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The Influence of a Digital Professional Development Program on Enhancing Thai Teachers' Learning in Teaching Science Literacy

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Abstract. This qualitative case study investigated the learning process of Thai in-service science teachers as they studied science literacy. This learning process was conducted in the form of a professional development program delivered on digital platforms. The program's design relied on adult learning and pedagogical content knowledge theories and included four phases: knowledge of science literacy, knowledge of pedagogy, integration between knowledge and lessons, and practice in lesson planning. The teachers were selected by a non-probability purposeful sampling technique and participated in the six-day program on weekends. Data from a focus group interview, thirty lesson plans, and ten individual interviews were analysed through conventional content analysis and triangulation techniques. The findings illustrated that the teachers had prior knowledge about scientific literacy but could not completely adapt it to plan effective lessons. However, through inquiry-based approaches such as receiving feedback, sharing lessons, and a community workshop, nine teachers appeared to improve their own lessons by connecting global issues to scientific concepts and local contexts. The findings recommend the use of reflective journals and classroom observations in school settings to obtain more details about teachers' learning and promote sustainable development of teaching science literacy.

Keywords: lesson; professional development program; science literacy; teacher; teaching

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1. Introduction

A significant goal of science education is "science literacy", a term which originated in the 1950s (Norris & Phillips, 2003). Science literacy promotes a diverse education ranging from broad to niche scientific knowledge (Roberts & Bybee, 2014). Developed countries reform science education by applying science literacy to the national science curricula. For example, science literacy in the United States is defined as students' understanding of fundamental concepts regarding science, nature of science, and scientific inquiry (American Association for the Advancement of Science, 1989). The US authorities set benchmarks for science literacy through the National Science Education Standards and Next Generation Science Standards (National Research Council, 1996, 2013). Furthermore, the Organisation for Economic Co-operation and Development (OECD) has initiated the Program for International Student Assessment (PISA) to investigate and report on the ways in which science literacy should be used as an indicator to reveal how 15-year-old students from various countries around the world are prepared for life in 21st-century society (Fensham, 2007; OECD, 2005).

According to the PISA results between 2003 to 2022, Thailand struggled to reform science education and increase science literacy. Thai students suffered a continual decline in scientific achievement. They demonstrated a relatively unclear understanding of scientific knowledge and low competency in applying that knowledge to describe and analyse 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 now specifies required guidelines for science education, including teacher professional development (PD), collaboration among teachers and educators to foster discourse within learning communities, and a greater focus on research concerning the teaching process. In addition, colleges and university faculties now provide academic ways for teachers to increase their science education in Thailand. Pre-service teachers generally engage in onsite courses that focus on student-centred learning approaches, general and special education, science content, and practical teaching experience in public schools (Faikhamta et al., 2018). The Institute for the Promotion of Teaching Science and Technology (IPST), the national academic organisation, also plays a key role to 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. Typically, the IPST works in collaboration with teacher colleges, universities, and educational service area agencies in an attempt to establish intensive PD programs through onsite workshops.

However, Musikul (2007) reported that the previous PD programs could not effectively advance the development of science teaching. This was because the PD program developers often struggled to integrate teachers' pedagogical content knowledge (PCK) into the PD programs. Further to this, Faikhamta et al. (2018) indicated that the PD programs often focused on rote learning and lecture-based teaching approaches, which relied on outdated knowledge about science and technology. The PD programs then contributed to the inefficiency of teachers' teaching practices and lessons. The primary focus of science literacy training programs was on developing teachers' understanding of how to create assessments such as tests to quantify students' achievement. The workshops that focused on the PISA framework and PISA-like online testing (Office of the Basic Education Commission, 2022) were carried out for this reason; essentially, they prioritised examinations over science literacy.

