how students learn through PBL activities and his role from being a directive teacher changed positively. He shared his views of implementing STEM group projects as a setting where students fully engaged in an active learning process. Significantly, his change of classroom practices provided students autonomy to succeed in their group work and be able to achieve learning goals. The results align with Pang’s (2010) case study of a Korean mathematics teacher that the more the teacher involved students with real-life applications, the more the students played critical roles in class discussion. According to the study of Liljedahl (2010), the sudden change of Tanwa’s classroom practice from traditional teaching to group work assignments right after STEM workshop participation can be called rapid and profound change as a shift in his beliefs and practices. Ultimately, Mesa showed a high degree of change in her classroom practice, beliefs and attitudes as a result of attending several PD programs. She believed that gradually but continually making changes in her classroom practice through STEM integration would improve students STEM knowledge and skills over time. Mesa’s change in practices and attitudes can be coined gradual change as the final type of change from Pang’s (2010) study because it occurred over a longer period of time as a result of her instilling a positive disposition. Although, Mesa faced time limitations, she tried to integrate STEM in her own way and solve challenges during implementation.
Kanya and Mena did not make substantive changes in classroom practices based on workshop participation. As Kanya believed that the topics she was teaching were a part of inquiry-based-learning that she acquired from the workshop, she continued to teach mathematical skills and problem-solving processes in her classrooms. With time constraints and mixed-ability students in different classes, she decided to focus only on mathematical skills by employing a questioning technique. Based on the Liljedahl (2010) study, Kanya was in the push-pull rhythm of change, where she was likely trying to make change in her classroom practices. At the same time, she realized that there were some factors beyond her classroom contexts such as curriculum pulling her from this attempt to change. Kanya argued that lecture and directive teaching was not her best option, however, she continued to employ it in the classroom of unmotivated students in a rush of mathematics-content coverage. Likewise, Mena learned about STEM integration but did not implement what she learned in her classroom, however, she perceived that the students could learn through the inquiry-based-learning process. Therefore, she encouraged her students to learn her statistics lessons packet individually and in groups. The nature of statistics and the focus of delivering content were Mena’s major factors for integrating her subject with STEM.

My study indicated that the differences of the four teachers’ STEM practices were affected by their personal beliefs and this is consistent with the study of Wang et al. (2011) in which differing perceptions and beliefs teachers hold shape their practices. It is also in accordance with Nadelson et al. (2013) that engaging teachers with hands-on activities was able to promote positive attitudes in STEM content and pedagogy and build up confidence in teaching STEM. After participating in the STEM education workshop,
the four teachers increased their confidence in STEM implementation resulting in attempts to deliberately integrate STEM activities (Tanwa’s case) or associate STEM concepts from what they actively learned in the workshop to their typical classroom practices (in the cases of Kanya, Mena, and Mesa).

Before examining the above four cases, I believed that teachers’ acceptance of STEM teaching should be the most dominant factor to influence their classroom practices, while the other factors such as student ability, curriculum or time for teaching have less significance in making the decision to implement STEM practices. From my study, I learned that there were compelling reasons why the teachers were not able to implement new innovations in their classrooms. For instance, Kanya and Mena learned and appreciated STEM learning as an integrative approach to promote their students in applications of knowledge and skills. They demonstrated positive attitudes toward STEM integration and seemed enthusiastic to implement STEM in the classroom. But in reality, they did not implement what they learned from the STEM education workshop. Furthermore, Kanya and Mena shared a common belief that the mathematics-content curriculum does not support teaching integrated STEM, whereas Tanwa and Mesa were able to integrate STEM group activities in their own specific ways. My assumptions were that Tanwa and Mesa have more years of teaching experience and attended several PD programs and on-going trainings previously, therefore, they are able to integrate accumulated multiple-gained knowledge and skills in their classrooms. Besides, having high-professional abilities and academic confidence plus being considered as senior-experienced teachers by the Thai school community, they are more likely to have autonomy with regards to risk-taking (Sparks & Loucks-Horsley, 1989) to implement
new approaches in the classroom. In addition to that, the professional autonomy and their regular self-reflective practices can promote them to exercise good judgement in teaching and determine the effectiveness of student learning (Castle & Aichele, 1994; Rogers et al., 2007).

