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Development of Thai Teachers' Pedagogical Reasoning by Utilizing Metacognitive Reflections in STEM Professional Development

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Abstract

The Ministry of Education, Thailand recently adopted science, technology, engineering, and mathematics (STEM) as one of the major topics of instruction in K-16 education. However, research found that Thai teachers' knowledge and skills about the instruction of the STEM field are limited. Thus, a professional inquiry-based STEM development institute was provided to improve K-16 educators' STEM instruction knowledge and skills of STEM instruction at Burapha University, Thailand for four consecutive years since 2014. This particular study took the 2015 data of 23 participants to investigate how metacognitive reflection helped develop and shape teachers' pedagogical reasoning of STEM instruction during the institute. Data includes metacognitive reflection journals of five days and a focus group interview. Reflective journals were analyzed with a reflection rubric while interview data was analyzed with a metacognitive knowledge scheme to provide more evidence of teachers' pedagogical reasoning behaviors. The findings indicated that metacognitive reflection journals were effective in developing teachers' pedagogical reasoning during the professional development institute. Implications are discussed on how a professional development program can effectively develop teachers' pedagogical reasoning of STEM instruction.

Keywords: STEM, Pedagogical Reasoning, Professional Development, Metacognitive Reflection

Introduction

A professional development program is considered as one of the key efforts for improving in-service teachers' teaching in many countries (OCED, 2009). Science, technology, engineering, and mathematics has long been accepted and implemented as an alternative solution to address current threats in education to produce competent generations in a sink-or-death competition around the world (Bybee, 2010) and the lack of a STEM workforce raises concerns about national security (Machi, 2009). Since the inception of STEM in the 1990s at the National Science Foundation in the U.S. (Bybee, 2010), each country has used it as a generic term for policy, program, or practice that involves STEM disciplines.

Thailand recently adopted STEM as one of the major topics of instruction in K-16 education. Thai in-service teachers are now inundated with a number of professional development programs on Science, Technology, Technology, and Mathematics (STEM) education to improve their teaching practices with student-centered instruction, scientific knowledge and skills on STEM education. However, research found that STEM teachers had limited knowledge and skills about teaching STEM education (Brown et al., 2010). Thus,the authors of this study have been providing a week long professional development institute every summer since 2014, and participants were given a chance to implement STEM lessons to improve their content knowledge and pedagogical skills of teaching STEM education in Burapha University, Thailand (Park & Prommas, 2014). Evaluation of the Thai STEM teacher professional development indicated a high degree of teacher satisfaction with what was provided (Park & Prommas, 2014).

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Thai teachers evidently had positive experiences with the content of the STEM workshop. Nevertheless, when it comes to teaching of STEM in their own classrooms, Thai participants tend to struggle to apply their acquired knowledge and skills as seen in other studies (Demet, 2009; Park & Kim, 2015). Such a struggle may have been caused by the fact that participants were not given enough reflective practices to develop and apply pedagogical reasoning to their classroom settings during the program (Park & Kim, 2015). Therefore, this study investigates how metacognitive reflections increase participants' pedagogical reasoning in their STEM instruction during the professional development program.

In this study, metacognitive reflection is a tool for effective reflection through writing, using metacognitive reflection to apply acquired knowledge and skills from the STEM workshop into real classrooms. Using metacognitive reflection, we took pedagogical reasoning as the theoretical framework for this study. According to Shulman (1987), pedagogical reasoning means that teachers need to reflect and practice their knowledge and understanding of subject matter to transform into "forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (p. 15). And, metacognitive knowledge has three variables including Knowledge of personal variable (KPV) which illustrates how people learn; Knowledge of task variables (KTV) that depicts knowledge about the nature of and the type of task; and Knowledge of strategy variables (KSV) which explains knowledge of cognitive strategies, conditional knowledge about when and where it is appropriate to use such strategies in teaching (Flavell, 1979). Using these three variables of metacognitive knowledge, we will analyze participants' metacognitive reflections to help increase participants' pedagogical reasoning to improve STEM instruction in their classrooms.

Thai STEM Teacher Professional Development

From 2014 through 2017, several professional development programs of Thaimath and science teachers focused on how to teach STEM education based on inquiry approach. Science teachers especially hoped to have opportunities to gain content knowledge and pedagogical skills to teach STEM education in K-12 through the professional development program, a seven-day summer institute, launched and managed by Burapha University with financial support from Laemchabang City Municipality, Chonburi Province, Thailand. Each summer, there have been around seven to eight STEM activities provided during the program. Since 2014, more than 120 Thai science teachers have participated in the teacher professional development institute. A STEM education expert from the U.S. higher education institution was invited to conduct the program over the years. The program provided an opportunity for the participants to experience the latest scientific content knowledge and science teaching pedagogies in STEM education (Park& Prommas, 2014, 2015).

The Thai STEM teacher professional development program has provided K-12 science teachers with advanced science content knowledge, pedagogical knowledge of STEM instruction that is inquiry-based, and metacognitive reflection practices to develop pedagogical reasoning(Park & Prommas, 2014). Figure 1 depicts a model of the professional development program used for this study. The Thai STEM teacher professional development program consists of (1) inquiry-based instruction, including inquiry approach, nature of science, authentic assessment, standards, and science education reforms, (2) metacognitive knowledge of pedagogical reasoning, i.e., (a) knowledge of personal variable (KPV), (b) knowledge of task variables (KTV), and (c) knowledge of strategy variable (KSV) and, finally, (3) STEM education which studies how to solve problems using science, technology, engineering, and mathematics. Most importantly, every session of the professional development program was formed with two critical components: (a) the latest theories of each topic followed by (b) laboratory experiments or activities that the teacher participants could utilize in their classrooms right away. The effect of a professional development institute is well documented in the literature, especially from an international perspective (Park & Prommas, 2014; Cho, Yager, Park, & Seo (1997). For example, some Thai teachers who had participated in the teacher-training programs applied the knowledge they have learned from the professional program over the years in their classrooms. Since the same participants had attended the program over years, students of the participants responded positively to inquiry-based instruction (Park & Prommas, 2014). In addition, Cho, Yager, Park, & Seo (1997) reported that, after a month-long, summer residential program in country overseas, participants taught five days in their own classrooms and continued to refine their modules of constructivist teaching and learning that they planned during the professional development program.

