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To: Imam Safi'i <imamsafii2077@uhamka.ac.id>

Imam Safi'i:

I believe that you would serve as an excellent reviewer of the manuscript, "Teacher Learning about Teaching Scientific Literacy through Professional Development Program: A Thailand Case Study," which has been submitted to International Journal of Learning, Teaching and Educational Research. The submission's abstract is inserted below, and I hope that you will consider undertaking this important task for us.

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"Teacher Learning about Teaching Scientific Literacy through Professional Development Program: A Thailand Case Study"

Abstract

Reports from the Programme for International Student Assessment challenge Thailand’s science education reform, revealing a persistent decline in scientific literacy among Thai students over the past two decades. Also, previous professional development programs for science teachers were considered ineffective and unsuitable for the demands of the digital society. As a qualitative case study, the researchers aim to conduct a teacher professional development program with the goal of enhancing teachers’ knowledge to plan effective scientific literacy lessons. The program was integrated by pedagogical content knowledge perspectives and delivered to ten science teachers from ten public schools in the northern educational area of Thailand through online platforms for six-day meetings on weekends. The program included updating knowledge lectures for the teachers, followed by practical sections to continuously improve the lessons. Additionally, the teachers were invited to participate in interviews before and after the program, recording their data from the interviews and online meetings as video clips. The data were verified and validated using content analysis and method triangulations. The findings illustrated that they knew about scientific literacy but could not integrate that into their lessons. After receiving individual feedback from the program, they made improvements by connecting global issues to scientific concepts and their local context and by promoting scientific competencies through inquiry-based approaches. Additionally, they needed support from online knowledge sharing and a challenge activity for the teacher community

to enhance their certain knowledge and ability to plan effective lessons.

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Teacher Learning about Teaching Scientific Literacy through Professional Development Program: A Thailand Case Study

Abstract. Reports from the Programme for International Student Assessment challenge Thailand's science education reform, revealing a persistent decline in scientific literacy among Thai students over the past two decades. Also, previous professional development programs for science teachers were considered ineffective and unsuitable for the demands of the digital society. As a qualitative case study, the researchers aim to conduct a teacher professional development program with the goal of enhancing teachers' knowledge to plan effective scientific literacy lessons. The program was integrated by pedagogical content knowledge perspectives and delivered to ten science teachers from ten public schools in the northern educational area of Thailand through online platforms for six-day meetings on weekends. The program included updating knowledge lectures for the teachers, followed by practical sections to continuously improve the lessons. Additionally, the teachers were invited to participate in interviews before and after the program, recording their data from the interviews and online meetings as video clips. The data were verified and validated using content analysis and method triangulations. The findings illustrated that they knew about scientific literacy but could not integrate that into their lessons. After receiving individual feedback from the program, they made improvements by connecting global issues to scientific concepts and their local context and by promoting scientific competencies through inquiry-based approaches. Additionally, they needed support from online knowledge sharing and a challenge activity for the teacher community to enhance their certain knowledge and ability to plan effective lessons.
Keywords: scientific literacy; professional development program; case study; Thailand

1. Introduction

A significant goal of science education in the term "scientific literacy" originates in the 1950s (Norris & Phillips, 2003), and it has been widely proposed to express a diverse education ranging from broad knowledge of science to specific science learning purposes (Bybee, 1997). Developed countries reform science education by applying scientific literacy to national science curricula. For example, scientific literacy in the United States is defined as students' understanding of fundamental concepts of science, nature of science, and scientific inquiry (American Association for the Advancement of Science, 1989). They set benchmarks for

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scientific literacy in such the National Science Education Standards and the Next Generation Science Standards (National Research Council, 1996; 2013). Furthermore, the Organization for Economic Co-operation and Development (OECD) has initiated the Programme for International Student Assessment (PISA) to investigate and provide critical information on how scientific literacy should be used as an indicator of how well 15-year-old students from various countries around the world are prepared for life in 21st century society (Fensham, 2007; OECD, 2005). However, developing countries such as Thailand have struggled to reform science education with scientific literacy. According to the PISA results for Thailand from 2003 to 2022, Thai students have suffered a continual decline in scientific achievement. They demonstrate a relatively unclear understanding of scientific knowledge and low competency in applying that knowledge to describe and analyze events in real-life contexts (OECD, 2005; 2017; 2023). Therefore, as outlined in the Thai National Education Plan (Office of the Education Council, 2017), the Ministry of Education of Thailand specifies guidelines for science education that require professional development of teachers, collaboration among teachers and educators to foster discourse within their new learning communities, and a greater focus on research concerning teaching for scientific literacy.

