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Unpacking and Transforming Teachers' Beliefs Toward Inquiry-Oriented Teaching Through Lesson Study: A Cross-Case Analysis of Thai Preservice Science Teachers

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Abstract

Teachers' beliefs can be seen as psychological seeds planted in teachers' minds. Teachers' beliefs about effective inquiry-based teaching impact their intentions, instructional designs, and actions required for inquiry-based lessons. This paper discusses how to help Thai preservice science teachers who engaged in their student-teaching practicum in middle schools transform their beliefs toward inquiry-based science teaching through Lesson Study (LS). The research questions guiding this study include: 1) What critical factor contributes to Thai preservice science teachers' transforming their beliefs toward inquiry-based science teaching? 2) How could LS help Thai preservice science teachers transform their beliefs toward inquiry-based science teaching? and 3) How can LS be integrated into Thai preservice teacher education programs to cultivate preservice science teachers' inquiry-oriented beliefs and experiences in LS? Multiple data sets were collected, including teacher interviews, LS discussion meetings, and reflection forms. The cross-case analysis indicated that although all preservice science teachers developed more inquiry-oriented beliefs through the LS sessions, their progression paths varied among preservice teachers. A non-anxiety-driven facilitation and flexible modifications were found to be essential for making the LS sessions meet each preservice science teacher's idiosyncratic needs so that their belief transformations take place towards inquiry-based teaching as they overcome their fear and anxiety in adopting this approach. This study suggests that this facilitation is vital in unlocking diverse avenues of transformations in preservice science teachers' varying belief systems toward inquiry-driven science teaching.

Keywords: inquiry-oriented teaching, lesson study, teacher beliefs

1. Introduction

A worldwide cornerstone of cultivating students as scientifically literate citizens encourages teachers to shift their pedagogical strategies towards more inquiry-based teaching. In this approach, teachers would engage students in questioning, data gathering, interpreting, discussing, and reasoning to explore various aspects of reality to understand scientific phenomena (NRC, 2000; Constantinou et al., 2018).

However, teachers' beliefs can shape how inquiry-based lessons are carried out in classrooms (Mohammed et al., 2020; Min et al., 2020). Teachers' pedagogical decisions and behaviors tend to align more with the teaching approaches they perceive as most effective for themselves and their students rather than what is generally considered suitable for teaching, even if they have been exposed to the importance of inquiry-based teaching in teacher education programs (Boesdorfer et al., 2019; Nawanidbumrung et al., 2022). Consequently, some of their beliefs can promote inquiry-based teaching, while others may hinder it.

The interplay between teachers' beliefs and the knowledge they acquire in teacher education programs remains intricate, with their mutual influence somewhat ambiguous (Fenstermacher, 1994; Hutner & Markman, 2017). Since teachers' beliefs represent a way of conceptualizing effective teaching, they can impact how teachers decide to teach specific topics in the ways they perceive that their students would grasp better (Shulman, 1986; Magnusson et al., 1999, 2017; Julie, 2015; Suh & Park, 2017; Tondeur et al., 2017). That is to say, teachers' beliefs can influence their pedagogical content knowledge (PCK). However, teachers could adopt inquiry-oriented beliefs when they can align their inquiry instruction with students' learning and needs—or develop inquiry-oriented PCK (Ladachart et al., 2022). Thus, assisting teachers in developing PCK for inquiry-based teaching could be essential for cultivating their inquiry-oriented beliefs.

Facilitating teachers' belief transformations is challenging since their beliefs are profoundly shaped through cultural processes, including past experiences as students (Richardson, 2003; Enderle et al., 2014), daily interactions, and exposure to a range of perspectives within their families and communities (Stigler & Hiebert, 1999; Chang & Song, 2015). According to the interconnected model of teacher professional growth (Clarke & Hollingsworth, 2002), facilitating this process requires teachers to reflect on their actions in reference to beliefs and past experiences through two critical areas, which are: 1*)* an enactment process, where teachers engage in actual teaching, and 2*)* a critical reflection, where teachers contemplate the need to transform their beliefs in relation to their practices.

Huang et al. (2021) stated that teachers' belief transformations typically go through four stages, which are: 1) confirmation: connecting long-held beliefs to newly presented information and situations; 2) realization: becoming more aware of or picking up new beliefs, 3) disagreement: rejecting long-held beliefs, and 4) elaboration: deepening and expanding existing beliefs in new dimensions. However, teachers' belief transformations could vary among individuals due to their sense-making of diverse encounters within their contexts (Cabaroglu & Roberts, 2000), and social-emotional factors, such as unintended consequences, they would experience during their development (Trevors, 2024). Based on these factors, they may differ in specific aspects of beliefs and time they are open for transformations, contributing to their unique trajectories of belief transformations and making generalizing teachers' belief transformations challenging (Vaino et al., 2013; Polat et al., 2019). This assumption stresses the need to further investigate this issue to understand the possible trajectories of teachers' belief transformations.

While teachers' individualized pathways of belief transformations make further studies crucial, their complexity may influence how the investigation is often conducted. Multiple studies have predominantly focused on the effectiveness of interventions on teachers' beliefs by comparing their pre- and post-intervention beliefs rather than exploring the context and process in which interventions influence specific aspects of belief (Yakar & Turgut, 2017; Du et al., 2020; Thurm & Barzel, 2020). For example, Yakar and Turgut (2017) used statistical analysis to examine the LS's impact on teachers' beliefs, revealing a shift from teacher-focused to student-focused beliefs following LS engagement. However, how the LS process could elicit these transformations and what factors serve as key players to catalyze this process remain unclear.

LS, widely implemented in Japan, is recognized as an evidence-based approach to teacher professional development (Stigler & Hiebert, 1999; Hendayana, 2015). Through this form of collaborative inquiry, teachers engage in a cyclic process of lesson planning, lesson implementation, observation, and co-reflection to improve teaching practices and students' learning (Widjaja et al., 2017). It can be hypothesized that, through LS, teachers could both co-construct their PCK and cultivate their inquiry-oriented beliefs by co-reflecting on their beliefs in relation to their practices.

While LS has gained international popularity in recent decades, numerous studies have highlighted that diverse contextual and cultural factors could impede LS implementations. For instance, US teachers expressed apprehension about opening their classrooms to their peer teachers due to the traditionally evaluative nature of classroom observations in their culture (Chokshi & Fernandez, 2004), while UK teachers were reluctant to invest extra time in collaborative lesson planning (Wake et al., 2013). These studies demand us to consider how meaningful adaptations of LS can be done within a particular culture in order to elicit teachers' belief transformations toward inquiry-based teaching effectively.

2. Research Questions

Lesson Study (LS) has gained attention in Thailand for teacher professional development in recent years. However, its implementation faces several cultural challenges, such as the traditional Thai classroom culture of teachers as authoritative figures (Inprasitha, 2010; 2022). In this regard, this study implemented LS in collaboration with an existing preservice teacher education program at a Thai university to investigate three questions in the following:

1) What critical factor contributes to Thai preservice science teachers' transforming their beliefs toward inquiry-based teaching?