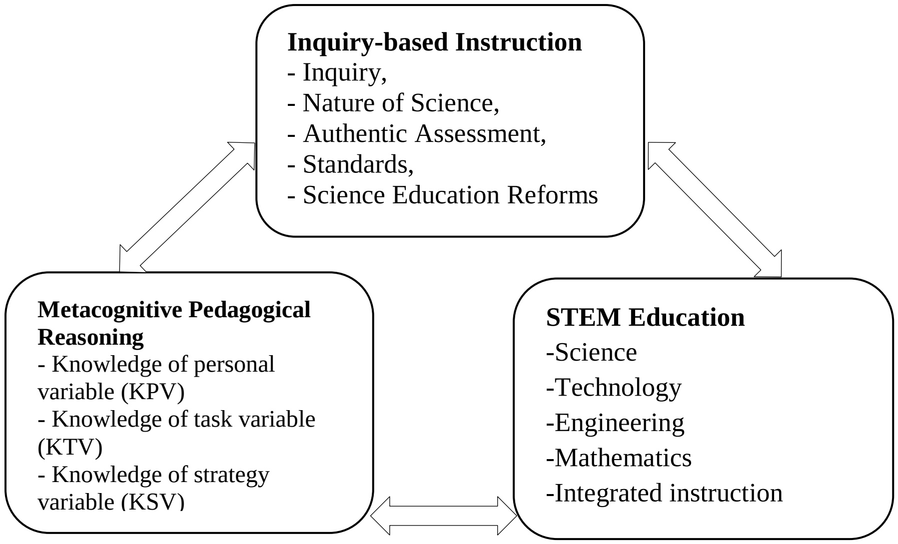

Figure 1 A Model of Thai STEM Teacher Professional Development Program for Inquiry-based STEM Education

They went to report that "the effect of the workshop was significant and that the learning was retained" (Cho et al., 1997, p. 400).Experienced Korean STEM teachers attended an institute for one month in advanced Western countries and applied what they hadlearned to their own classrooms after returning to their local school. This was a project funded by the Korean government since late 1980s until 2010. The Korean overseas professional development institute provided an opportunity for STEM teachers to experience the latest scientific content and science teaching pedagogies (Park & Kim, 2015).

Pedagogical Reasoning

Because this study adopted the research design of Park and Kim's study (2015), the design of pedagogical reasoning we used for this study naturally may look similar (Note: One of the authors of Park & Kim's study (2015) is also the same author of this study).As Shulman indicated (1987), pedagogical reasoning is,by nature, to illustrate reflective practice during the teaching process. When teachers' pedagogical reasoning occurs during instruction planning and implementation, they transform their comprehension of the subject matter into "forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (Shulman, 1987, p. 15). As suggested by Shulman (1987), a model of pedagogical reasoning and action for teachers use is a cycle of pedagogical activities including (a) comprehension, (b) transformation, (c) instruction, (d) evaluation, (e) reflection, and (f) new comprehension. Among these five components of cycle of pedagogical reasoning and action, this particular study only adopted two activities – comprehension and transformation due to too much preparation on the teachers' end and un-readiness of implementation in school. Shulman described the two activities as follows.

• *Comprehension:* Of purpose, subject matter structures, ideas within and outside the principle
• *Transformation:* First, 'Preparation' is critical interpretation and analysis of texts, structuring and segmenting, development of curricular repertoire, and clarification of purposes. 'Second, 'Representation' is use of a representational repertoire, which includes analogies, metaphors, examples, demonstrations, explanations, and so forth. Third, 'Selection' is choice among an instructional repertoire, which includes models of teaching, organizing, managing, and arranging. Finally, 'Adaptation and Tailoring to Student Characteristics' is a consideration of conceptions, preconceptions, misconceptions, difficulties, language, culture, motivations, social class, gender, age, ability, aptitude, interests, self-concepts, and attention.

However, we created an operational definition of comprehension and transformation specifically targeted on the context of the STEM workshop in this study.

• *Comprehension*: Thai teachers' comprehension of the purpose and focus of the subject matter and their development of the subject matter knowledge in multiple ways relevant to students' understanding.

• *Transformation*: Thai teachers' transformation of their knowledge on the subject matter in ways that are pedagogically powerful and yet adaptive to the variations in students' abilities and backgrounds.

The reason why we took these two components was that, during this study, Thai teachers had limited opportunities to fully teach students about STEM while they were in the professional development institute. Nevertheless, during the workshop program, Ward and McCotter (2004) argued that participants are able to experience 'comprehension' and 'transformation' through the act of pedagogical reasoning. One of the key acts of pedagogical reasoning is, in Shulman's model, the process of 'transformation' which means "wherein one moves from personal comprehension to preparing for the comprehension of others" (Shulman, 1987, p. 16).