Additionally, in light of the swift digital transformations in 21st-century society and the COVID-19 pandemic, science education has strayed from onsite teaching and learning (Annetta & Shymansky, 2006; Dhawan, 2020). Distance education has in numerous ways replaced traditional onsite schooling for student learning, and teachers have received training to facilitate distance learning on digital platforms. These training programs taught participants how to effectively teach online courses and enact pedagogical change (Izhar et al., 2021). Further, teacher trainers had previously established programs aimed at enhancing teachers' PD; however, they did not sufficiently inform teachers about the disadvantages of employing science lesson plans that solely emphasised student listening and writing skills. Teachers were subsequently assigned passive roles in teaching practices (Kaptan & Timurlenk, 2012), and they also were required to integrate digital technology into their science lessons. Furthermore, teacher development faced obstacles due to insufficient access to teaching and learning resources, time limitations, and a lack of experience in science subjects (Pan, 2017).

A challenge of bringing about new change in teacher PD for increased scientific literacy and to deal with global issues is the reorientation of teachers' teaching practices from the existing rigid methods (McFarlane, 2013). Teacher perceptions of science literacy are somewhat ambiguous. While teachers view science learning as the result 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 consider the social and global contexts of science literacy (Budiman et al., 2021). Therefore, teachers lacking sufficient knowledge in science and pedagogy are unable to fulfil their responsibilities when teaching science literacy. It is crucial to enhance teachers' science literacy and pedagogy to encourage students to act in response to global issues (McFarlane, 2013).

2. Research Objective and Questions

This study's objective is to use a new PD program delivered via digital platforms to promote teacher planning for effective science literacy lessons. The following questions are used to guide this study:

- How do teachers view the use of science literacy for their lesson plans, prior to the PD program?
- What do teachers change in the science literacy lessons during the PD program?
- Which circumstances promote teachers' learning in the PD program?

3. Literature Review and Framework

PD refers to a process of teacher learning to enhance experience, knowledge, skills, and judgement, with the aim of systematically examining their teaching practices (Loucks-Horsley et al., 2010; Qablan, 2016). Teacher PD stems from both formal experiences, such as studying in university, attending workshops and professional meetings, as well as informal experiences, including reading professional publications, watching documentaries, and consuming digital media related to their academic discipline (AbdulRab, 2023; Fransson & Norman, 2021). PD requires an understanding of how to learn, how to put theory into practice to enhance student achievement, and how to contribute to professional communities (Farnsworth et al., 2016).

The development of PD programs for teachers is grounded in various theories of student and teacher learning (AbdulRab, 2023). The adult learning theory developed by Malcolm Knowles is recognised as a valuable framework to guide successful teacher PD programs (Fantacone et al., 2024). The theory emphasises the distinct characteristics and requirements of adult learners and highlights the significance of self-directed learning, its relevance to real-life experiences, and the role of problem-solving in adult education. PD for teachers constitutes a form of adult education that prioritises addressing the diverse needs of educators in relation to their varying learning and teaching contexts (Knowles et al., 2020). The individual teacher has access to rich information, resources, and knowledge from other teachers within their teaching community. Engagement in teaching-related activities and discussions, collaboration on innovative practice improvements, and feedback from experienced professionals constitute valuable learning opportunities for teachers (Gregson & Sturko, 2007). A teacher PD program includes various activities such as formal courses, seminars, conferences, workshops, online training, mentoring, and supervision. Additionally, it encompasses informal learning among staff through reflection, collaborative problem-solving, networking, and shared expertise and experience. The benefits of PD, however, depend on the quality of the programs, feedback, and follow-up support (OECD, 2019).