2) How could LS help these preservice teachers transform their beliefs toward inquiry-based teaching?

3) How can LS be integrated into the Thai teacher preparation program to cultivate preservice teachers' inquiry-oriented beliefs and experiences in LS?

3. Methods

This research employed the cross-case study method to examine commonalities and distinctions within and across cases while considering contextual variables and individual differences (Merriam, 1998) to answer the above research questions. This approach was adopted to help us examine how Thai preservice teachers developed inquiry-oriented beliefs, the critical factors driving such processes, and how effective adaptations of LS can be made in the context of the Thai preservice teacher education program.

3.1 Context

This study investigated the issues above within a 5-year preservice science teacher education program in Bangkok, Thailand, that is designed to prepare future secondary school science teachers with an emphasis on inquiry-based science teaching. Throughout the initial four years, students acquire scientific knowledge and pedagogical foundations for inquiry-based science teaching through the coursework, some of which is taught by faculty from either science or education departments. In the fifth year, students engage in student-teaching practicum at two partner secondary schools, which is typical in preservice teacher education programs in Thailand.

In this program, all preservice teachers had yet to gain prior exposure to LS sessions, as the concept is relatively new within the cultural context. We invited all fifth-year preservice teachers in the academic year 2022 to participate in this research, and four preservice teachers who engaged in their student-teaching practicum at two middle schools voluntarily joined.

3.2 Design

Based on their school placements designed by the faculty, the four preservice teachers who practiced teaching in two partner schools were placed into two LS groups, Groups A and B. Given preservice teachers' limited PCK and classroom experiences, we postulated that knowledgeable others would be crucial in prompting their reflections and guiding them to go beyond their existing knowledge boundaries (Norton et al., 2019). The second and third authors—preservice teachers' academic advisors in the program—joined all research activities as the knowledgeable others. Table 1 provides information on LS team members using pseudonyms. Following Clarke and Hollingsworth's (2002) model discussed above, preservice teachers engaged in the enactment (lesson planning and teaching) and reflection processes (critical co-reflection and discussion on lesson planning and teaching) (see Figure 1). The first author played the role of LS facilitator to ensure that both LS groups went through the initially set procedure and gathered information on how the LS process prompted (or failed to promote) preservice teachers' belief transformations.

Table 1. Demographic data of LS members

LS Group	Members	Gender	Status
A	Teacher Ing	Female	Preservice teacher teaching science in 9^{th} grade
	Teacher Noi	Female	Preservice teacher teaching science in 8^{th} grade
	Second author	Female	A university professor in Science Education
B	Teacher Tim	Male	Preservice teacher teaching science in 7^{th} and 10^{th} grade
	Teacher Pun	Male	Preservice teacher teaching science in 8^{th} and 10^{th} grade
	Third author	Male	A university professor in Science Education

This study aligned with Pajares' (1992) assumption that teachers' beliefs can be accessed through making inferences from teachers' verbal data on decision-making, intentions, and actions. We refined the pre- and post-cycle interview questions from Tosa (2011) and Nawanidbumrung et al. (2022) to elicit preservice teachers' critical reflections on their initial beliefs about science teaching and whether their beliefs transformed in each LS cycle (see Table 2). The interview protocol was conducted with each preservice teacher in their native language (Thai) before LS started and after each LS cycle was done. The interview data was interpreted, synthesized, and thematized in light of scientific inquiry features outlined by the NRC (2000) using qualitative content analyses (Berg, 2004). They then were compared to extract the themes across different cases. To enhance the accuracy of the data interpretation, 1) preservice teachers were later asked to verify what they meant in the interviews when further clarifications were needed in each cycle, 2) the facilitator (the first author) and the knowledgeable others (the second and third author) held data analysis meetings (member checking) after completing each activity and LS cycle to cross-check each other's understanding on emerging themes regarding preservice teachers' existing beliefs. Based on these emerging findings, the facilitator and the knowledgeable others discussed how LS should be more effectively implemented to facilitate preservice teachers' belief transformations toward inquiry-based teaching. After the final key findings were ensured, they and the teachers' quotations were translated back and forth between Thai and English and then represented in the findings section.

Table 2. Teacher interview protocol (adapted from Tosa [2011] and Nawanidbumrung et al. [2022])

Timing	Interview questions
Before LS	Could you tell me about your recent/future lesson that involved inquiry activities?
	In your opinion, what are the characteristics of effective inquiry-based science lessons?
	In your opinion, how important is it to implement inquiry-based science lessons?
	In your opinion, what do you envision to be the keys to the success of science lessons?
	How do you describe your beliefs about inquiry-based lessons in a few words?
	How was it organized?
After each cycle	What did you learn about the effective implementation of inquiry-based science lessons?
	What do you believe now are the factors making inquiry-based science lessons successful?
	What kinds of teachers' roles do you think can promote students' inquiry-based learning?
	In your opinion, how are inquiry activities supposed to take place in the science classroom?
	What is "good science teaching" for you now? Why?
	What features of LS do you think affected your lesson planning and inquiry teaching?
	What features of LS do you think affected your beliefs about science teaching?

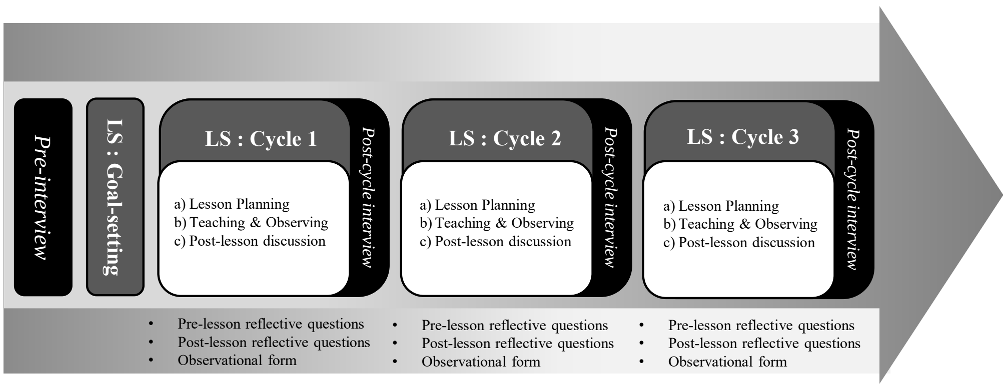

Figure 1. LS design

As in Figure 1, a goal-setting activity occurred before LS started due to two objectives: 1) To set up inquiry-based teaching as their explicitly shared goal, and 2) To serve as an "icebreaker" fostering their sense of shared responsibility to collaborate towards achieving the goal. Before this activity, preservice teachers started their student teaching at their practicum schools for around three weeks. Thus, they were encouraged to share their perceived teaching difficulties based on such experiences, set personal goals to overcome them through LS, and discuss how to achieve the preservice teacher education program's goal with their knowledgeable others in each LS group. Following this, they engaged in three steps constituting each cycle. Each cycle lasted approximately 35 days.