A challenge of bringing about new change in teacher professional development (PD) for higher scientific achievement in literacy is the reorientation of teachers' teaching practices to focus on science as scientific inquiry rather than using a rigid teaching method for student learning to deal with global issues (McFarlane, 2013). Also, teacher perceptions of scientific literacy are somewhat ambiguous. While teachers view science learning as results of reading scientific texts and knowledge, applying science to everyday decision-making, and incorporating science learning tools into teaching and learning activities, they fail to take into account the social and global contexts of scientific literacy (Budiman et al., 2021). Teachers lacking sufficient knowledge in science and pedagogy are unable to fulfill their responsibilities when teaching scientific literacy. It is crucial to enhance teacher knowledge of scientific literacy and pedagogy to encourage students to take action in response to global issues (McFarlane, 2013).

Moreover, science education has taken the initiative to discontinue onsite school teaching and learning considering the digitally rapid changes in 21st century society (Annetta & Shymansky, 2006) and the COVID-19 pandemic (Dhawan, 2020). Distance education has frequently supplanted onsite schooling for students. Furthermore, teachers have been trained to facilitate distance learning through online platforms, which has enabled them to conduct online courses and implement pedagogical changes (Izhar et al., 2021). Consequently, teachers are faced with the task of integrating digital technology into their science lessons as an effect of the rapid changes. Even though teacher developers have previously established teacher training programs that are intended to promote teacher development, they have failed to adequately inform teachers about the disadvantages of utilizing science lesson plans that exclusively focus on student listening and writing skills. So, teachers are being relegated to passive roles in teaching practices (Kaptan & Timurlenk, 2012). Additionally, teacher development is hindered by a lack of accessible teaching and learning resources, time constraints, and teaching experience in science subjects (Pan, 2017).

In Thailand, teacher colleges and university faculties of education have provided science teacher education. Pre-service teachers generally engage in onsite courses that focus on student-centered learning approaches, general and special education, science content, and practical teaching experience in public schools (Faikhamta et al., 2018). In addition, the Institute for the Promotion of Teaching Science and Technology (IPST), the national academic organization, plays a main role in providing PD programs to in-service teachers who have embarked on careers in science education. The IPST retrains in-service science teachers' knowledge and teaching practices in accordance with government policies (Mullis et al., 2016). These include developing scientific literacy understandings, such as the PISA framework and PISA-like online testing (Office of the Basic Education Commission, 2022). Typically, the IPST has worked in collaboration with teacher colleges, universities, and educational service area agencies to establish intensive professional development programs through traditional onsite workshops. However, Musikul (2007) reports that PD programs cannot effectively advance the development of science teaching. A cause of ineffectiveness of PD programs is that PD program developers often struggle to integrate teachers' pedagogical content knowledge (PCK) into the PD programs. Also, Faikhamta et al. (2018) indicate that PD programs focused on rote learning and lecture-based teaching approaches with outdated knowledge. The PD programs then contribute to the inefficiency of teachers' teaching practices.

Therefore, Thailand continues to require innovative professional development (PD) programs that expand teachers' knowledge of science, pedagogy, and social and global contexts, facilitate their time management, and provide learning support for scientific literacy in the digital society. This present study, as a first step towards addressing the challenges in science teacher development, aims to strengthen the PD program based on online platforms by integrating the pedagogical content knowledge perspective, with the goal of enhancing teacher knowledge for the planning of effective scientific literacy lessons.

2. Research Questions

The following questions are used to guide this study.

1. What do teachers know about scientific literacy for their lesson plans?
2. How do teachers change/re-plan scientific literacy lessons during the professional program?
3. Which circumstances facilitate teachers' learning in the professional development program?

3. Theoretical Backgrounds

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2. Explanation of theoretical background needs to be strengthened again so that it has a very close relationship with the problem or background being studied.