Pedagogical content knowledge (PCK), as introduced by Shulman (1986), refers to teachers’ comprehension of how to effectively teach subjects with an approach that students will respond to. PCK includes the comprehension of subject matter and content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, student knowledge, knowledge of goals, purposes, and values, as well as teacher understanding of educational contexts, settings, and governance. PCK comprehension can aid teachers when making decisions in the classroom (Musikul, 2007; Shulman, 1987). However, Carlson et al. (2019), who developed the Refined Consensus Model (RCM) of PCK, argue that PCK can be divided into three levels: collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). First, 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, cPCK, which can range from science discipline knowledge to more specific-topic knowledge, is often found in books, academic/research articles and is the subject of discussions by teachers and researchers at conferences. Second, pPCK is a contextualized area of knowledge acquired when a science teacher gains direct teaching experience, from various students and discussions with colleagues, and from university educators and scientists. Here, pPCK serves as a set of knowledge bases for teachers to draw upon when planning, teaching, or reflecting on a science lesson. Finally, pPCK transforms into ePCK when a teacher integrates pPCK into their teaching practices for a particular student group and learning objective. This occurs through multiple cycles of planning, teaching, and reflecting on lessons. When teachers continuously modify each lesson plan in response to students' reactions or unplanned situations, they are empowered to succeed in ePCK.

Science literacy is broadly defined as understanding science and its applications to society. Literature has continuously redefined this concept based on the natural world and society (Asiyah et al., 2024; Choi et al., 2011; Hanfstingl et al., 2023; OECD, 2023; Roberts & Bybee, 2014). In Southeast Asian countries, such as Thailand (Office of the Education Council, 2017) and the Philippines (Asiyah et al., 2024), the policymakers and science educators pay attention to developing students' achievement under the definition of science literacy based on the framework provided in the PISA (OECD, 2017). Science literacy is a student's ability to understand and engage in critical discussion about issues of science and technology in society, and it encompasses three competencies: explaining natural phenomena, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically (OECD, 2017, 2023). Therefore, to enable students to practice science literacy, it is crucial to plan a science lesson that prioritises 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 the application of this knowledge in the fields of life science, health, earth science, and environmental science. The second focuses on scientific processes, where 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 the classroom or laboratory setting. This allows students to understand interactions between science, society, and technology (MacKenzie et al., 2023; Utami et al., 2016).

This present study relies on the adult learning theory devised by Knowles et al. (2020) and the refined consensus model of pedagogical content knowledge from Carlson et al. (2019). These concepts serve as the research framework for designing and organising a new PD program for science literacy teaching within the PISA framework (OECD, 2017, 2023).

4. Methodology

The researchers employed the qualitative case study approach for two reasons. First, the researchers aimed to gain an in-depth understanding of the actions of science teachers during their participation in a specific PD program for science literacy. Second, they wished to examine the ways in which teachers digitally interacted with or related to the program (Lichtman, 2023).

4.1 Population, Samples, and Sampling Technique

Participants included ten teachers from public schools in the lower northern educational area of Thailand. They were selected by a non-probability purposeful sampling technique that was based on the following eligibility criteria:

- an educational background in science education, such as the Bachelor of Science (B.Sc.) or the Bachelor of Education (B.Ed.) in science/science teaching;
- at least five years of experience in science teaching;
- able to communicate via digital platforms, such as Zoom, Facebook, and/or Line;
- permission received from their school principal to participate in this study and willing to sign an informed consent as a volunteer.

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. The codes were used throughout the study to guarantee their anonymity.

Table 1: Participant teachers

Teacher code	Age	Gender	Educational background	Teaching experience (Years)
T01	28	Female	B.Ed. (Physics)	5
T02	29	Male	B.Ed. (Physics)	6
T03	30	Female	B.Ed. (Physics)	6
T04	30	Female	B.Ed. (Physics)	6
T05	32	Female	B.Ed. (General science)	8
T06	32	Male	B.Ed. (General science)	8
T07	38	Female	B.Ed. (Secondary education)	13
T08	41	Female	B.Sc. (Biology)	16
T09	43	Female	B.Sc. (Biology)	16
T10	46	Female	B.Sc. (Biology)	19