a) Lesson planning was the first activity in each LS cycle. Preservice teachers first presented their chosen inquiry-based lesson plans. They responded to pre-lesson reflective questions (see Table 3), adapted from Nawanidbumrung et al. (2022), to critically reflect on their beliefs that could have served as the foundation of their lesson planning—in reference to their lesson plans. Subsequently, they collaboratively discussed how each lesson would impact student learning and its improvement. The knowledgeable others supported this process by offering them feedback and possible modifications. The first author facilitated discussions by gathering LS team members' opinions/comments on the development of inquiry-based lessons (e.g., when someone offered suggestions/ideas, the facilitator would invite others to share their opinions and then ask everyone to consider whether they agree or disagree while directing the discussions towards consensus building on the modifications). Preservice teachers decided whether they wanted to revise their lesson plans on their own and then shared the final versions online with their LS team members.

b) **Teaching & Observation** were done after the planning stage. Preservice teachers taught modified lessons in their classes with their LS team members, including the knowledgeable others and the facilitator observing. The observing preservice teachers used the provided observation form to record (1) student activities, (2) student reactions and learning, and (3) their opinions and suggestions at each lesson step to reflect on their beliefs while analyzing their peer teachers' lessons. After teaching, the preservice teachers who taught the lessons completed the post-lesson reflection forms (see Table 3), adapted from Inoue et al. (2019), to reflect on their actual teaching, student learning, and its potential improvements.

Table 3. Reflective questions (adapted from Nawanidbumrung et al. [2022] and Inoue et al. [2019])

Timing	Interview questions
Pre-lesson	1. What are the goals of your science lesson? Why?
	2. How would you evaluate these goals?
	3. How do you attempt to accomplish each goal through this lesson design? Why?
	4. What is the inquiry/key question you are asking to your students? Why?
	5. How do you think students would respond to your inquiry question? Why?
	6. How are you going to help students engage in inquiry of scientific concepts? Why?
	7. What possible challenges do you anticipate in this lesson?
Post-lesson	1. What did you envision to be the keys to the success of today's lesson?
	2. What aspects of your lesson today do you think were successful and unsuccessful?
	3. Did any of your students struggle with their learning through the inquiry process?
	4. Did you make any decision during the lesson beyond the lesson plan? How?
	5. What experiences made you become capable of making these decisions?
	6. If you teach the lesson again, what aspects of the lesson do you want to modify/add?

***c*) Post-lesson discussion** was done after teaching and observing lessons. The preservice teachers who taught the lessons first shared their post-lesson reflection forms, followed by those who observed the lessons presenting evidence of student learning (e.g., observation forms, photos) and their interpretations. Then, they co-reflected and exchanged ideas on how the lesson design and actual teaching influenced students' learning. The knowledgeable others also shared additional evidence and provided suggestions for deepening their reflections. The facilitator guided these discussions by ensuring claims about student learning were supported by evidence (e.g., photo, video, note-taking) and encouraging others to share supporting or conflicting evidence.

4. Findings

This study generated diverse data sets at different points in time, and we started analyzing the data as the first pre-interview proceeded. We found that all pre-service teachers came to LS with different initial beliefs and perceived challenges in science teaching. Some of the challenges they felt were about science teachers' roles and responsibilities, while others addressed instructional methods and tools for science teaching.

In the LS process, a notable finding was that after the first *a) lesson plannin*g, the facilitator and knowledgeable others noticed and agreed that some preservice teachers were experiencing varying levels of anxiety due to their fear of failure and criticism about their teaching. They expressed concerns about whether their lessons could be seen as effective by others. Recognizing that the traditionally evaluative nature of classroom observation in the context could have affected their sense-making of LS features, we modified the LS dialogues by introducing non-academic conversations (e.g., holidays, food, daily life) and the compliment-critique-encouragement model (Procházka et al., 2020) to structure reflection and discussion activities in every meeting. Based on this model, everyone was asked to first share positive comments about observed teaching before offering critique and encouraging words in a constructive way. After that, we learned that preservice teachers gradually replaced their fear of failure and criticism with acknowledgment of effort and improvement of each other, resulting in their greater engagement in LS.

Another notable finding was that in *b) Teaching & Observing*, the facilitator and knowledgeable others noticed and agreed that some preservice teachers adjusted their lesson plans based on group discussions but unconsciously adhered to their initial beliefs during actual teaching. For example, some preservice teachers had students engage in a scientific experiment but tended to provide (excessive) explanations to students. Although this could have been due to their limited teaching experience, their beliefs in the knowledge transmission model of teaching were seen to have influenced their actual teaching and LS participation. We also learned that in *C) post-lesson discussion*, the role of knowledgeable others was crucial in helping preservice teachers build consensus on lesson improvement. For instance, in discussing one of the preservice teachers' lessons that the group observed, the knowledgeable other pointed out that another preservice teacher used a totally different teaching approach that seemed to have elicited better student responses in the lesson and facilitated the discussion among LS members, resulting in her deep reflection on her initial belief and teaching practice.

While preservice teachers came to LS with different initial beliefs and perceived challenges in science teaching, we found that they underwent diverse learning and reflection processes throughout the three LS cycles (see Table 4).

Table 4. Lesson study process

LS Cycle	Preservice teachers	Research Lessons	Lesson planning meeting topics	Challenges in actual teaching	Post-lesson discussion meeting topics	Post-lesson reflection topics
1	Noi	Soil quality	• Engaging students in investigation and discussions	• Too much teacher-to-student explanations • Students' confusion about experiment	• Eliciting students' curiosity and opinions • Promoting students' sense-making of the scientific experiment	• Frustrated with her teaching • Questioned the feasibility of inquiry-based teaching in her context
	Pun	Gas exchange	• Engaging students in mind-on experience	• Students' distracted attention	• Connecting students' interests with lessons	• Frustrated with his teaching • Questioned the benefits of teacher collaboration in his learning
	Tim	The universe model	• Eliciting students' thoughts and ideas	• Students' struggles with expressing their ideas	• Modifying questions to be simpler • Providing students with scaffolding questions	• Impressed in his students' increased engagement
	Ing	Electric currents and potential differences	• Connecting lessons to real-life situations • Engaging students in investigations	• Students' struggle with identifying a hypothesis and variables	• Providing students with diverse scaffolding when needed	• Recognized her students' needs • Felt more confident in her content knowledge
2	Noi	Crystallization	• Posing critical questions • Connecting lessons to real-world situations	• Students' struggle with interpreting their observations	• Supporting students' verbalization • Providing students with diverse support	• Impressed in her students' increased engagement Recognized helping her students' verbalization
	Pun	Nuclear force	• Facilitating group discussions among students	• Students' distracted attention	• Connecting the lesson with real-world situations	• Frustrated with his teaching • Recognized including hands-on and mind-on experiences in his class
	Tim	The universe expansion	• Promoting students' sense-making of experiment	• Students' struggle with identifying hypotheses and variables	• Giving students ample time to reason on their ideas	• Recognized helping his students grasp concepts themselves