This study is influenced by Shulman (1986; 1987), who defines PCK as the teaching knowledge that teachers possess. According to Shulman's perspective, the PCK encompasses teachers' understandings of subject matter or content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, student knowledge, knowledge of goals, purposes, and values, as well as their understanding of educational contexts, settings, and governance. The reasoning and actions associated with teaching can be helped by the understandings of PCK. Thus, professional teachers who possess the PCK exhibit effective lesson planning and teaching practices by connecting their subject matter knowledge to their pedagogical knowledge and adapting it to the diverse requirements of their students through appropriate reasoning.

In addition to Carlson et al.'s (2019) the Refined Consensus Model (RCM) of PCK, this focuses on three areas of PCK: the collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). First, the cPCK refers to the public knowledge of teachers or people within a particular subject, such as science content knowledge, pedagogical knowledge, knowledge of students, curricular knowledge, and knowledge of assessment. Also, the cPCK, which can range from science discipline knowledge to more specific-topic knowledge, is often found in books, academic/research articles, and discussions by teachers and researchers at conferences. Second, the pPCK is a contextualized area of knowledge that a science teacher receives from direct teaching experience, knowledge acquired from various students and discussions with colleagues, and contributions from university educators and scientists. The pPCK serves as a set of knowledge bases to draw upon when a teacher is planning, teaching, or reflecting on a science lesson. Finally, when he/she can integrate the pPCK into teaching practices for a particular student group and learning objective, their pPCK is transformed into the ePCK. This occurs through multiple cycles of planning, teaching, and reflecting on his/her lessons. Then, when teachers continuously modify each lesson plan in response to students' reactions or unplanned situations, it empowers them to succeed in the ePCK.

Up to this point, this study adapts Shulman's PCK perspective to select appropriate knowledge for the teacher PD program, while Carlson et al.'s (2019) model serves as the program's goal, encouraging teachers to enhance their ePCK through improved lesson plans for teaching scientific literacy.

Additionally, this study implements the definition of scientific literacy based on PISA's framework (OECD, 2017), for lesson planning. According to PISA, scientific literacy is a student ability to understand and engage in critical discussion in society about science and technology issues, and it encompasses three competencies: explaining natural phenomena, evaluating and designing scientific enquiry, as well as interpreting data and evidence scientifically (OECD, 2017; 2023). Therefore, to enable students to practice scientific literacy, it is crucial to plan a science lesson that prioritizes their learning process and integrates the three following elements. The first element is to enhance students' scientific knowledge and concepts of natural phenomena, concentrating on their application in the fields of life science, health, earth science, and environmental science. The second one focuses on scientific processes; teachers encourage students to engage in scientific inquiry. The students receive chances to identify questions, evaluate and design appropriate procedures, interpret data, and act upon evidence. Lastly, it involves connecting the first and second elements to scientific situations or contexts in students' daily lives, rather than restricting science to a classroom or laboratory setting. This allows students to understand interactions between science, society, and technology (MacKenzie, 2023; Utami et al., 2015).

4. Methodology

In this study, the researchers implemented the qualitative research approach and case study design as lenses to uncover answers to the research questions. Case study research was an in-depth investigation of what happened during the development of a particular program or project, as well as the way an individual interacted with or related to the program (Lichtman, 2013).

4.1 Participants

There were ten in-service science teachers participating in this study. These participant teachers were from ten public high schools in the lower northern educational area of Thailand. They were selected by purposive sampling based on educational backgrounds, teaching experience, and accessibility to online platforms, i.e., Zoom, Facebook, and Line, and they had appreciated being volunteers for this study. To address ethical concerns, the researchers named the teachers by codes such as T01, T02, and T03. All teachers' codes and characteristics were presented in Table 1.