Metacognitive Reflection

Metacognitive reflection is an effective way of developing and practicing pedagogical reasoning through reflective writing as it is an important tool to help teachers critically reflect on their teaching practices and pedagogical reasoning (Ward & McCotter, 2004). In their studies, pre-service teachers were asked to write metacognitive reflections on students learning through research projects. While analyzing participants' reflective writing, Ward and McCotter (2004) developed a rubric, which demonstrates the dimensions and quality of reflection in four different levels including (a) routine, (b) dialogue, (c) technical, and (d) transformative. We adopted these four dimensions for our data analysis. Each level indicates how teachers would teach STEM as they reflect on their instructional pedagogies, modes of knowledge presentation, and what their experiences would look like in the classroom. The benefits of metacognitive reflection journals are reported through a number of studies. Harland and Myhill (1997) reported that reflective journal writing helped make clearer interconnections between school experience and one's own experiences as well as to clarify confusing ideas. Other benefits of reflective writing include teachers' positive attitude toward journal writing (Demet, 2009), being used for self-assessment (Black & William, 1998), developing reflective practices for teaching (Morrison, 1996), and improving knowledge (Cantrell, Fusaro, & Dougherty, 2000). A synthesis of teachers' reflective thinking culminated the important relationship with pedagogical reasoning as follows (Sparks-Langer and Colton, 1991).

"critical reflection may be promoted through close examination of cases that illustrate particular aspects of context, pedagogy, content, … of teaching and learning that will help teachers develop a rich, flexible, repertoire of ideas, attitudes, and skills." (p. 43)

Through a critical reflection on teaching context and pedagogies, teachers move closer to a better understanding of the complexities within teaching. Writing a reflective journal uses metacognition, which is thinking over thinking in the process of instruction. As a guideline, we asked the participants three metacognitive questions; (a) what have you learned from the workshop, (b) how would you apply STEM ideas to your teaching (provide an example)? And (c) do you expect to have any challenges when applying?

Research Question

The purpose of this study is to enhance the metacognitive pedagogical reasoning of teachers attending the professional development program. Specifically, it aims to develop a strategy of reflective journal writing and to explore the relationship between journal writing and pedagogical reasoning. The following research question guided this study:

How does the metacognitive practice of reflective journal writing effect the development of Thai teachers' pedagogical reasoning in teaching STEM education through a teacher professional development program?

Methodology

Research Design and Sampling. This study investigated how reflective writing helped teachers develop their pedagogical reasoning in teaching STEM education in Thailand. The study utilized a qualitative methodology with selective and purposeful sampling design. Patton (2002) stated "qualitative inquiry typically focuses in depth on relatively small samples, even single case, selected purposefully" (p. 230).

To make this study clear and simple, we only took the participants of 2015 although the STEM professional development institute has been offered every year since 2014. Of the 30 teachers (26 females and 4 males with 6 to 15 years of teaching experience) who went through a week-long professional development institute, only 23 teachers participated in metacognitive reflection writing practice (N=23), which is called "pedagogical reasoning journal."

Data Collection and Analysis: We collected two sources of data including (a) a pedagogical reasoning practice worksheet (see Appendix A) and (b) a focus group interview (Appendix B). The worksheet and the focus group interview were completed during the professional development institute. Per the pedagogical reasoning practice worksheet (reflective journal), at the first meeting of the Professional Development program in Thailand, we explained the purpose of the worksheet. The worksheet was completed during the week of the program. Teachers altogether wrote a reflective journal, thinking of what and how they planned to apply what they had learned each day. A focus group interview was conducted on the last day of the entire workshop. Two authors of this paper analyzed the teachers' journal worksheet to see how the participants developed their pedagogical reasoning. One author read the teachers' reflective journals using an open code looking it over to find patterns and thematic ideas from the first reading (Merriam, 1998). The second author interpreted and explained the patterns and then categorized them into either Focus or Inquiry or Change. As the first author read the journal over, up to fourth one, each journal was analyzed in a time series. Once the person had finished reading each journal, the next person repeated the same process. When the readers found thematic ideas after multiple readings of a journal, they then analyzed them as being one of four levels including Routine, Technical, Dialogic, and Transformative by using the reflection rubric (see Appendix C). The readers sat down and discussed each reflective journal one by one to justify and finally determine the level and category (Lincoln & Guba, 2000). When we were in disagreement on the rubric-level decision, we discussed ituntil we closed the gap in between. The data of the focus group were analyzed by coding them on Excelto see if there was any insight in the participants' beliefs and behaviors, which helped us thoroughly interpret the teachers' development of pedagogical reasoning.

Focus Group Interview: The post focus group interview was designed to probe the thoughts of participants on a deeper level. The interview helped up to gather more in-depth data to be able to better answer the research question. The questions listed focused on how the teachers felt when teaching STEM education in their classrooms (see Appendix B). Four teachers participated in the focus group interview with five questions for about twenty minutes (N=4). The questions could elicit teachers' opinions on the effectiveness of pedagogical-reasoning practice as a technique to improve STEM teaching in different levels and learning environments as well. We transcribed the interview data and analyzed how they support their thoughts and ideas of STEM teaching as appeared in the reflective writing.

The Context of this Study: Over the years since 2014, Burapha University provided an inquiry-based STEM education professional development program for Thai teachers who teach in Laemchabang City Municipality, Chonburi Province, Thailand. Each year, the program offers seven to eight STEM activities to meet the teachers' needs and reform goals of Thai science education and STEM education. Such education typically claimed to be lacking in teaching inquiry-based science and the nature of science due to an over-emphasis on the content-oriented science teaching. This particular study was conducted to evaluate the program theme, "Inquiry-based STEM education" which emphasized increasing teachers' subject matter knowledge and pedagogical skills in teaching inquiry-based STEM instruction. Their learning is situated in particular physical and social contexts and is social in nature as they engage in rich discourse, thinking, interacting with other local school teachers, and sharing experiences during the program activities. For a full week each year, participants attended the institute from 8 am to 4 pm every day. This particular study used the program of 2015, a total of eight full-day lectures and laboratory activities were offered for the entire period of the workshop. Each lecture was structured with STEM activities in the morning and the same format in the afternoon so that the participants understood effectively what the theories were and how they applied to STEM activities. Some of the activities of the program areshown in Fig. 2.