4.2 Teacher Professional Development Program

The teacher PD program was conducted by the researchers. It consisted of four main phases: 1) knowledge about science literacy and its assessment based on the PISA framework; 2) knowledge of pedagogy for science literacy and the relevant curriculum; 3) integration of science literacy into a science lesson; and 4) practice on the improvement of science lessons. During the first and second phases, the researchers conducted lectures, sparked discussions, and provided examples to the participants. In the third phase, the participants joined a group discussion and had chances to analyse and link science literacy to science content standards based on the existing curriculum and explore pedagogy for their lesson plans at the junior high school level. In the fourth phase, the participants individually improved their lesson plans three times. Firstly, they independently developed the lessons using a lesson template from the PD program and the skills they learned from the previous three phases. 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 apply 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 on weekends. The PD program was conducted over three-hour Zoom meetings across a total of six days. All meetings were recorded into 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 science curriculum, and lesson templates, as well as the improved lesson plans created by all participants. This sharing tank was created to support participants who wished 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 Instruments

This study used interviews and lesson plans to collect data through the Zoom platform. A focus group interview was implemented to reveal the participants' knowledge, specifically their prior teaching experience related to science literacy. This interview provided opportunities for the participants to interact with each other, stimulate each other's thinking, and develop positive relationships between all involved in the process. Through their interactions with others, the participants responded to the interview questions in their own words and generated examples and ideas that might not have appeared in a structured interview or a questionnaire (Lichtman, 2023). In this study, the first author, serving as the moderator, conducted and recorded a one-hour focus group interview on Zoom with ten participants using guided questions (Appendix 1) grounded in the pedagogical content knowledge framework.

During the PD program, this study used lesson plans as documentary materials to represent the participants' knowledge and learning tasks (Chandler-Olcott & Dotger, 2023; Jacobs et al., 2008; Unal-Coban, 2022). The lesson documents provided data that could compare and triangulate emerging findings in conjunction with interviews or observation (Merriam & Tisdell, 2016). The researchers assigned a lesson template with guided topics (Appendix 2), enabling the participants to explicitly illustrate their knowledge. In the fourth phase of the PD program, each participant individually created a lesson plan to teach energy and/or environmental concepts integrated with science literacy to junior high school students in Grades 7-9. Following this, they received feedback and improved the plan accordingly.

Individual interviews were conducted with a semi-structured method, which included the use of guided questions (Appendix 3). Findings from the individual interview analyses would be used as follow-up data for comparison with the findings from the lesson plans (Merriam & Tisdell, 2016) and to identify the circumstances that facilitated the participants' learning in the PD program. The interview schedules were organised after the fourth phase of the PD program. Each participant was invited to a 45–60-minute Zoom meeting, which was recorded and saved in the form of a video clip. Before the instrument was implemented, the guided interview questions and lesson plan topics were reviewed by external university peers. Three science educators recommended that the researchers used simple words rather than academic terminology in the guided questions and provided examples and explanations for each lesson plan topic to enhance participants' understanding.

4.4 Data Analysis and Trustworthiness

The researchers employed a conventional content analysis to clarify the meaning of the participants' statements and actions. The researchers also utilised triangulation techniques to verify and ensure the consistency of the data, thereby establishing the trustworthiness of the research findings (Lichtman, 2023; Merriam & Tisdell, 2016; Patton, 2015). One recorded video clip from the focus-group interview data and ten sets of individual interview data were transcribed verbatim to generate manuscripts for data interpretation. Next, the manuscripts were coded, categorised, and meaningful concepts or themes were extrapolated. Additionally, thirty lesson plans (three per teacher) were analysed directly from the texts and contents associated with each topic. The two authors independently analysed the focus group manuscript as part of the investigator triangulation technique, after which they compared their results. In cases of conflict, the authors would review the recorded video clips for reinterpretation and to reach a final decision. Data comparison between the lesson plans and individual interviews was conducted through the method triangulation technique. The aim of this was to clarify changes in lesson planning and the circumstances that supported teachers' learning within the PD program.

5. Findings

The data analysis of this study offered the following results:

5.1 Teachers' Prior Knowledge about Science Literacy

The analysis of the focus group interview indicated that ten teachers—each with a minimum of five years of teaching experience, a background in science education, and a bachelor's degree in education (T01-T07) or science (T08-T10)—understood the concept of science literacy. Scientific literacy is considered to be the capacity of students to apply scientific knowledge and process skills to address problems encountered in their everyday lives. It also encompasses the ability to evaluate, plan, and determine the most suitable solution to social issues.