Overall, from my point of view, these four case studies represented hidden significant factors that influence teachers to make decisions on STEM classroom implementation. The results of my case studies reflect Warfield et al.’s (2005) argument that teachers’ beliefs about learning and teaching mathematics may not be consistent with actual practice resulting from the different sets of beliefs held by the teachers. According to Warfield et al., these sets of beliefs could be the belief of students (e.g., learning abilities). For example, Kanya claimed that teaching the students from non-math-sci classrooms who have less interest in mathematics was one of her challenges. Additionally, the other key factor is the constraints of change in teaching practices (e.g., time constraints and curriculum). As shown in my study, all of four teachers were faced with time limitations for content teaching and activity implementations. With inadequate time, the four teachers were more likely to teach mathematics content as their first priority but increase students’ engagement on given tasks.

In conclusion, all four teachers were satisfied with the STEM education workshop and gained knowledge and skills of STEM implementation in the classroom. Only Kanya reflected that the STEM education workshop should provide more guidelines and evidence on how teachers from previous STEM education workshops implemented STEM learning activities in their classrooms. She believed it would be helpful to guide her in the right direction on how to conduct STEM activities as she was willing to
integrate STEM skills in her future classroom. They all believed that integrating STEM in the classroom will improve student learning, but the degree to which they made deliberate change was strongly affected by their different sets of beliefs and their interpretations of their teaching contexts.

**The strengths of the STEM education workshop in this study.** According to the characteristics of quality PD programs presented by PD educators (Loucks-Horsley & Matsumoto, 1999; Loucks-Horsley et al., 2003, 2010; Desimone, 2011) reviewed in Chapter 2, this STEM initiative workshop provided distinguishing courses aimed at improving student learning through increasing teacher professional knowledge. The workshop courses provided the teachers both STEM core content and pedagogy content knowledge. According to the study of Nadelson et al. (2013) and Wang et al. (2011), these are two vital domains required of teachers during the PD programs. In addition, the workshop engaged the teachers with hands-on experience in effective ways to learn how to foster STEM integrated skills of students in their own classrooms. The STEM lessons provided by the core trainers facilitated the teachers to directly implement what they learned in their classrooms. Additionally, the STEM education workshop built up teachers’ leadership skills as reflected by Tanwa who created his own STEM lesson plan while Mesa collaborated with her science and computer teachers for a future STEM Club establishment. The STEM education workshop propelled the teachers to want to develop their STEM teaching proficiencies more in the future.

**The weaknesses of STEM education workshop in this study.** In my opinion, one potential weakness of the STEM education workshop is that it may be difficult to find trainers who are knowledgeable in all areas of STEM, as the core trainers from the
current workshop seemed to demonstrate higher propensities toward science and mathematics. The current STEM education workshop did not follow-up with the teacher participants in classroom instruction to determine if teachers faced challenges in implementing what they learned. This was in contrast to what I found in my reviews of the PD literature where the PD educators or researchers would monitor and evaluate the effectiveness of PD implementation afterwards and be able to further generate ideas for research studies for future PD improvements (Arbaugh, 2003; Franke et al., 2001; Zehetmeier & Krainer, 2011).

**Recommendations**

STEM education in Thailand is driven by an urgent national top-down policy of implementation in response to a global trend of empowerment and recruitment of more students in scientific career paths (The Ministry of Education [MOE], 2016). The STEM education workshop provided by the IPST aimed to disseminate STEM learning management for K-12 teachers in the four disciplines. Classrooms are the smallest but most crucial unit of STEM implementation. Teachers are the key performers to bring changes in the classroom and increase student learning with support from school stakeholders such as principals and administrators. PD educators play a significant role to facilitate teachers in gaining requisite sets of knowledge and skills.

Regarding that STEM integration has recently been introduced in Thailand and teaching learning is the process of change (Guskey, 1986, 2002), teachers are in need of quality time for change-making and being supported by STEM experts. Thus, STEM PD educators should continue to provide teacher workshops pertaining to STEM classroom implementation. In terms of the features of ongoing STEM education workshops in
Thailand, they need to be continuous and customized PD sessions that meet the needs of individual teacher’s career paths. Additionally, providing possible channels for STEM teachers to easily access the abundance of STEM resources and guidelines for STEM PBL activities is highly recommended.