Table 1: Participant teachers

Teacher codes	Age (Year)	Gender	Educational Backgrounds	Teaching Experience (Year)
T01	28	F	B.Ed. (Physics)	5
T02	29	M	B.Ed. (Physics)	6
T03	30	F	B.Ed. (Physics)	6
T04	30	F	B.Ed. (Physics)	6
T05	32	F	B.Ed. (General science)	8
T06	32	M	B.Ed. (General science)	8
T07	38	F	B.Ed. (Secondary education)	13
T08	41	F	B.Sc. (Biology)	16
T09	43	F	B.Sc. (Biology)	16
T10	46	F	B.Sc. (Biology)	19

4.2 Teacher professional development program

The teacher PD program for the participants was conducted by the researchers. It consisted of four main sections: 1) knowledge about scientific literacy and its assessment based on the PISA framework; 2) knowledge of pedagogy for scientific literacy and relevant curriculum; 3) integration of scientific literacy into a science lesson; and 4) practice on improvement of science lessons. During the first and second sections, the researchers gave lectures, discussions, and examples to the participants. In the third section, they participated in group discussion and had chances to analyze and link scientific literacy, science content standards based on curriculum, and pedagogy for their lesson plan at the junior high school level. In the fourth section, the participants individually improved their lesson plans three times. Firstly, they developed the lessons by themselves using the lesson template (Appendix 1) from the PD program and what they learned from the previous three sections. Subsequently, the researchers provided feedback on the lessons twice, which the participants utilized for their lesson improvement. Later, the researchers set up an online workshop for the community of science teachers around the university, giving them the opportunity to adaptively utilize the lessons with audiences. Following the workshop, the participants finally received feedback from the audience, which they used to improve the lessons once more.

Due to the participants' time constraints, it was necessary to schedule the teacher PD program only on weekends. The PD program spanned six days through Zoom meetings that lasted three hours each, and all meetings were recorded in video clips. Additionally, this study utilized the Facebook group as a sharing tank to gather materials for the PD program, such as lecture-video clips, the curriculum, and the lesson template, as well as the improved lessons of all participants. This sharing tank was created to support participants who would like to continue their self-study outside of the meetings. Furthermore, if the participants encountered difficulties with their lessons, they had the option to contact the researchers via the Line application for consultation.

4.3 Data collection and analysis

According to the first research question, the participants were invited to participate in an hour-long focus group interview about the topic of teaching scientific literacy through a Zoom meeting featuring a recorded video clip. The researcher, who was also the first author of this article, was the moderator, and the goal of the interview was to reveal how individual teachers think and experience scientific literacy for their lesson plans. Also, the researcher used guided questions to stimulate the participants to think of examples and share ideas. For example, 1) What is scientific literacy? 2) How have Thai students performed in the PISA's scientific literacy assessment? 3) In the classroom, what evidence or performance confirms the scientific literacy of your students? 4) How do you teach scientific literacy in the classroom? 5) What are the factors that influence the teaching of scientific literacy?

Later, the researchers used content analysis to analyze the interview data and then triangulated the results with data from the participants' first lessons to establish their credibility. The researchers used a lesson plan as a model to reveal teachers' knowledge in science teaching (Cerbin & Kopp, 2006; Chandler-Olcott & Dotger, 2023; Jacob et al., 2008; Unal-Coban, 2022). If the data from the interview and lessons did not support each other, the researchers would revisit the recorded video clips for re-interpretation and final decision-making.

To address the second research question, the researchers also utilized content analysis to examine the first to third improved lessons, thereby revealing their process of changing or replanning the lessons. In addition to the third research question, each participant individually was invited to a 45–60-minute Zoom meeting for a one-on-one interview and recorded a video clip during the meeting. This was to identify the circumstances that facilitated their learning in the PD program. The interview guide included the following questions: 1) Could you explain your experience of participating in the PD program? 2) How could you improve the lesson plan? 3) What have you learned from the six-day meetings? 4) What knowledge or abilities will a science teacher need to teach scientific literacy in a classroom, and could you provide examples? 5) What additional information would you like to share about the PD program? Finally, the researchers would verify the trustworthiness of the lessons and interview data by triangulating them with data from the six-day meeting clips of the PD program.

5. Findings

This study analyzed the data according to the research questions and came up with the following results:

5.1 Teachers knew about scientific literacy but could not integrate that into science lessons.

The data from the focus group interview revealed that all teachers understood the meaning of scientific literacy, which involved students' ability to use scientific knowledge and process skills to solve problems in their daily lives, and students were able to criticize, plan, and decide which knowledge was the best solution appropriate for their social contexts. The data presented below serves as examples of two teachers who noted that:

> "*...It means that students can use the knowledge and process skills of science that they have studied to solve problems in their lives…*" (T07).