LS Cycle	Preservice teachers	Research Lessons	Lesson planning meeting topics	Challenges in actual teaching	Post-lesson discussion meeting topics	Post-lesson reflection topics
	Ing	Electrical circuits	• Initiating lessons with student-related situations • Developing students' calculation skills	• Students' struggle with constructing result-recording tables and fear of sharing ideas	• Allocating suitable periods for students' individual thinking and sharing their ideas	• Recognized her students' potential and progress.
3	Noi	Solution compositions	• Promoting students' predictions	• Students' struggle with initiating data analysis	• Helping students construct evidence-based explanations	• Recognized her students' needs and progress
	Pun	Factors affecting the sound	• Promoting students' sense-making of the scientific experiment and awareness	• Students' distracted attention	• Supporting students' data interpretation and summary	• Recognized increasing his students' motivation
	Tim	Stars' life cycles	• Eliciting students' curiosity and appreciation in science	• Students' struggle with verbalizing their ideas • Students' fear of mistakes	• Facilitating small and whole-class discussions among students	• Recognized his role in developing his students' understanding, skill, and curiosity
	Ing	Gravitational interaction	• Connecting lessons to students' prior learning • Developing students' calculation skills	• Students' struggle with analyzing and drawing a graph	• Providing students with ongoing chances to continue improving essential skills	• Recognized her facilitator role in guiding students' active exploration

At this point, we found that the trajectories of their belief transformations toward inquiry-based teaching significantly varied (see Table 5).

Table 5. Preservice teachers' belief transformation

Preservice teachers	Before LS started	After 1st LS cycle	After 2nd LS cycle	After 3rd LS cycle
Noi	Science teaching should be giving engaging lectures to students.	Directly delivering concepts to students was still the most effective way	Science teaching should be eliciting students' ideas and curiosity	Science teaching includes identifying students' difficulties and offering assistance.
Pun	Science teaching should employ ICT tools to introduce concepts.	ICT-led practice remained the most effective way	ICT-led practice was still the most effective way	Instead of presenting everything to students, students should engage in inquiry experience
Tim	Science teaching relies on teachers' explanations and analogies.	Science teaching is about igniting students' curiosity to grasp concepts.	Science teaching involves encouraging students to develop the skills needed for investigations.	Science teaching demands a balanced nurturing students' curiosity, skill, and understanding
Ing	Science teaching includes well-structured activities and explanations led by the teacher	Science teaching entails promoting students' sense-making of investigation.	Science teaching entails guiding students to construct evidence-based explanations.	Science teaching entails promoting students' active exploration, with the teachers' guidance.

To describe each preservice teacher's belief transformation in more detail, their learning and reflection processes are discussed as case studies in the following subsections:

4.1 Teacher Noi

Before LS started, Teacher Noi believed that science teachers should "make (scientific) concepts attractive for students and give them engaging stories (of these concepts)." In the goal-setting activity, she stated that she faced challenges in eliciting students' attention during her actual teaching although she felt confident in her public speaking and scientific understanding. Due to this expectations-reality gap she had experienced, she prioritized enhancing student engagement as her personal LS goal.

In her 1st lesson, on soil quality, she planned to explain concepts to students directly. However, during the planning activity, she was given the idea from her LS group and agreed to have students engage in scientific investigation (e.g., soil pH testing), and then let them discuss improving soil quality.

In her actual teaching, she modified her lesson by incorporating soil pH testing (see Figure 2) but tended to give students too many explanations of the experimental procedures without ensuring their sense-making of the experiment. Hence, her students seemed to struggle to grasp the experiment's purpose and choose appropriate methods for each soil problem's improvement during a whole-class discussion.

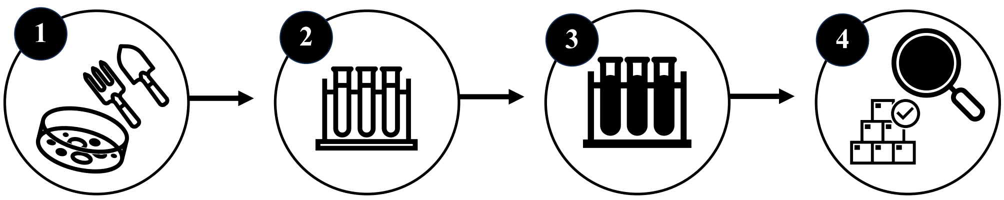

Figure 2. Soil pH testing

In the post-lesson discussion, she expressed disappointment with her own teaching and attributed this to her students' performance and their lack of attention. Her LS team members agreed that it might be better if she could first spark students' curiosity on the topic they were about to learn and ensure they understood the experiment's purpose and design beforehand. Meantime, she reflected on her peer teacher's practices that having students share and exchange their ideas would possibly get them more engaged in the lesson. Her LS team members agreed with her reflection and suggested incorporating whole-class discussions to elicit students' ideas regarding the investigation in the social dialogue. However, in the first post-cycle interview, she contended:

> It is too difficult for my students to construct their own knowledge… I should give them basic knowledge before activities. It helps them understand concepts better than letting them explore it themselves… I knew that I am perfectionist… Everything should follow my plan, but (I felt sad that) everything was not on plan.

It seems that her fear of failure influenced her reflection. Although she possibly learned about involving students in hands-on and mind-on experiences, her sense of failure in teaching possibly resulted in her holding on to her initial belief. Here, we learned that preservice teachers' social-emotional factors can hinder their belief transformations.

In her 2nd lesson, on crystallization, her initial plan involved having students watch a digital video demonstrating a crystallization experiment, which she considered a thought-provoking activity, followed by transmitting key concepts to students. During the planning phase, she gained feedback on eliciting students' curiosity by having them think about real-world issues (e.g., seawater components and salt farming) before viewing the video and posing critical questions during the video. She was also advised to have students discuss real-world situations related to the scientific phenomenon after viewing the video.

In her actual teaching, she incorporated the above feedback by having students share their prior understanding of salt harvesting before watching the planned video. She then asked students about the video: "In this solution, what do you think the solvent and solute are? What is happening? What will happen if we continue adding copper sulfate to the solution?" To her surprise, not only did her students respond to her questions, but they also started asking meaningful questions themselves. She included students' questions in whole-class discussions and helped them make a connection to salt harvesting, but at this point, we noticed that students needed help in interpreting their observation.