My findings, for instance, have shown the different levels of teachers’ efforts toward STEM classroom implementation. Significantly, it revealed that each teacher had different challenges in which they might require different professional support needs. For teachers, like Tanwa and Mesa who eagerly implemented STEM learning activities for the short-term use of innovation, it is necessary to assist them to carry out implementation on a long-term routine basis. PD educators might provide constructive guidelines such as daily STEM hands-on activity plans. Besides the informative support, PD educators can connect teachers to be involved in a potential teacher STEM collaborative network where the teachers would be able to share their experience of STEM classroom implementation. For teachers who have been facing a major concern similar to the case of Kanya where students have less academic readiness and interest, PD educators can facilitate these teachers by providing them alternative STEM workshops/programs. In the workshop, the STEM core trainers should focus on STEM learning for inattentive students, provide STEM manuals for teacher participants, and demonstrate STEM activities related to the students’ real-life experience in order to gain students’ interest. For the teachers who are considered as Orientation level of use (Hall, Dirksen, & George, 2006), like Mena, PD educators can encourage them to attend fundamental programs to acquire more constructive STEM information and engage them
in a variety of STEM hands-on activities until they are ready and willing to start implementing new innovation.

To gain teacher confidence in integrating STEM in the classroom, I agree with Loucks-Horsley et al. (2010) that STEM educators should schedule visits to teachers’ classroom to support them. Being in the teachers’ actual classroom settings will help the STEM PD educators to evaluate the provided workshop and make improvements for future PD programs. Moreover, when physical classroom visits are not feasible, follow-up visits via other forms such as phone calls, email, or questionnaires may also assist PD educators in making improvements to future workshops.

Creating a STEM professional learning community (PLC) (Dufour, 1998, 2004; DuFour & Marzano, 2011) as an organizational support within school and networking schools together will help to promote teachers’ collaborations in both content knowledge and pedagogy content knowledge of the four disciplines. The PLC will provide the teachers academic encouragement and it is a comfort zone where teachers will be able to share their thoughts, expertise, struggles, and achievements.

My research study contributes to the body of STEM education literature in the study of STEM classroom implementation. This study demonstrates Thai teachers’ specific processes of STEM implementation and their challenges as a result of differences of school and student contextual elements and teachers’ beliefs. Future research should focus on science and technology in addition to mathematics, such as investigating students’ abilities in applying knowledge and skills of science and technology through engineering design projects or examining the way science and technology teachers integrate mathematics in their classroom. Additionally, barriers and challenges to
implement STEM learning activities in Thailand should be more closely investigated to assure that STEM educators from outside the country are familiar with unique social, cultural, and educational context that may pose challenges to the success of STEM implementation in Thai classrooms.
References


The Institute for the Promotion of Teaching Science and Technology (IPST). (n.d.). STEM in daily life: Bamboo rice container. STEM learning management handouts, retrieved from


Appendix A

Informed Consent Form

Study Title: Mathematics Teachers’ Classroom Instruction after Participating in STEM Education Workshop in Thailand

Principal Investigator: Waeodao Autid

I am a Ph.D. student at the Pennsylvania State University in the College of Education. I am planning to conduct a research study which you are invited to participate in.

Participant’s Printed Name:

You are being asked to participate in a research study about mathematics teachers’ classroom instruction after participating in STEM Education Workshop in Thailand.

The purpose of this study is to examine how mathematics teachers integrate knowledge and skills teachers in their classrooms after participating in STEM Education Workshop.

Data Collection

You will be asked to be observed in your classroom and be interviewed about your classroom implementation. The study participation will take approximately one school semester. I will visit your classroom about 8-10 times and conduct 30-45 minutes semi-structured interviews 3-4 times. I would like to audio-record the interviews so as to make sure that I remember accurately all the information you provide. Additionally, I will photograph/ save digital files of your classroom artifacts by your permission only. I
will keep these recorded audio and digital files in my computer and they will only be accessed by myself. Your identity will not be disclosed in the materials provided.

The study data will be handled as confidentiality as possible. Individual names and other personally identifiable information will not be used. Pseudonyms will be used to storage and quote from interviews as a means to secure participant’s identity.

Your participation in this study does not involve any physical or emotional risk to you beyond that of everyday life.

**Potential benefits**

Taking part in this research will benefit you to learn and improve your teaching and learning. The study results may be used to enhance other teachers’ classroom instruction and inform professional developers how to provide effective PD activities in the future.