> "*…The scientific literacy is students' ability to solve problems and make decisions when they face any circumstances in their daily lives... They use this knowledge and apply a reasonable process to find solutions…*" (T09).

Despite all teachers having the understanding of scientific literacy, they struggled to integrate it into their lesson planning. Two teachers used the teacher-centered approach in their students' learning activities, which involved memorizing scientific concepts, while the remaining eight teachers planned to teach scientific concepts through an approach that seemed like storytelling. What they focused on was the use of online news or media reports to encourage students to read, write, and communicate with a vocabulary of scientific concepts without consistently linking them to the inquiry process, scientific competencies, and social contexts or global issues. For example, T02 utilized two YouTube video clips to explain the definitions of renewable energy, different types of energy, and the origins of fossil fuels while simultaneously conducting an interactive question and answer session, but T02 planned to instruct the students to remember the energy concepts by building a model that illustrated the general production of fossil fuel energy, and its effects based on the video clips, as required by the teacher. As part of T02's lesson, it was noted that:

> "*…[the teacher] asks questions: Do you know any energy from the clips? …What are the differences between the fossil fuels, coal, oilstone, and petroleum? ...What are the advantages and disadvantages of fossil fuel energy? ...Next, each group of students…makes a plasticine model...that*

illustrates an advantage or disadvantage, such as air or water pollution…" (T02).

5.2 After feedback, teachers re-changed lessons for scientific literacy.
The analysis of all lesson plans revealed that providing feedback enhanced teachers' ability to improve lessons that incorporated scientific literacy by encompassing scientific contexts, competencies of scientific literacy, and student-centered approaches.

Firstly, all ten teachers (100%) demonstrated the ability to identify both global and local contexts that relate to scientific concepts and the curriculum. They devised their lesson plans to encourage students to identify problems within an environmental issue related to their local contexts by assigning students to seek a scientific method for exploring, interpreting, evaluating, and drawing conclusions, even though they previously had favored relying on less relevant news or events through storytelling to launch laboratory studies without a convincing rationale and scientific variables.

For example, T08 previously promoted students' engagement in reading a lab direction and then conducting experiments aimed at measuring lung volume as a means of investigating air pollution. Later, she revised the lesson by incorporating the controversial topic of PM2.5 dust, the environmental issue in their local context, into the students' learning activity, supported by data graphs and online news that illustrated its impacts on their community. In the end, she planned to motivate the students to search for data on the internet and to interview parents and people in the community. This was to explore scientific debates about the optimal resolution for the environmental issue. As part of T08's lesson, it was noted that:

> *"...[The teacher] introduces the PM 2.5 issue from a global perspective... and motivates students to think about the danger of PM 2.5 dust by questioning... Next, the teacher presents graphs depicting the dust quantity in the northern region of Thailand and inquires, "What is the current trend in dust pollution?" Does the dust impact on your health, and if so, how? ... What causes the dust in our province? ...(*T08).

Secondly, nine teachers (90%) successfully implemented student-centered approaches that focused on scientific inquiry. These approaches included argument-driven inquiry, context-based learning, model-based learning, science, technology, society, and environment (STSE), as well as science, technology, engineering, and mathematics (STEM) education, with the aim of enhancing students' scientific competencies in their lessons.

For example, T04 and T10 used the STSE approach to enhance the students' competencies to explain natural phenomena and interpret data and evidence scientifically. They planned to assign their students to search the internet for alternative explanations and evidence, aiming to identify the most suitable solutions for global warming and the hidden costs of fossil fuels. Furthermore, T01, T06, and T09 employed the STEM education approach to cultivate these competencies in their students while also enhancing their competency to evaluate and design scientific inquiries. Specifically, T06's activity involved using Microsoft Excel to create a graph that illustrated the growth of hydroponic plants in the context of the COVID-19 pandemic. Additionally, T01 advocated for the use of an online application to compute electricity expenses for constructing a model of an eco-friendly house, and T09's activity focused on repurposing plastic waste to create a household item.