Figure 2. A Sample of STEM Activities during the Program

Pedagogical Reasoning Practice Worksheet and a Reflection Rubric: This study investigated how metacognitive reflection writing was effective in developing teachers' pedagogical reasoning through a STEM education professional development program. However, participants were unfamiliar with pedagogical reasoning. Thus, we developed a pedagogical reasoning practice worksheet. In fact, the worksheet was modified from what was suggested in Shulman's work (1987), using the key process of pedagogical reasoning and action. Participants had a chance to exercise during the beginning of program, practicing the pedagogical reasoning by filling out the worksheet. This training helped the teachers increase their confidence by using the worksheet before they actually implemented it into their own classrooms. This process of self-reflection journal writing was metacognitive in nature. Implementing the worksheet was a necessary step because it showed that teachers were using reflective practices during the professional development.

The participants wrote the pedagogical reasoning practice worksheet every day. We adapted a reflection rubric from Ward and McCotter's work (2004) to analyze the worksheet (see Appendix C). Using the rubric, we modified it to fit the purpose of our study. Table 1 shows the extent to which teachers developed their pedagogical reasoning reflection in the areas of comprehension and transformation as a result of reflective writing. As shown in Table 1, we grouped Focus and Purpose under Comprehension based on similar concepts that asked, "What have you learned?" We also put Change under Transformation. Transformation was divided into Adaptation and Tailoring so Change included Adaptation and Tailoring. Table 1 presents the analysis scheme of the reflective journal used in this study.

Table 1. Analysis Scheme of Teacher's Reflective Journal

Topic Journal	Comprehension	Transformation
	Focus, Purpose (What have you learned?)	Change (Is the teacher able to actively use what they have learned and tailor it to their class?) Adaptation, Tailoring
Reflection Level of Journal		

As Ward and McCotter (2004) described in their rubric, we evaluated each metacognitive reflection journal using four levelsincluding*(a)Routine, (b) Technical, (c) Dialogic, and (d) Transformative*. *Routine* reflections tend to contain very definitive statements that revealed either a lack of curiosity or a lack of attention to complexity. *Technical* reflection can be instrumental, in that the reflection is used as a means to solve specific problems but does not question the nature of the problem itself. *Dialogic* reflection is an ongoing process. The term itself reveals discussion and consideration of the views of others. *Transformative* reflection considers a scope beyond that of the study, into the real world, and grasps important implications.

Results

Based on the results of our analysis, we found some common themes and patterns - routine, technical, and dialogic/transformative. The results are presented in two sections. The pedagogical reasoning practice analysis (reflective journal) of 23 participants is presented firstfollowed by the focus group interview analysis.

Pedagogical Reasoning Practice Worksheet (Reflective Journals)

We had 23 volunteers who wrote reflective journals. Each participant keptfour journals, and we analyzed them by using a reflective journal rubric. Table 2 presents the analysis results of the reflective journals.

Table 2. *Analysis of Teachers' Reflective Journal (N=23)*

Topic Journal	Comprehension	Transformation
	Focus, Purpose (What have you learned?)	Change (Is the teacher able to actively use what they have learned and tailor it to their class?) Adaptation, Tailoring
Reflection Level of Journal 1 (STEM Definition)	Routine	Technical
Reflection Level of Journal 2 (Inquiry-based STEM Instruction; Build a Crank)	Technical	Technical
Reflection Level of Journal 3 (STEM with Engineering Focus-Build a Towerand Chair)	Technical	Dialogic/Transformative
Reflection Level of Journal 4 (STEM with Engineering Focus – Build a Racing Car)	Technical	Transformative

ReflectiveJournals in Focus and Purpose stage under Comprehension: In this stage, two levels of reflection emerged, *Routine Level and Technical Level* (see Table 2). Routine level of reflection tends to contain definitive statements (Ward & McCotter, 2004).

This level of reflection was found in Journal 1, "STEM is to combine concepts about torque, rotation and inertia to make a chair and a car work property"; "STEM is an instructional process for science, math, engineer and teaching"; and "STEM is an instruction that integrates science, math, engineer and technology." Technical reflection can best be thought of as instrumental in the reflection (Ward & McCotter, 2004). Technical level of reflection was continuously presented in Journals 2 and 3, "From the workshop, I learned that the different forms of energy, mechanical, light, sound, thermal, the position and motion through an activity of Build a Crank." (Journal 2); "I learned how to appropriately teach STEM through student centered learning activities through Build a Tower and Chair." (Journal 3) Therefore, 23 reflections demonstrated a stage of Focus and Purpose in their development of pedagogical reasoning by demonstrating definitive statements (Routine) and instrumental reflection (Technical) about what they learned from the STEM professional development program. On the other hand, a Transformative level of reflection asks about deeply fundamental assumptions and purpose (Ward & McCotter, 2004). For example, the common themewas, "Today, I have learned how to build a car that moves fast. This is interesting. I am now in the process of learning STEM, but I am wondering, to meet the purpose of STEM education, how difficult it will be in selecting STEM problem that is relevant to the curriculum content" (Journal 4). This theme falls into Transformative reflection, which transforms what was learned into fundamental purpose from their own context. Overall, in the Focus and Purpose stage, 23 teachers showed their reflection in Routine, Technical, and Transformative levels.