Your participation in this study is voluntary. If at any time and for any reason, you prefer not to participate in this study, please feel free not to. You may withdraw from this study anytime without affecting your relationship with the researcher of the study. Any information collected from the participant will not be used if the participant decides to withdraw before finishing the study.

If you have questions, you may contact the researcher: Waeodao Autid, telephone number: 095-134-9079, email address: wua107@psu.edu or wd.autid@gmail.com

**Consent**

I have read this form and the research study has been explained to me. I have been given the opportunity to ask questions and my questions have been answered. If I have additional questions, I have been told whom to contact. I agree to participate in the
research study described above and will receive a copy of this consent form after I sign in.

(…………………………………………………)

Participant’s signature

__________________________

Date
โครงการวิจัยเรื่อง การจัดการเรียนการสอนคณิตศาสตร์yclayหลังการเข้าร่วมอบรมเชิงปฏิบัติการการจัดการเรียนรู้สะเต็มศึกษาในประเทศไทย

Mathematics Teachers’ Classroom Instruction after Participating in STEM Education Workshop in Thailand

ชื่อผู้วิจัยหลัก นางสาวแววดาว อุทิศ นักศึกษาระดับปริญญาเอก คณะศึกษาศาสตร์ มหาวิทยาลัยPennsylvania State กำลังวางแผนเพื่อดำเนินการวิจัย ตามที่ท่านได้รับข้อมูลเข้าร่วมในครั้งนี้

ข้อผิดพลาดในการวิจัย

ผู้มีส่วนร่วมในการวิจัยจะได้รับการจัดการเรียนรู้อย่างเท่าเทียมกับการจัดกิจกรรมการเรียนรู้คณิตศาสตร์หลังการเข้าร่วมอบรมเชิงปฏิบัติการจัดการเรียนรู้สะเต็มศึกษาในประเทศไทย

วัตถุประสงค์ของการวิจัย

เพื่อศึกษาแนวทางการสร้างข้อมูลความรู้และทักษะของครูคณิตศาสตร์สำหรับจัดกิจกรรมการเรียนรู้คณิตศาสตร์หลังการอบรมเชิงปฏิบัติการสะเต็มศึกษา

วิธีดำเนินการเก็บข้อมูล

ผู้วิจัยจะดำเนินการจากการสังเกตการจัดกิจกรรมการเรียนรู้นั้นที่มีผู้มีส่วนร่วมในการวิจัยนั้นทำให้เห็นการศึกษานั้น โดยผู้วิจัยจะขออนุญาตบันทึกเสียงสนทนาของผู้มีส่วนร่วมในการวิจัย โดยใช้เครื่องบันทึกเสียงแบบดิจิตอล ที่มีระยะเวลาประมาณ 30-45 นาที เป็นจำนวน 3-4 ครั้ง โดยที่ผู้วิจัยจะขออนุญาตบันทึกเสียงสนทนา เพื่อเพิ่มความถูกต้องของการเก็บข้อมูล รวมถึงข้อมูลที่เกี่ยวกับผลการวิจัยจากข้อมูลที่ได้จากการวิจัยแบบดิจิตอล

ไฟล์เอกสารและเสียงกล่าววิจัยจะบันทึกไว้ในคอมพิวเตอร์สำหรับบุคคล ซึ่งผู้วิจัยเพื่อผู้วิจัยเท่านั้นที่เข้าถึงข้อมูลเท่านั้นได้ และผู้วิจัยจะไม่เปิดเผยข้อมูลใด ๆ ของผู้มีส่วนร่วมในการวิจัยในสื่อต่าง ๆ ข้อมูลเก็บวิจัยจะเป็นความลับ จะไม่เปิดเผยชื่อ หรืออัตลักษณ์ใด ๆ ของผู้มีส่วนร่วมในการวิจัยผู้วิจัยจะใช้ชื่อสมมุติในการจัดเก็บข้อมูลและผลการวิจัยสะเต็มศึกษา ที่เป็นการป้องกันข้อมูลสำหรับบุคคลของผู้มีส่วนร่วมในการวิจัย
การเข้าร่วมโครงการวิจัยครั้งนี้จะไม่ทำให้เกิดความเสี่ยง หรือผลกระทบใด ๆ ทั่วทางสุขภาพ ร่างกายและจิตใจ