In the post-lesson discussion, she reflected that her students seemed eager to learn but struggled in interpreting their observations. She and her LS team members discussed the importance of gradually increasing the questions' complexity to help students verbalize their observations and ideas. Also, the group agreed that, if needed, she should provide scaffolding questions to promote students' critical thinking. In the second post-cycle interview, she reflected:

> They looked more confident to share whether they agree with my explanation and posed 'what if' questions based on their own observation… Science teaching is not only providing students with an experiment procedure, but also helping them verbalize their exploration.

The statements above imply her positive impression of students' behavioral change, realizing that eliciting students' ideas and opinions is essential to support their science learning. Also, it seems that she had gradually shifted away from her initial belief that teaching should be like a one-way communication.

In her 3rd lesson, on solution compositions, she planned to have students analyze various solutions' compositions—some with identical and others with differing states of solvents and solutes. During the planning stage, she obtained feedback that students will grasp the concepts more effectively and overcome misconceptions if they make predictions based on their prior knowledge and experience. She agreed with this feedback and included it in her lesson plan.

In her actual teaching, she initially asked students a series of questions from general life-related issues (e.g., What kinds of solutions do you know? What are their states?) to lesson-specific issues (e.g., How do we identify the solute and solvent in different solutions?). Then, she had her students make predictions and engage in the planned activity. However, we noticed that some students struggled to initiate information analysis. Recognizing this, she asked them to recall previously learned concepts about states of matter and highlighted the similarities and differences across provided solutions. Her scaffolding support seemingly helped students initiate their analysis meaningfully.

In the post-lesson discussion, she reflected that her students' learning seemed to depend on her interaction and support. Thus, the knowledgeable other encouraged her to continue helping students to connect the gathered data to scientific explanations when they needed help. In the third post-cycle interview, she indicated:

> Science teaching should emphasize students' exploration… gather data to discover underlying concepts. While providing questions and methods, I should pinpoint areas where they struggled and give them support… They looked more confident to speak up and discuss with peers… It gets them to become engaged to explore concepts themselves.

Here, she seemed to acknowledge the importance of engaging students in scientific inquiries and helping those in need to grasp key concepts in her class. It seems she evolved her belief about the teacher's role towards guiding and supporting students' learning.

In conclusion, due to three LS cycles, Teacher Noi transformed her belief of teaching as a direct delivery of concepts to guiding students in inquiry activities and tailoring support. Her fear of failure served as a challenge to her initial LS participation. However, her belief was transformed through observing her peer teacher's teaching, receiving concrete feedback on her actual teaching, and teaching the revised lesson plans.

4.2 Teacher Pun

Before LS started, Teacher Pun believed science teaching should be an ICT-led sensory experience where the teachers "employ videos, games, and PhET simulations to leverage students' sensory of seeing… It helps them (students) get the concepts effectively rather than listening to a lecture." In the goal-setting activity, he said his students were more interested in languages and art than science, so they became distracted with their smartphones or dozed off during his classes. Thus, he set eliciting students' motivation in science as his LS personal goal.

In his 1st lesson, on gas exchange, he planned to have students watch a video explaining the concepts and then answer his questions (e.g., Where does gas exchange occur?). During the planning stage, he gained feedback on the teacher-centered nature of his lesson and the importance of including mind-on experiences in the lesson. However, he decided to actualize his initial plan possibly because of his science teaching belief.

In his teaching, he executed the steps he had initially outlined for the lesson. Although he did not ask students to use their smartphones in the class, most students took out their smartphones and became distracted, while some dozed off. Despite his attempts to redirect their attention to the video by asking them questions, it was not effective.

During the post-lesson discussion, he seemed disappointed about his teaching and attributed this to his students' performance and their lack of attention. His LS team members discussed about this issue and agreed that it would be better to have students share their prior experiences relevant to the lesson and identify what they still do not know and want to know before initiating the activity—to get them engaged in the lesson. In the first post-cycle interview, he stated:

> Having students explore concepts themselves is still unsuitable (for my class)… (I learned that) I should help them understand the relationship between science and their lives… (but) I knew best that they are not interested in science and avoid any scientific issues… They thought why they need to know things like calculating speed and acceleration since they do not need to use them in their lives.

The above statements imply that his belief in authority to guide students' learning possibly resulted in his reluctance to accept suggestions from his LS team members. Even though he had recently learned about inquiry-based teaching, it seems that his sense of failure hindered his attempt to actualize this approach in his actual classroom.

In his 2nd lesson on nuclear force, he planned to have students read digital knowledge cards about nuclear force and then answer knowledge-recall questions on paper worksheets he would provide to students. During the planning phase, his LS team members discussed the importance of facilitating group discussions on how nuclear forces operate and their influences on human life to get students engaged in his lesson. Again, he chose to stick with his original plan, possibly due to his underlying belief in teacher authority.

In his teaching, we noticed that most students merely 'copied and pasted' the presented content from the digital cards onto their worksheets. Again, most students became distracted with their smartphones while some dozed off during his class.

During the post-lesson discussion, he expressed that he really would like his students to use their own words to answer the given questions, but it might be too challenging for his students. He seemed disappointed and stated that, "I find myself getting stressed out when unexpected issues arise. I may not be suitable for this job." Here, we learned that the expectation-reality disparity affected his confidence as a teacher. Recognizing this, the knowledgeable other advised him again to first help students connect the lesson to real-world situations by having them share their prior experiences and opinions. His LS peer member agreed that it might help his students, who were not interested in science, better understand the benefit of science learning and become curious about scientific phenomena. In the second post-cycle interview, he stated:

> (I think) I should show them the video and control everything in the class myself as before… They have limited performance and cannot explore science themselves… I wanted them to study knowledge cards themselves, but they cannot… Teacher-centered teaching might be the most suitable (for my classroom context).

The above statements imply that his sense of failure heavily affected his reflection, resulting in his holding on to his initial belief. However, in this interview, he also reflected that observing his peer teacher's lesson made him realize that what he understood about inquiry-based teaching did not seem to align with the group's desired inquiry approach. Here, we learned that engaging in classroom observation followed by co-reflection can help preservice teachers reconsider what they actually believed and understood about effective science teaching. This could be seen as a starting point for reconsidered their possible transformation of beliefs.

In his 3rd lesson, on factors affecting the sound, he planned to have students engage in a 'sound intensity' experiment (see Figure 3) and then calculate sound intensity. During planning phase, he was encouraged to help students comprehend the experiment's purpose and design through facilitating whole-class discussions. His LS group also discussed and agreed that once the students understood factors affecting the sound well, he could have them think about noise-related risks and hearing protection, where students' awareness towards science could be sparked. He agreed to include this activity in his lesson.