Reflective Journals in Change stage under Transformation: In the Change stage, there were three levels of reflection demonstrated in teachers' metacognitive reflections: *Technical Level, Dialogic Level, and Transformative Level* (see Table 2).For the Technical level of reflection, the Change dimension shows narrow change or change without new insight. The following journal quotes demonstrate this point: "From the workshop, I learned how to apply STEM into each subject area – i.e., science, mathematics, etc." (Journal 1). Dialogic level of reflection considers and synthesizes new ideas. For example, the participants wrote, "Maybe I will be able to provide the objects of learning for students so it makes science fun and enjoyable like us today in the workshop" (Journal 2); "Teachers will have to introduce the problems of Thailand and do use 5E's model for instruction in science, mathematics, and even language arts" (Journal 3); "From today's workshop, I learned the fact I could change the degree of kinetic energy. I was so excited about it. I felt like I could teach my students that they could change kinetic energy from something like elastic and spring etc. So using daily life problem is so powerful. Science is not difficult. Instead, it is fun and very beneficial to us every day" (Journal 4); and "Teaching STEM in my classroom seems difficult from a Thailand context because of lack of resources and I do not know much about it. But I learned teaching materials should be expensive, and I learned what STEM is through activities. Defining a problem in teaching STEM seems important. So I need to study more what kinds of problems that my students have and my community has around the school I teach now. I am excited about STEM education." (Journal 4)Transformative level of reflection questions "fundamental assumptions and purpose more deeply" (Ward & McCotter, 2004, p. 253). One high school mathematics teacher became more conscientious about how to change her own teaching toward the end of the week-long program evident as follows, "I create activities that integrate some all element of STEM to my mathematics classroom. Even if STEM seems to deal with a lot in science, I can see why not in mathematics. So I have to appreciate the essence of STEM instruction which is based on inquiry approach in teaching my mathematics to high school students" (Journal 3); "I write my lesson plan by posing question that matches STEM, let students to critically think about and do problem solving, communicate conclusion with group members, and explain and reflect about STEM for that content" (Journal 4); and "I apply STEM Education in my class and stimulate students to connect Science, Technology, Engineer and Mathematics for expanding their knowledge in, for example, building a chair using engineering" (Journal 4); "I apply STEM in my classroom when I teach science. I have to use technology or engineering and math in my lesson plan from now on. I am not sure why I was not able to think of integrating all subject areas in building a racing car, which we did in the workshop. I think I can do it because the materials are cheap and easy to obtain for everyone." (Journal 4) Overall, Thai participants demonstrated Technical, Dialogic, and Transformative level of reflection in the Change stage of Transformation during the process of pedagogical reasoning.

In sum, 23 teachers' reflections demonstrated rich information on how to transform what they learned from the program into their own teaching as reflected through narrow changes, synthesizing new ideas and considering Thai context in teaching, and proposing insightful teaching ideas that fit in their classroom context. As 23 participants wrote their reflective journals over time, they noticeably advanced the level of their pedagogical reasoning from routine and technical to dialogic or transformative reasoning (see Table 2).

When teaching STEM in building a crank, no teacher had ever thought about why they had to use mathematics and engineering and what to use. After the workshop, the participants realized that they could connect mathematics to real life, not confining the knowledge within the classroom but taking it out of the classroom boundary and using it to expand students' understanding about the real world. This is the purpose of STEM education.

Frequency of Thematic Languages: We read, multiple times, two data sets including reflective journals and interview data. We were looking for thematic languages using a non-judgmental, open code (Merriam, 1998). We then invited two participants to check our findings to confirm perceived accuracy and reactions (Lincoln and Guba, 1985). Thematic languages were chosen when the frequency (the number of appearance in twenty three teachers' metacognitive reflections) was more than five, thus meeting one of the fundamental assumptions of chi-square analysis.

As shown in Table 3, seven thematic languages were found to represent the participants' perception and reflected outcome of pedagogical reasoning. Application, problem solving, and implementation in the classroom are the most used languages as a theme in their pedagogical reasoning of the program. Specifically, the program focused on inquiry-based teaching and learning in STEM education. Many of the program sessions provided teachers with the scope of inquiry-based teaching with the understanding of the nature of science, and knowledge of the subject (torque, tension, and compression, stability, velocity, kinetic energy), and STEM activities that included curricular materials and assessment. In chi-square test, there was a significant difference between the observed frequencies and the expected frequency for each word (χ^2 (7) = 28.56, p = .001). We set up the expected frequency with no differences in the expected number of times each language might appear in our data sets because our assumption was that it appears equally in any data during the process of pedagogical reasoning.

Table 3. Frequency of Thematic Languages Appeared in Twenty Three Teachers' Reflective Journals.

Thematic Languages	Observed Frequency*
Application	23
Relevancy	8
Problem solving	15
Subject matter knowledge (Math; science)	11
Pedagogical knowledge	6
Student-centered instruction	6
Implementation in classroom	16

***** (p<0.001)

Focus Group Interview on STEM

The focus interview was designed to probe teachers' thoughts and ideas at a deeper level. The questions focused on what they learned and how they planned to use the knowledge. The questions elicited the participants' opinions on the effectiveness of pedagogical reasoning. To achieve this purpose, a couple of questions were selectively analyzed below. In addition, to better answer the research question, the interview data were transcribed and analyzed by using metacognitive knowledge of variables(Flavell, 1979), which includes (a) knowledge of personal variable (KPV), (b) knowledge of task variables (KTV), and (c) knowledge of strategy variable (KSV).

Importance of STEM Education: Participating teachers indicated that STEM education in school is important. A common theme was "STEM can help students to think more often especially on problems they run into in their real life." (KTV) At the same time, teachers believed that "STEM makes a good learning environment that will make the classroom to be effective for meaningful learning."(KSV) In addition, teacher emphasized the importance of STEM education by commenting, "Yes, I definitely think that STEM education is very important in school. As I understand, STEM is a teaching approach in which students can learn not only integrated content knowledge, but also the process of thinking systematically through problem solving, which requires in 21st century." (KPV; KSV)

Advantages and challenges of STEM education in Thailand: Thai teachers were able to reflect more upon adapting STEM instruction to classrooms and evolved in the following patterns: comprehending, applying, organizing, and thinking critically. Teachers' responses to the advantages of STEM instruction are summarized as follows (Table 4).