ประโยณฑ์การเข้าร่วมการวิจัย

ประโยณฑ์การได้รับจากการวิจัย

ประโยณฑ์ที่ได้รับจากการวิจัย

การยินยอม

การเข้าร่วมโครงการวิจัยครั้งนี้ยินยอมให้ดำเนินการวิจัยลงในเอกสารต่อไป

การยินยอม

ข้าพเจ้าได้อ่านข้อความข้างต้น และได้รับการอนุญาตให้เข้าร่วมโครงการวิจัย

ทั้งนี้ หากข้าพเจ้าไม่ต้องการเข้าร่วมโครงการวิจัย ข้าพเจ้าจะแจ้งให้ทราบ

(............................)

ผู้มีส่วนร่วมในการวิจัย

วัน/เดือน/ปี ______/______/_______
Appendix B

Samples of Interview Questions from Each Phase

(Translation from Thai Version)

Initial Interview Phase

1. Please provide your educational background, teaching experience, and numbers of years you have been teaching?
2. What mathematics classes are you teaching? And how many classes are you teaching this semester?
3. How often did you participate in the mathematics workshop or other PD programs in mathematics?
4. What did you learn from the workshop and from which parts of the workshop did you gain the new knowledge? And was there anything taught in the workshop you already learned prior to attending?
5. What teaching approach are you employing in this class? Why do you use this approach?
6. What kinds of teaching materials, technology or artifacts do you use?
7. How long have you prepared for teaching the class?
8. How can you apply the new innovations learned from STEM education workshop in your classroom?
9. Why do you think the new innovation from STEM education workshop is applicable to your classroom?
10. Will you make any changes to your lesson plan after participating in the STEM education workshop?
11. How and when will you introduce the new innovations to the students (e.g., Project-Based-Learning (PBL) activity by integrating other disciplines)?
12. How will you assess/evaluate the new innovations you implemented in the classroom?

Follow-Up Interview Questions

1. What strategies did you use to get students engaged in the classroom through new innovations gained from STEM education workshop?
2. What knowledge and skills did you plan to integrate in today’s math lesson?
3. What outcomes did you expect the students to achieve from today lesson?
4. What role did you place yourself on while doing this activity?
5. In which way, did you see the students change and what challenged them while working on assignment?
6. (Tanwa’s case) Why did you decide to implement Tower Model Activity in the class?
7. (Tanwa’s case) Apparently, after 2 period-observation, you suddenly implemented the new innovations you learned from the STEM education workshop. How did you prepare this activity plan?

8. (Tanwa’s case) It seemed that the students are familiar with you and your teaching style, have you taught them before? And how do you describe your classroom management with the students?

9. (Tanwa’s case) Could you briefly talk about the process of creating the PBL activities in the classroom?

10. (Kanya’s case) How did you differentiate your teaching between math-sci and non-math-sci classrooms?

11. (Kanya’s case) Now you are teaching in the topic of mathematics process skills, which specific skills do you emphasize the most?

12. (Kanya’s case) I observed that the students rarely wrote down on their notebooks but mostly asked and answered verbally. What do you think about this students’ learning behavior?

13. (Kanya’s case) You were faced with overspending time on classroom management? How did you attempt to solve this problem?

14. (Kanya’s case) In some classrooms you led the students to solve the questions by themselves, but some classrooms you had to direct them in solving. Can you explain why?

15. (Kanya and Mena case) Since there were unexpected events that delayed your teaching, and as we know that teaching this chapter (mathematics process skills and problem solving) it needs time for practice, do you have any alternative plan or adjust your lesson plan? How?

16. (Mena’s case) I observed that the students are more likely to work individually rather than in groups. According to previous interviews, you mentioned that you would like to engage the students to work in a group. How will you encourage them to work more in a group?

17. (Mena’s case) As your students are very good and active learners, how do you expect to help them improve their abilities?

18. (Mena’s case) After showing some examples of quartiles, you then let the students continue studying deciles, and percentiles by themselves? Do you think the students would struggle in solving problems?

19. (Mesa’s case) During the game-based-activity, some groups struggled with word problems about money and speed and time. Do you have any solutions to help the students gain more understanding?