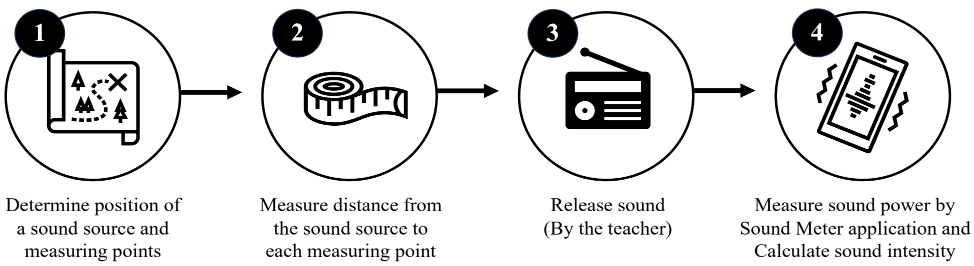

Figure 3. Sound intensity experiment

In his actual teaching, he first showed a video of himself acting as a commentator during a school sports event and asked, "How would my voice change if I did not use a microphone?" and "What do you think affects sound loudness?" After having students share their opinions, he guided them to formulate questions, hypotheses, and variables before engaging in the planned experiment. We noticed that very few students played with their smartphones, and nobody dozed off. Most students looked active in this learning activity as they raised their hands and shared their findings during whole-class discussion.

In the post-lesson discussion, he shared his positive impression of students' behavioral changes and his possible improvement, such as having students create relationship graphs to help them construct evidence-based conclusion. His LS members agreed on this approach that would help students interpret their investigation and construct scientific explanations themselves. In the third post-cycle interview, he articulated his new realization:

> Science learning is having students discover how science knowledge is obtained. It is not like telling them all knowledge… Let them experience themselves. Let them see the (concrete) evidence. It will make the knowledge they gain even more valuable (for themselves).

The above statements imply that he came to embrace the central idea of inquiry-based teaching—it is not just about ICT-led hands-on activity but also about promoting their meaningful inquiry experiences. He evolved his perception towards helping students experience science and come to understand scientific concepts themselves.

In conclusion, Teacher Pun transformed his belief from using ICT applications as the primary deliverer of content to complement students' inquiry activities due to three LS cycles. His fear of failure and tentative commitment to LS initially served as a challenge in his participation, but observing his peer teacher's teaching, receiving concrete feedback on this teaching from his LS group, and experiencing how his students became more engaged in his lessons provided him with alternative perspectives on inquiry-based science teaching.

4.3 Teacher Tim

Before LS started, Teacher Tim believed science teachers should "use analogies like comparing Earth's structure to a stuffed bun, or light travel to human commuting, while explaining concepts to students… (I believe that) this approach helps students visualize and relate their experiences to the subject." In the goal-setting activity, he said his students usually became distracted with smartphones since they had already gained all concepts—they were about to learn in his class—from tutor schools in addition to regular schooling. Thus, he prioritized finding a more effective strategy for teaching science to these students as his personal LS goal.

In his 1st lesson, on the universe model, he planned to have students conduct an internet search about several universe models, followed by his summary and memory cues. During the lesson planning, he gained the idea to have students discuss why different hypotheses for the universe's creation exist—to spark their curiosity, followed by having them collaboratively identifying the strengths and weaknesses of each hypothesis.

In his teaching, he incorporated the above suggestions into his lesson by first asking: "What universe models do you know? Why are there various hypotheses about the creation of the universe? Why did they need reconstruction?" After students shared their opinions, he engaged them in the recommended activity. We observed that his students looked active in the discussions and shared their group's consensuses during the whole-class summary but seemingly struggled to express their scientific ideas meaningfully.

In the post-lesson discussion, he noted a positive impression of his students' behavioral changes and the challenging point we noticed. The knowledgeable other suggested modifying his questions to be simpler and posing scaffolding questions when necessary. He and his LS peer agreed on this approach that might help students gradually learn to express their ideas meaningfully. In the first post-cycle interview, he stated:

> I kept lecturing and lecturing, but did not know that they are much more active when engaging in activities to speak up and explore… I should get them curious. If not, they do not want to learn anything. Then, (I should) set up an atmosphere where they can explore something on their own other than listening to my lecture.

The above statements imply that his students' increased engagement helped him begin to recognize the importance of sparking students' learning passions and aiding them to explore science themselves.

In his 2nd lesson, on the universe's expansion, he planned to have students engage in the universe's expansion demonstration activity (see Figure 4) and calculate the average speed of the universe's expansion using the gathered data set. During the planning phase, he received the suggestion to have students discuss scientists' discoveries of the universe's expansion, generate experimental questions, and experimental variables before initiating the planned activity. He agreed to include these steps in his revised lesson.

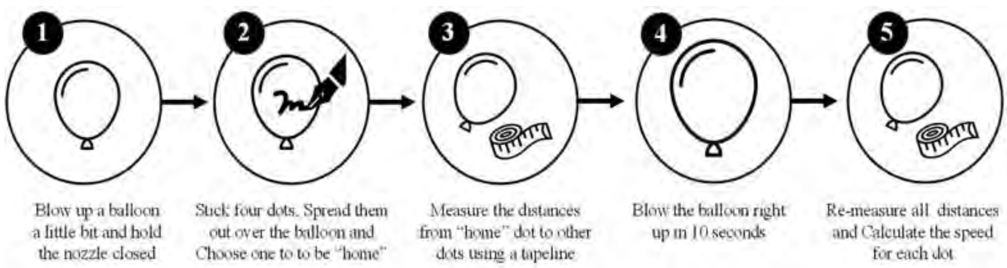

Figure 4. The universe expansion demonstration activity

In his teaching, he incorporated the above suggestions into his lesson by first asking, "In your opinion, how did scientists discover the universe's expansion?" and had students establish inquiry questions and variables. Although his students seemingly enjoyed sharing their ideas in response to this opening question, they struggled to construct inquiry questions and variables needed to get the planned activity started. Also, there was variation emerging among students' gathered data and he seemed to have struggled to help them construct a conclusion relating to scientific concepts.

In the post-lesson discussion, he reflected on the above problem and speculated that variations in balloons' shapes and sizes across student groups could have caused their gathered data to vary. He proposed improvements, such as providing balloons of same shapes and sizes and guiding whole-class discussions on data variations. The LS team members agreed on these modifications, anticipating they would address these unexpected challenges when needed. Also, the knowledgeable other suggested giving students ample time to reason about their observations and interpretation without making immediate judgments on their ideas to support their meaningful thinking. In the second post-cycle interview, he stated:

> When I see students studying happily, I feel good. I sense that they want to grasp concepts themselves… Teachers must arouse curiosity rather than give answers… When students are curious, (I should) let them hypothesize what it will be like, prove it, and then conclude that why what they found and originally thought are similar or different.

The above statements imply that he learned to nurture students' active participation in scientific inquiries alongside content mastery. He came to recognize his students' desires to grasp concepts themselves as he realized the limitations of science teaching as knowledge transmission.