Table 4. Thai Teachers' quotes about the Advantage of STEM Education

Advantages of STEM Education (Teachers' Quotes)	Metacognitive Knowledge of variable
promote students' thinking	(KPV)
help students understand concepts of S, T, E and M	(KPV)
connect knowledge of S, T, E and M	(KPV)
think together and collaborate in learning	(KTV)
provide hands on activity that makes students learn actively	(KTV)
help student learn how to think	(KSV)
improve teaching skills	(KPV)
create meaningful learning for both teacher and student	(KSV)
promote teacher thinking	(KPV)
help students to solve the problem by themselves	(KSV)
help students solve their daily life problems	(KSV)
help students acquire scientific knowledge by themselves	(KPV)
increase students' collaboration in group activities	(KSV)
With STEM and full inquiry approach, students can engage themselves in real life problems, set up an investigation to problem solve, collaborate to explain the solution reasonably, and explore new knowledge by themselves	(KSV)

The challenges that Thai teachers face are as follows (see Table 5). Thai teachers mostly struggle in how to manage STEM activities within the given lesson period, how to create content that covers each area of STEM discipline, and how to evaluate student learning as well as classroom management. When reflecting on how they teach STEM education in a real classroom, as shown in Table 5, teachers metacognitively crossed over all areas of knowledge variables in metacognition, including Knowledge of personal variables (KPV), Knowledge of task variables (KTV), and Knowledge of strategy variables (KSV), which means they are readily able to practice good instruction on STEM subjects in terms of pedagogical reasoning.

Table 5. Thai Teachers' Quotes about the Challenge of STEM Education

Challenges of STEM Education (Teachers' Quotes)	Metacognitive Knowledge of variable
I am not sure how to manage activities completely within one or two hours of each period.	(KSV)
I am not sure, yet, how to create activities which fit with the contents of S, T, E, and M.	(KTV)
I would need more training of how to evaluate the students when teaching STEM in the classroom.	(KSV)
I personally think that the main challenges of implementing STEM program center on three areas. First, STEM program needs teachers to be well prepared in terms of materials. This could be our problem in Thailand as some material could not be found in the local market. (KPV) Second, it may take longer time for students to create things in innovative way. (KTV) Third, if the class is large, STEM may not really work as teachers may not be able to go around and give individual guidance to all students.	(KSV; KPV)

Confidence about STEM instruction: As shown in the above responses, teacher professional development programs with reflective journal writing helped participants organize their ideas and make those ideas relevant to students and readily to apply. Reflective journal writing also gave a specific direction to what teachers need to do to improve their teaching by comprehending the subject matter knowledge and then transforming it into a way that students could understand better.

In this way teachers become confident about STEM teaching as shown, "After I participated this workshop I think I became more confident about teaching STEM. However, I became more curious to know about how to apply STEM to teach science content especially of chemistry and biology. I think if I have a chance to participate in STEM workshop like this again I would get more confident of teaching STEM in my classroom."(KPV) Also, one teacher commented, "I think what I learned from the workshop is just beginning. I can't say that I am really confident about teaching STEM education at this point. I need to have more training on its approach. (KPV) Also, because the nature of STEM education requires teachers to teach the integration of science, technology, engineering, and mathematics. I alone can't really teach students STEM effectively. Therefore, I would like to be trained about co-teaching, which would give me more confidence." (KSV)

As Shulman (1987) noted, a teacher must act to transform his/her comprehension of subject matter into "forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (p. 15). Twenty three teachers in this study showed that they learned to think about what it meant to learn different materials for different purposes and how to decide which kind of learning were most necessary in different learning contexts. Therefore, these reflective journal-writing activities helped to develop the comprehension and transformation that are an integral part to Shulman's theory of pedagogical reasoning.

Discussion

This study investigated how metacognitive reflection writing developed and enhanced teachers' pedagogical reasoning through an Inquiry-based STEM professional development. Pedagogical reasoning is not remote to teachers' deep understanding of content knowledge, instructional strategies, and pedagogical skills in connecting ideas across subject areas in each of the STEM disciplines through problem solving. This type of teachers' understanding was related to a cycle of pedagogical reasoning (Shulman, 1987). Teachers need to first,fully comprehend the knowledge of the subject matter that they are teaching. At the same time, they need clearly to understand how to transform it so that their students can readily understand (Darling-Hammond, 1998).

As shown in other studies, a professional development institute was an effective way to contribute to teachers' increased subject matter knowledge and their pedagogical skills (Cohen & Hill, 2000). Such positive effects of professional development were also supported by a number of other studies (Cho, Yager, Park, & Seo, 1997; Nelson & Hanegan, 2003; Loucks-Horsley, Hewson, Love, & Stiles, 1998). Cho, et al.'s study (1997) particularly drew our attention because its purpose and content of the professional development program was very similar with that of our study. They reported successful accomplishment of overseas professional development about the stated goals in which teachers were trained with a new model of training in-service Korean STEM teachers with state-of-the-art subject matter knowledge (e.g., biology), pedagogy (biology education), and cultural experience (learning environment - several visits to schools and communities) for one full month in one of the American universities. Participants, after one month of training in a residence program, returned to their school in Korea, attempted to apply the acquired knowledge and skills for five days because they tended to lose opportunities to teach the acquired knowledge and skills. Additionally, they continued to have workshops in the fall and spring as a whole group of participants, plus bimonthly meetings in their own schools to refine and re-design their lessons by getting feedback from local peer teachers to make it more relevant to the condition of Korean education. Finally, many of the Korean teachers were able to teach science lessons based on inquiry approach and constructivist teaching despite challenges and difficulties delaying the process. It was difficult because the current Korean education system put a heavy focus on the college entrance exam, which is a hindrance to inquiry-based constructivist teaching in science. A successful application was difficult because the students and parents are deeply concerned with academic scores so the teachers had to modify the constructivist teaching of science based on inquiry approach by combining with direct teaching. For example, the teachers explained the concepts and theories rather than having students do it instead. Also, the teachers gave selective inquiry questions for students to conduct the experiment right away in order to fit the given timeframe of each lesson. The professional development institute was initially completed with a high level of teacher satisfaction. Nevertheless, the teachers often struggled later when they applied the acquired knowledge and skills into their own classroom (Cho, et al., 1997; Park & Prommas, 2014). This type of struggle was also found in literature. Park and Kim (2015) reported that the cause was, in part, related to a couple of factors, which include "various learning environments, a wide demographic spectrum, and the cultural variations of learners" (p. 479).