20. (Mesa’s case) From this game-based-activity, in what ways do you think students can be aware of connecting mathematics they have learned with real-life situations?

**Member-Check Interview Phase**

1. Which parts of implementation did you struggle with and feel needs some improvements?

2. Do you think this new innovation that you learned from the STEM education workshop better benefits student learning than the traditional approach? In which ways?
3. Do you plan to continue implementing this new innovation to other classes?
4. (Tanwa and Mesa) You said, you have a plan for STEM Club in the new semester, could you tell me more about this plan?
5. (Kanya’s case) Do you think what you are teaching on process and skills in mathematics is STEM skills? Do you think you are implementing it in the right direction?
6. (Mena’s case) As mentioned about implementing statistics with research study, can you clarify this plan?
7. (Mesa’s case) What changes have you seen in you, your students, and classroom atmosphere while you were implementing the game-based activity?
8. Overall, how did you assess yourself for this STEM implementation?
9. What are the reasons that can influence your decision to continue or stop you from implementing this new approach in future classes?
10. What knowledge or skills from STEM education workshop did you integrate most into your mathematics classroom?
Appendix C

Teacher Self-Reflection Report

แบบรายงานการสะท้อนคิดของครู

ชื่อ Name: .......................................................... ระดับที่สอน/ ห้อง Grade /Room...............................
วันที่ Date ................. บทเนื้อหาที่สอน Chapter/Content ..................... ภาคการศึกษา Semester ....

การจัดทำแบบรายงานการสะท้อนคิดทั้งหมด 2 ตอน Instruction: There are 2 parts of Teachers Self Reflection Report

ตอนที่ 1 ประเมินตนเองจากการจัดกิจกรรมการเรียนการสอน Part 1: Self-evaluate your classroom instruction
ตอนที่ 2 เขียนสะท้อนคิดที่ได้จากการจัดกิจกรรมการเรียนการสอน Part 2: Write reflection your classroom instruction

<table>
<thead>
<tr>
<th>เลขการปฏิบัติการจัดกิจกรรมการเรียนการสอน</th>
<th>ไม่เคยNever</th>
<th>เรารายไม่Rarely</th>
<th>บางครั้งOccasionally</th>
<th>บ่อยครั้งFrequently</th>
<th>สามัญVeryfrequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching-Preparation Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1. เข้าจัดออกแบบการเรียนการสอนตามหลักสูตรแกนกลาง I design lesson plans according to national curriculum.</td>
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<tr>
<td>2. เข้าจัดออกแบบการเรียนการสอนตามหลักสูตรสถานศึกษา I design lesson plans according to school curriculum.</td>
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</tr>
<tr>
<td>3. ขับเคลื่อนการเรียนการสอนโดยเน้นเนื้อหาเป้าหมาย I prepare teaching by focusing on contents.</td>
<td></td>
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<tr>
<td>4. ขับเคลื่อนการเรียนการสอนโดยเน้นเนื้อหาเป้าหมาย I prepare teaching by focusing on contents.</td>
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<tr>
<td>5. ขับเคลื่อนการจัดกิจกรรมที่โต้ตอบมี</td>
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</tr>
</tbody>
</table>

ชั้นเตรียมการจัดกิจกรรมการเรียนการสอน

หมายเหตุ

ตัวอย่างขอให้ระบุการประเมินตามข้อปฏิบัติการที่เกี่ยวข้อง

หมายเหตุ

ตัวอย่างขอให้ระบุการประเมินตามข้อปฏิบัติการที่เกี่ยวข้อง
I add extra activities from the STEM education workshop in mathematics classrooms.

I apply knowledge and skills from the STEM education workshop in mathematics classroom.

I receive teaching materials and medias supported from school.

I together with students set and agree on classroom rules and regulation.

I enact my teaching based on my lesson plans.

I inform students learning objectives at the beginning of the class.

I teach regarding differences of students’ mathematics abilities.

I receive teaching materials and medias supported from school.

I apply knowledge and skills from the STEM education workshop in mathematics classroom.

I receive teaching materials and medias supported from school.

I together with students set and agree on classroom rules and regulation.

I enact my teaching based on my lesson plans.

I inform students learning objectives at the beginning of the class.

I teach regarding differences of students’ mathematics abilities.

I receive teaching materials and medias supported from school.
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13. I connect mathematics knowledge and skills with daily-life applications and real situations.