In his 3rd lesson, on stars' life cycles, he planned to have students discuss a story of particular stars and their life cycles, followed by categorizing various stars' life cycles. During planning phase, he received the suggestion to begin and end the lesson with questions relevant to students' lives, as well as having students share their group consensus before collaboratively constructing scientific explanations.

In his teaching, he incorporated the above suggestions into his lesson by having students first discuss the formation and future death of the sun, including its impact on their lives. Then, he asked a key question: "How would the mass of a star, compared to the sun's, impact its life cycle?" After students shared their opinions, he proceeded with the planned group activity. We noticed that although students eagerly participated in group discussion, they still required assistance in verbalizing their ideas and constructing scientific explanations.

In the post-lesson discussion, he highlighted the need to help students verbalize their ideas and overcome their fear of mistakes. He reflected that when students struggled with categorizing stars' life cycles, they copied what they found in online resources. For this, the knowledgeable other suggested fostering student-generated ideas through small-group discussions with a series of guiding questions in the whole class before giving tailored support to each struggling student. He and his LS peer member agreed that this approach could encourage students' co-reflection and overcome the fear of mistakes together. In the third post-cycle interview, he stated:

> Science teaching should involve more than memorizing or listening to lectures. If students face situations different from what they listened to, they cannot adjust their understanding… Students should participate in data collection, analysis, and discussion. If teachers arouse students' interest, they become more engaged in such explorations.

The above statements imply that he came to realize the importance of balancing the development of students' understanding, skills, and engagement as the keys to effective science teaching through engaging in LS process.

In conclusion, Teacher Tim's belief in the teacher's role evolved from an information provider to a learning facilitator through three LS cycles. His initial concern about maintaining teacher authority as a knowledge provider influenced his confidence in teaching. However, receiving concrete feedback on his actual teaching from his LS group, modifying his teaching, and witnessing his students' improved learning behaviors helped him overcome this concern and progressively transformed his belief toward inquiry-based teaching.

4.4 Teacher Ing

Teacher Ing believed science teaching should be a series of well-structured activities where teachers "first convey all the concepts in a lecture and have students engage in activities to experience the concepts." In the goal-setting activity, she expressed her concern about students' performance and her content knowledge in tackling unexpected situations. Although she agreed with student-led scientific exploration, her limited confidence made her decline to do it. Hence, she identified boosting her confidence in actualizing inquiry-based lessons as her personal goal.

In her 1st lesson, on electric currents, she planned to have students conduct online research, followed by her summarizing key concepts. During the planning phase, the knowledgeable other suggested integrating real-life scenarios into the lesson and then having students engage in a scientific investigation, including constructing hypotheses and experimental variables. She agreed to revise her lesson accordingly.

In her teaching, she first displayed a picture of birds perching on high-voltage power lines and asked, "Why can birds stand there without getting electrocuted?" After having students share their opinions, she had students engage in Ohm's law experiment themselves using a PhET interactive computer simulation. At this point, we noticed that most students needed help developing a hypothesis and experimental variables, but she seemingly failed to address it effectively.

In the post-lesson discussion, she reflected on the above issue we noticed. The knowledgeable other suggested facilitating whole-class discussions on this and guiding students on where to begin or offering hints and tips (i.e., scaffolding questions) when needed. Everyone agreed that this approach would support students' critical thinking and self-confidence. In the first post-cycle interview, she indicated:

> I usually compare concepts with something to make it easier for students to understand. But it is not the same thing and made them confused… Establishing hypotheses and variables allows them to experience why an experiment is conducted themselves… They want to see how science knowledge is gained by doing it themselves.

Before LS, she might have underestimated her students' capabilities or motivations, resulting her limited confidence in actulizing inquiry-based lessons in her actual context. However, the above quotes imply that she now realized her students' capacities and willingness to engage in inquiry. In this interview, she also reflected that the discussion on scientific topics in her LS group helped her tackle her concerns in her knowledge base, and start designing the lessons by valuing students' thinking and opinions. Here, it seems that she had gradually shifted away from her initial belief that teaching should merely entail students following her instructions towards promoting students' active participation in scientific investigation and content mastery.

In her 2nd lesson, on electrical circuits, she planned to have students design their own data-recording tables and use them to record electric currents and potential differences in different circuits during experiment. During the planning stage, her LS group discussed the importance of relating the lesson content to students' prior experiences and incorporating circuit calculations.

In her teaching, she integrated insights from the group discussion into her lesson by first presenting images of light bulbs connected in series and parallel circuits and asking: "Despite using identical light bulbs in terms of model, size, and brand, why do we observe the differences in brightness?" After students shared their opinions, she engaged them in the planned activities. At this point, we noticed that her students required assistance constructing data-recording tables. Recognizing this, she initiated a whole-class discussion, prompting students to consider variables and potential table structures, and then facilitating modifications to each student-generated table.

In the post-lesson discussion, she highlighted her students' fear of mistakes in sharing ideas with the class. The knowledgeable other advised her to have students collaboratively develop their ideas in small groups and give them enough time to explain them before supporting struggling students. She and her LS peer agreed that this approach might help students overcome their fear of mistakes and gradually acknowledge their learning processes through a collaborative effort. In the second post-cycle interview, she indicated:

> (I realized that) every student could think critically… They normally asked questions based only on the blackboard (what the teacher showed them), but now questioned about their daily lives and started constructing logical explanations based on hypotheses and gathered data themselves… I began to see how they had learned about science (through the inquiry lesson).

The statements above imply that by monitoring students' learning progress and identifying the specific support they needed, she acknowledged the importance of initiating inquiry-based lesson and having students construct scientific explanations themselves.

In her 3rd lesson, on gravitational interactions, she planned to have students share their prior understanding regarding how planets orbit around the sun, followed by engaging them in a learning activity (see Figure 5). During the planning stage, the LS group (including her) agreed to add more opening questions relevant to students' prior learning on solar system interaction. Also, the knowledgeable other suggested integrating gravitational force calculations once students understood the key concepts.

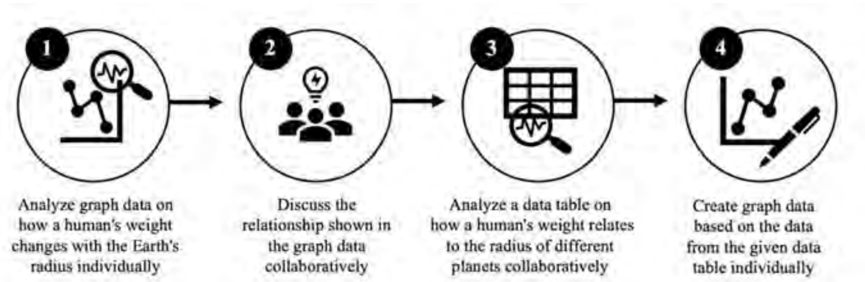

Figure 5. The gravitational interaction activity

In her teaching, she incorporated the above ideas into her lesson. After asking her planned question, she asked, "Why do you think the weight we measure on the Earth differs from that on the Moon?" and "What do you think influences the gravitational force?". After students shared their opinions, she proceeded with the planned activity. At this point, we noticed that some students were actively sharing their opinions, while others struggled with analysing the data table and drawing its graph (the third and fourth steps in [Figure 5]).