Up to this point, the teachers illustrated their ability to improve scientific literacy lessons during the PD program. The one-on-one interview data conclusively validated and demonstrated that the researchers' feedback shaped the teachers' enhancement in lesson planning. The interview data presented below serves as examples of two teachers who explained that:

> *"...When I first started [this lesson], I didn't think I'd be able to develop something like that, but the ideas had been worked out step by step...I could do that because [the feedback] was very friendly and useful for me, and I think it enabled me to teach as a professional..."* (T02).

> *"…your critical feedback and good examples helped us... Even though you had not directly provided an answer or conclusion on whether my task was either right or wrong, it significantly helped me to think independently of what was truly appropriate for my lesson plan…"* (T10).

However, T05 was the only teacher who could not complete developing the lesson for scientific literacy. She stated, *"I did not have enough time to complete the lesson plan."* As a result, she was only able to incorporate the competency of explaining natural phenomena into her previous lesson, but not the competencies of evaluating and designing scientific inquiry or of interpreting data and evidence scientifically into her final lesson.

5.3 The sharing tank and the community workshop enhanced teachers' learning in the PD program.

The data from interviews highlighted two critical components that significantly facilitated the teachers' development in designing lesson plans through the PD program.

First, there was the sharing tank where the PD program adaptively used a Facebook group to store learning materials, Zoom-meeting video clips, and all improved lessons. This tank consistently offered opportunities for teachers to revisit and learn more about scientific literacy, teaching approaches, learning resources, and ideas discussed during meetings, as well as feedback for self-study. Therefore, the teachers were able to observe their peers' adept use of ideas in creating lesson plans, which served as a valuable example for achieving the lesson plan design goal. This was especially beneficial for the teacher who had not much expertise in teaching scientific literacy, such as T02, who noted that:

> *"…At the time that I didn't comprehend what the feedback meant, specifically, I had no ideas to improve my teaching preparation,... I went*

> *back to see the others' lesson plans [in the sharing tank], and it became WOW! How did they do this? Then, I understood the feedback and could revise my lesson plan...*" (T02).

Second, the PD program included a more challenging activity called the online workshop for the community. In this workshop, teachers were required to share their knowledge of designing lesson plans by demonstrating them to the workshop audience, which included science teachers from the university and the teachers' school communities. This activity not only enhanced the teachers' self-knowledge awareness but also contributed to their professional development. For instance, T02 previously planned the lesson to teach students about energy concepts, which involved creating a model based on YouTube clips for storytelling purposes. However, when he realized he needed to demonstrate the lesson to community science teachers, he returned to the sharing tank and revised it to incorporate more active learning activities. There, he used data graphs to encourage students to formulate hypotheses about the origins of fossil fuels and human energy consumption from a history of science perspective, seek online information to confirm or refute these hypotheses, and then summarize the data by creating a model. The data presented below serves as an example of T02, who noted that:

> *"…I went back to see the others' lesson plans [in the sharing tank],…Then, I understood the feedback and could revise my lesson plan [for the workshop] multiple times, and...when I ran the workshop, I'm proud to be a knowledge-giver…"* (T02).

6. Discussions

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The teachers who had educational backgrounds in science education learned to teach scientific literacy through lesson planning activities in the PD program, which were integrated by PCK perspectives and comprised sections of updating knowledge and practices.

In the PD program, teachers with a certain level of knowledge had the opportunity to update their scientific literacy during the lecture sections. However, they continued to utilize activities that involved memorization of scientific concepts or a teacher-centered approach. It is possible that they perceived the knowledge they gained from prior experience and the lecture sections as public knowledge, similar to the cPCK they encountered in academic books and conferences. The PD program with only lecture activities that focused on updating knowledge, giving examples, and the passive roles of teachers could not empower them to transform the cPCK into the pPCK for creating effective lessons by themselves (Carlson et al., 2019; Faikhamta et al., 2018; Kaptan & Timurlenk, 2012).