15. I utilize a variety of teaching methods.

16. I mainly give lectures in the classroom.

17. I provide students opportunities to ask questions in the classroom.

18. I provide students time to think and work on assignment in the classroom.

19. I listen to students’ opinions.

20. I pose questions from simple to more difficult level in order to practice students in exercising systematic thinking.
I create challenging situations for students to critically analyze, rationalize, and solve problems.

I motivate students to participate in teaching by questioning, doing activities, and classroom discussions.

I friendly talk with students.

I assign students to work individually.

I assign students to work in group.

Assessment and evaluation stage

I inform students in advance about classroom assessment and evaluation process.

I assess students with paper tests.

I assess students from activity worksheets.

I evaluate students from their answering, participation, and engagement
| 30.  | ข้าพเจ้าเห็นผลการประเมิน และให้อิจฉาแก่ผู้เรียน มีการให้ผลการเรียนผลและให้โอกาสให้ผู้เรียนมีโอกาสทดสอบหรือปรับปรุงผลการเรียน | 
|      | | 
|      |  | 
|      |  | 
|      |  | 

**Table 2:** Write reflection your classroom instruction

2.1 ข้าพเจ้าเห็นความรู้จากจิตการเข้าอบรมเชิงปฏิบัติการสอน Part 2: I comprehended STEM education as follows:

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|  |  | 
|  |  | 
|  |  | 

2.2 ข้าพเจ้าสามารถนำความรู้และทักษะหลักจากเข้าร่วมอบรมเชิงปฏิบัติการสอนมาบรรยายการในวิชาคณิตศาสตร์ที่กล่าวสอนอยู่ ดังต่อไปนี้ คือ I was able to apply knowledge and skills from STEM education workshop to integrate in my classrooms as follows.

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|  |  | 

2.3 ข้าพเจ้าได้พบปัญหาหรืออุปสรรคที่เกิดจากการจัดการเรียนการสอนจึงมีการระดมสมองในการจัดการเรียนการสอนในชั้นเรียนคณิตศาสตร์ของข้าพเจ้าดังนี้ คือ I faced with the problems or obstacles of integrating STEM in my classrooms as follows.

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2.4 ข้าพเจ้าเห็นว่า การจัดกิจกรรมการเรียนการสอนโดยการลงมือกระทำในการสอนคณิตศาสตร์นั้นจะบรรลุผลได้ดีขึ้นเมื่อมีการตั้งคำถามที่มีส่วนร่วม In order to successfully integrate STEM education in mathematics, I think there are some following factors as follows.

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2.5 ข้าพเจ้าเห็นว่า การเปลี่ยนแปลงในตนเอง อาทิ ความจดจ่อ พัฒนาคิดและการจัดกิจกรรมการเรียนการสอนภายหลังจากการเข้าอบรมเชิงปฏิบัติการสอนมีส่วนช่วยเพื่อ There were some changes in my myself regarding beliefs, attitudes and teaching after participating in STEM education workshop as follows.

|  |  | 
|  |  | 
|  |  | 
|  |  | 

2.6 อื่นๆ Others..............................................
VITA

Waeodao Autid

Education History

2017  Doctor of Philosophy in Curriculum and Instruction, and in Comparative International Education, Pennsylvania State University, Pennsylvania, USA
2008  Master Degree of Education (Educational Research and Statistics) Chiang Mai University, Chiang Mai, Thailand
2002  Graduate Diploma of Teaching Profession, Rajabhat University, Chiang Mai, Thailand
2001  Bachelor of Science (Mathematics) Chiang Mai University, Chiang Mai, Thailand

Work History

2011  Private mathematics tutor
2009  ESP (English Special Program) coordinator and mathematics teacher, Wachirawit Secondary School, Thailand
2005  Mathematics teacher, Wichai Wittaya Bilingual School, Thailand
2004  Secretary of academic affairs, Wichai Wittaya Bilingual School, Thailand
2002  Instructor in “Thinking and Decision Making” and statistics Institute of Physical Education, Chiang Mai, Thailand

Master Thesis Participatory

Action Research for Enhancement of Applying Mathematical Process Skills in Daily Life of Mathayom Suksa 1 Students (English Program) at Wichai Wittaya Bilingual School, Mueang Chiang Mai District