In the post-lesson discussion, she reflected on students' learning progress but highlighted the above issue we noticed. The LS group discussed and agreed to balance facilitating whole-class and small-group discussions so that students gain diverse perspectives and ideas on this activity from peers. She also received the suggestions to continue to help students practice drawing graphs and interpreting the trends of the data since students may require varying amounts of time developing these skills. In the third post-cycle interview, she stated:

> Students are marathon runners, testing their running practice ideas… Each student needs different kinds of support… (I should) offer them guidance, and feedback as needed while tracking their progress…. (I should also) look at how students draw scientific conclusions rather than relying only on experimental procedure.

The above comments imply her recognition of the student-driven nature of scientific investigation and tailoring support when necessary. It seems that she evolved her belief towards incorporating students' voices and needs into her science teaching.

In conclusion, over three LS cycles, Teacher Ing's belief shifted from a teacher-centered design of science lessons to more detecting students' needs. Initially, her lack of confidence in science teaching seemingly hindered her attempt to initiate inquiry-based lessons in her actual classrooms. However, group discussions on scientific topics and concrete feedback on her actual teaching from the LS group helped her cultivate confidence and belief in inquiry-based teaching.

5. Discussion and Conclusion

As discussed above, all preservice teachers came to LS with different beliefs and perceived challenges in the science teaching that they had experienced in their student-teaching practicum in the weeks prior to LS starting. Although they developed more inquiry-oriented beliefs following their engagement in LS, their progression paths were found to be quite idiosyncratic. This required us to flexibly modify the LS process to meet each preservice teacher's idiosyncratic needs so that their belief transformations could occur beyond their fear, anxiety, and persistence, as is often done in design-based research. Through this approach, we found that such flexible modifications of LS are essential for unlocking diverse avenues of preservice teachers' varying belief transformations towards inquiry-driven teaching.

Looking more closely, preservice teachers' idiosyncrasies could be seen to have originated in their individual sense-making of various encounters in their contexts during their development (Cabaroglu & Roberts, 2000; Vaino et al., 2013; Huang et al., 2021). Although they were studying in the same teacher training program (or teaching in the same schools), what they idiosyncratically perceived as challenges of science teaching in their contexts can be different and might have led to the different social-emotional factors they had experienced throughout LS sessions. For example, Teacher Noi and Teacher Pun were disappointed when their teaching expectations were unmet in their minds, and they attributed their sense of failure to themselves and/or their students. This situation is often reported to happen among novice teachers with limited experience in effectively addressing classroom challenges (Voss & Kunter, 2020; Qiu et al., 2021). In such situations, novice teachers attempt to protect their self-images from failures and public embarrassment in unfamiliar scenarios (Gavish & Friedman, 2011). Due to these differences in preservice teachers' sense-making of teaching challenges and their experienced social-emotional factors, generalizing their belief transformations and stage-based theorization could be seen to be highly challenging.

Preservice teachers became more aware of inquiry-based teaching and transformed their beliefs in this direction when they addressed their teaching challenges and the sense of social-emotional crisis. LS was found to support this process effectively. Through its form of collaborative inquiry, they co-constructed PCK, received concrete feedback on their teaching, and experienced alternative teaching methods in different classroom contexts through mutual observation. What should be noted is that once they experienced how students could benefit from inquiry-based science lessons, they gradually developed positive awareness—and confidence—in this approach (Baricaua Gutierez, 2016; Ladachart et al., 2022), shifting their beliefs toward an inquiry-oriented direction. In a way, this social-emotional journey served as a foundation for teachers' belief transformations, aligning with the notion that teachers' beliefs can be effectively transformed within the context of their own intrapersonal and interpersonal needs (Shulman, 1986; Pajares, 1992; Scott, 2016).

Although this study was conducted in a Thai context, we believe that the findings can be applied to other non-Thai contexts. This is because what matters most seems to be adjusting the LS process in ways that consider the cultural context in which LS unfolds and reflect preservice teachers' idiosyncratic needs throughout the LS process. Thus, to integrate LS into the preservice teacher education program to guide preservice teachers in transforming their beliefs toward inquiry-based teaching effectively, this suggests three following points:

1) Flexibly modifying the LS process by reflecting preservice teachers' individual differences and needs by examining their initial beliefs and perceived teaching challenges: As evident in this study, preservice teachers embarked on belief transformations when they were able to overcome social-emotional challenges in their teaching. Thus, tailoring LS to their diverse needs is essential. In order to do this, it would be essential to examine and capture preservice teachers' beliefs and perceived teaching challenges before the LS process starts and their transformations throughout the LS process. This would serve as a framework for guiding the LS process to elicit preservice teachers' belief transformations toward inquiry-based teaching in personally meaningful ways.

2) Having preservice teachers engage in actual enactment of their teaching plans in their classroom contexts, followed by co-reflections on their students' learning and possible improvements: This would help them contemplate the need to transform their beliefs in relation to their actual practices on their own while collaborating and learning from and with their peer teachers.

3) Providing preservice teachers with constructive input from knowledgeable others and their LS peers in a non-anxiety-driven manner: Besides recognizing preservice teachers' idiosyncrasies, it seems highly essential to create a safe and flexible environment so that they become free from anxiety and go through diverse trajectories of their professional development. As evident in this study, as we came to realize the importance of considering Thai preservice teachers' social-emotional well-being, we introduced informal, non-academic conversations and implemented the sandwich model—Compliment-Critique-Encouragement (Procházka et al., 2020). This seems to have helped Thai preservice teachers overcome their fear of failure and criticism which may be formed through the traditional nature of classroom observation and teacher professional development in this context. Ultimately, these strategies seem to have ushered them to transform their belief about effective science teaching towards inquiry-based teaching while developing their PCK for science teaching. However, the helpful strategies for tackling the same issues may vary across cultural contexts. Therefore, the facilitators and knowledgeable others should work closely in considering the cultural context in which LS unfolds, pointing out blind spots in preservice teachers' improvement, and providing them with meaningful suggestions and suitable support/encouragement.

We acknowledge our limitations in making any generalizations from the results of this study, which used cross-case analysis. However, this study's results suggested implementing LS to reflect and help preservice teachers overcome their idiosyncrasies that may hinder their belief transformations towards inquiry-based teaching. Finally, further investigations on this dimension would be essential to consider meaningful LS implementations in diverse contexts to promote preservice teachers' belief transformations toward inquiry-based teaching in personally meaningful ways, as this study attempted to do.

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No additional data are available.

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