The authors argued that the participants struggled due to lack of opportunities to discuss and reflect on accommodating these factors into their own context of teaching, so they went to suggest that reflective writing be part of any professional development program.

Many workshop participants may not automatically reflect on what they learned from the professional development program. Reflection, as defined by Hatton and Smith (1995b), is a deliberate thinking and planning action with the acquired knowledge and skills of teaching through the professional development programs. We deliberately asked all the participants in our professional development program to write a metacognitive reflection daily. Our research revealed thata number of participants discussed in their reflections on how to accommodate the related factors of challenges in their classroom, which helped the teachers to make it clear how to approach teaching STEM content more relevantly. This finding showed some possible explanations for the relationship between metacognitive reflection writing and pedagogical reasoning development. In other words, teachers' pedagogical reasoning using metacognitive reflection during a professional development helped to make relevant about what they acquired and deeply reflect on how to use knowledge to make students' learning meaningful in their own classroom. As indicated in our findings, teachers' level of pedagogical reasoning grew more sophisticated from dialogic to transformative reasoning. We believe that this was possible as participants used their 'metacognitive knowledge.' As evidenced in the participants' interview, they used metacognitive knowledge across all three variables including (a) knowledge of personal variable (KPV), (b) knowledge of task variables (KTV), and (c) knowledge of strategy variable (KSV) (Flavell, 1979). For example, one teacher indicated some of the challenges of STEM instruction in the interview, "I personally think that the main challenges of implementing STEM program center on three areas. First, STEM program needs teachers to be well prepared in terms of materials. This could be our problem in Thailand as some material could not be found in the local market. (KPV) Second, it may take longer time for students to create things in innovative way. (KTV) Third, if the class is large, STEM may not really work as teachers may not be able to go around and give individual guidance to all students." (KSV) When they imagined how they could implement new knowledge and approaches of STEM instruction into their classroom, which is unique in terms of social-cultural perspectives, participants were able to consider the knowledge of personal, task, and strategy variables of students and unique learning environment.

The increased level of Thai teachers' metacognitive reflection, as shown above, was possible as they involved in a process of over thinking about what they learned and why and how they could teach in the learning environment and conditions they were situated under. The worksheet used during the professional development used deliberate questions of comprehension and transformation, which played as a vehicle for teachers to development their pedagogical reasoning. The comprehension questions were "What have you learned from today's lectures?" and "Why do you think the lecture was valuable?" while the transformation question was asked, "What do you want to change about your previous lesson based on today's workshop?" As they answered these two questions in the reflective journals, participants were able to understand and utilize pedagogical reasoning over time. For instance, in the Change stage under Transformation, teachers noted that their reflective thinking process helped clarify how to teach STEM in their classroom. As shown in the result section, one mathematics teacher tried to contextualize what she had learned in her own classroom as follows, "I apply STEM in my classroom when I teach science. I have to use technology or engineering and math in my lesson plan from now on. I am not sure why I was not able to think of integrating all subject areas in building a racing car, which we did in the workshop. I think I can do it because the materials are cheap and easy to obtain for everyone." She pedagogically approached STEM teaching by integrating mathematics relevantly to the level of her students' understanding and by considering the material cost, which would be needed toprepare STEM instruction in her mathematics class. This piece of metacognitive reflection showcases an example of transformative reflection after comprehension (Ward & McCotter, 2004). Grossman (2008) stressed in his study that integration is critical to make a meaningful reflection because reflection is facilitated by integrating content-based reflection, metacognitive reflection and transformative reflection together. As teachers continue to practice this type of reflection, their pedagogical reasoning develops over time. In other words, teachers are now able to transform the acquired knowledge into knowledge more relevant to their classroom, which tends to be rather unique and different from the unified and universal conditions. Teachers should do this because they are the one who knows the best about the classroom, students, and community that surrounds their school. We argue that the ability of transforming may be achieved, based on what we found through this research, by questioning the fundamental assumptions of education and, at the same time, practicing pedagogical reasoning through metacognitive reflections over time.