Later, giving feedback on the teachers' lesson plans improved their understanding and ability to identify global and local contexts that had connections to scientific concepts and to include a range of scientific competencies in the lessons (Bom et al., 2019; Hanfstingl et al., 2023). With positive and productive feedback by the researchers, who are specialists from the university, the teachers trusted and regarded the suggestions and then used that to balance their self-reflection on the lesson plans (Hudson, 2014; Kleinknecht & Gröschner, 2016). Additionally, the PD program's three cycles of feedback and the self-reflection balance during the practice section of lesson improvement allowed the teacher to transform the cPCK into the pPCK and subsequently the ePCK (Carlson et al., 2019). Then, they were able to modify their own lessons to an unplanned situation, such as the workshop for the science teacher community. Additionally, the provision of online learning resources, such as the Sharing Tank, for the PD program helped teachers who had limited experience in teaching scientific literacy and time to visit the researchers for consultations to advance their learning by viewing and criticizing their peers' lesson plans and then make clearer comprehending the feedback by themselves. If the PD program did not effectively support the online tank, teachers might not be able to complete their lessons (Mavuso et al., 2022).

Moreover, establishing the community workshop as a forward-looking objective for the teachers in the PD program significantly induced them to continuously improve the lesson plans in a more clear and effective manner. To accomplish the objective, the teachers were active in learning to create acceptable lesson plans for sharing their expertise and experiences with others outside of the PD program. It is possible that the community workshop naturally empowered them to commit to the PD program and their school community so that they become authorities on teaching scientific literacy. As a result, they would implement the PD experience into classroom teaching practices to preserve their membership in the communities (Barr & Askell-Williams, 2020; Wenger, 1998).

6. Conclusions and Implications

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This study delivered the teacher professional development program through the Zoom platforms to ten science teachers from ten public schools in Thailand's northern educational area. The PD program consisted of four main sections: 1) knowledge about scientific literacy and its assessment based on the PISA framework; 2) knowledge of pedagogy for scientific literacy and relevant curriculum; 3) integration of scientific literacy into a science lesson; and 4) practice on improvement of science lessons. As a result, the teachers enhanced their learning and practical experience in planning lessons for scientific literacy based on the PISA framework. This was achieved through the feedback, the knowledge sharing tank, and the community workshop where they shared the experience with other teachers and school communities. To successfully implement the PD program, the researchers need to 1) establish friendly relationships with teachers before and during the PD activities to build their trust and confidence in the feedback; 2) provide online learning resources to support teachers' self-study after PD meetings; and 3) create an unplanned situation to challenge teachers to improve their specific level of knowledge affecting their practices in teaching scientific literacy.

7. Acknowledgements

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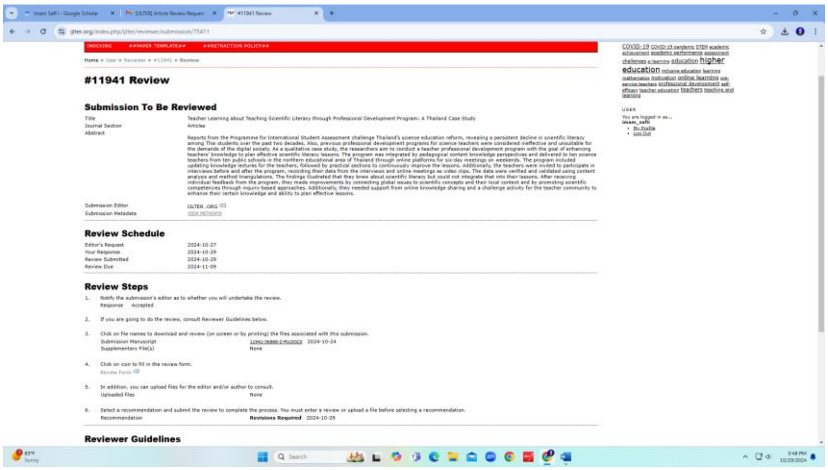
Appendix 1

In this study, a lesson plan for scientific literacy covered the following topics:

1. Title and time for teaching.
2. Relevant learning indicators/standards/curriculum
3. Scientific competencies (based on the PISA framework)
4. Teaching and learning objectives
5. Core scientific contents
6. Scientific issues and information in global/social contexts
7. Teaching models/approaches
8. Student learning activities (based on the model or strategy)
9. Student learning materials and resources
10. Student learning assessment



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Thank you for completing the review of the submission, "Teacher Learning about Teaching Scientific Literacy through Professional Development Program: A Thailand Case Study," for International Journal of Learning, Teaching and Educational Research. We appreciate your contribution to the quality of the work that we publish.

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