This finding of our study implies that pedagogical reasoning can play a role as a vehicle to lead to more meaningful teaching by putting in-depth reflection over time (Park & Kim, 2015). In this sense, pedagogical reasoning is a developing process in educational practices (Pultorak, 1996). The idea of developing aprocess in pedagogical reasoning involves the analytical interaction between experiences and beliefs about teaching practices (Newell, 1996). Metacognitive reflection writing helps teachers to think over the thinking progress about what and how they teach in ways that meet the needs of students in terms of learning and, at the same time, what needs to be done to perform good teaching. Thus, it is recommended that metacognitive reflection on what and how to teach the acquired knowledge and skills about reformative topics over time be part of everyday teaching practice. Reiman (1999) argued that when utilizing a framework of reflection and action in teaching practice, teachers' metacognitive reflection can shape their reflective practice about teaching. During the professional development institute, metacognitive reflection can help teachers to become reflective by analyzing and trying to apply concepts into their own classroom over time. Metacognitive reflection writing can be effective when specific direction is given on what has to improve and how to apply to their unique situations and conditions. During metacognitive reflection on the newly acquired knowledge and skills from the professional development program, teachers tend to think about how it is connected to their current curriculum, i.e., standards, assessment, content, instructions, etc., what it means to be teaching it in different learning environments, what kinds of materials are readily accessible for that topic in local schools, and what should be considered in students' understanding. In our study we found that teachers tend to show a high level of satisfaction with "what" but not with "how" in the professional development institute. As a benefit, they are satisfied with new subjective matter knowledge and pedagogies in teaching reformative topics like STEM and Inquiry-based science. However, as a challenge, they are concerned with the curriculum alignment, the availability of teaching materials, assessment, and ways of implementation in their own classroom. These challenges and benefits are revealed through metacognitive reflections to come to a point of transforming. Shulman (1987) stated that transformation is planning the act of teaching, teaching as deliberate reflection, and the culmination of pedagogical reasoning. During and after the professional development, teachers become transformative of what they acquired by reflecting what the benefits and limitations would be when teaching and applying concepts into their own classroom. Thus, an act of metacognitive reflection is critical in developing the transformative level of pedagogical reasoning.

The limitation of this study, in fact, lies in the selection of only two components – comprehension and transformation. Because of too much preparation on the teachers' end as well as un-readiness of implementation in school, the design of this study was not using the whole process of pedagogical reasoning actions of Shulman's model, which involves a cycle and sequence through activities of comprehension, transformation, instruction, evaluation, reflection, and new comprehension (Shulman, 1987). We suggest that a further study use the whole cycle of pedagogical reasoning in the professional development.

Literature shows that there are numerous professional development programs for teachers (Nelson & Hanegan, 2003; Bain, Ballantyne, Packer, & Mills, 1999; Loucks-Horsley& Matsumoto, 1999; Birman, Desimone, Porter, & Garet, 2000). But using metacognitive reflection writing during the professional development is missing. We suggest metacognitive reflection should be part of the professional development to encourage teachers to apply what they learned into their own classroom during and after the program through multiple practices of pedagogical reasoning.

Conclusion

STEM teaching was new to most of Thai teacher participants in its approach and curricular knowledge when the STEM professional development program was offered. Pedagogical reasoning was also a new concept to Thai teachers in this study. The inquiry-based STEM professional development institute offered knowledge and skills of STEM teaching based on inquiry approach. Through multiple metacognitive reflection writings during the institute, teachers developed their pedagogical reasoning skills of how to teach STEM education by demonstrating the comprehension and transformation stage of reflection from dialogic to transformative reasoning. This behavior of teaching in pedagogical reasoning helps to grow as an effective teacher. As evident in literature, the professional development can help teachers to become effective in their teaching. This study also adds, based on the findings, to literature that metacognitive reflection writing over time, during the professional development, can help teachers to develop pedagogical reasoning, which may lead to effective teaching. Metacognitive reflection can also shape their reflective practice though multiple practices of pedagogical reasoning.

Therefore, it is suggested that teachers use metacognitive reflection writing during and after the professional development institute. At the same time, to get the knowledge and skills of STEM teaching sustainable and attainable after the program, it is recommended that teachers continue to refine and modify their lessons through the exchange of feedbacks among the members of professional community including faculty, teacher colleagues, and the program staff members even after the professional development. Thai teachers participated in this study may then be able to teach new knowledge and skills of STEM education to their students meaningfully and relevantly.

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APPENDIX A: Pedagogical Reasoning Practice Worksheet

Name: ________________________ Date: ___________________

Your school level: ______________

Years of teaching: ______________ years

1. Today's lecture topic:______________________________
2. What have you learned from today's lectures?
   Please summarize the lecture and think about some of the ideas to apply
3. How do you want to change about your lesson based on what you learned?
4. Why do you think the lecture was important to your lesson, if any?
5. How do you want to incorporate today's lecture ideas into your class?

Briefly summarize as below.

1) Grade Level: ____________
2) Topic: ______________
3) Activities and Instructions
4) Assessment – Exit Slip

APPENDIX B. Focus Group Interview Protocol on STEM

1. What have you learned about STEM?
2. Do you think it is important to teach STEM education? If so, why?
3. What are the advantages of STEM program?
4. What are the challenges of implementing STEM program in your classroom?
5. Are you confident about teaching STEM education?

APPENDIX C. Reflection Rubric (Adopted from the work of Ward & McCotter (2004))

Reflection Rubric

	Level			
	Routine Self-disengaged from change	**Technical** Instrumental response to specific situations without changing perspective	**Dialogic** Inquiry part of a process involving cycles of situated questions and action, consideration for others' perspectives, new insights	**Transformative** Fundamental questions and change
Focus (What is the focus of concerns about practice?)	Focus is on self-centered concerns (how does this affect me?) or on issues that do not involve a personal stake. Primary concerns may include control of students, time and workload, gaining recognition for personal success (including grades), avoiding blame for failure.	Focus is on specific teaching tasks such as planning and management, but does not consider connections between teaching issues. Uses assessment and observations to mark success or failure without evaluating specific qualities of student learning for formative purposes.	Focus is on students. Uses assessment and interactions with students to interpret how or in what ways students are learning in order to help them. Especially concerned with struggling students.	Focus is on personal involvement with fundamental pedagogical, ethical, moral, cultural, or historical concerns and how these impact students and others.
Change (How does inquiry change practice and perspective?)	Analysis of practice without personal response — as if analysis is done for its own sake or as if there is a distance between self and the situation.	Personally responds to a situation, but does not use the situation to change perspective.	Synthesizes situated inquiry to develop new insights about teaching or learners or about personal teaching strengths and weaknesses leading to improvement of practice.	A transformative reframing of perspective leading to fundamental change of practice.