The interview data provided below illustrates teachers' comprehension of science literacy:

> *"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 science 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)

Moreover, the teachers recognised that promoting science literacy requires the incorporation of active learning activities that connect to students' life experiences and align with the science learning indicators outlined in the science curriculum. The subsequent interview data exemplified teachers' perspectives on teaching science literacy:

> *"teaching for students' science literacy relies on the activities teachers use. These must be active learning activities, not passive ones."* (T04)
>
> *"teaching science literacy needs linking between situations from children's daily life and context, and the indicators."* (T07)
>
> *"the indicators inform us what they need…such as identifying a problem, knowledge inquiring… I think that there is enough information for teaching science literacy."* (T10)

5.2 Disconnection between Knowledge and Lesson Planning

Although ten teachers possessed prior knowledge of science literacy and updated this knowledge during the first three phases of the PD program, they encountered difficulties in integrating it into their lesson planning. Analysis of the lesson plans revealed that two teachers, T02 and T05, continued to employ a teacher-centred approach in their lesson plans, which focused on the memorisation of scientific concepts. The remaining eight teachers intended to present scientific concepts using a narrative-based approach. These teachers placed an emphasis on utilising online news or media reports to promote students' reading, writing, and communication skills with scientific vocabulary. However, they did not consistently connect these activities to the inquiry process, scientific competencies, and relevant social or global issues. For instance, T02 employed two YouTube video clips to explain the definitions of renewable energy, various energy types, and the origins of fossil fuels, while concurrently facilitating an interactive question and answer session. Additionally, T02 intended to guide students in constructing a model that represented the general production of fossil fuel energy and its effects, as demonstrated in the video clips, in accordance with the teacher's requirements. Within T02's the first lesson plan, 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)

5.3 Ways to Connect/Rechange for Science Literacy Lessons

The data analysis of lesson plans and individual interviews revealed that providing feedback in the fourth phase of the PD program enhanced teachers' ability to improve lessons through the incorporation of science literacy. Teachers achieved this by expanding lesson plans to include scientific contexts, competencies of science literacy, and student-centred approaches. Firstly, all teachers could demonstrate the ability to identify both global and local contexts that relate to scientific concepts and the science curriculum. They devised their lesson plans to encourage students to identify problems within an energy or environmental issue related to their local contexts by assigning students to seek a scientific method for exploring, interpreting, evaluating, and drawing conclusions. This is despite the fact that they had previously relied on less relevant news or events through a narrative-based approach to launch laboratory studies without a convincing rationale or scientific variables.

For example, T08 previously promoted students' engagement in reading a lab direction by 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 the students' 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 final goal was aimed at helping students explore scientific debates about the optimal resolution for the environmental issue. As part of T08's the final lesson plan, 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 successfully implemented student-centred 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 scientifically interpret data and evidence. 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, while T09's activity focused on repurposing plastic waste to create a household item.

Up to this point, the teachers illustrated their ability to improve science literacy lessons during the PD program. The individual interview data conclusively validated and demonstrated that the researchers' feedback shaped and improved the teachers' lesson planning. The interview data presented below is proof of this:

> *"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)

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

5.4 Circumstances Facilitating Learning in the Professional Development Program

The data analysis of individual interviews and lesson plans highlighted two critical components that significantly facilitated the teachers' improvement in designing lesson plans. First, the research's Facebook group was adaptively used as a sharing tank within which 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 science literacy, teaching approaches, learning resources, and ideas discussed during meetings, as well as access feedback for self-study. Teachers were able to observe their peers' adept lesson plan ideas, which served as valuable inspiration for achieving their own lesson plan goals. This was especially beneficial for T02, who did not have much expertise in teaching science literacy. They 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 Facebook group, 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' awareness of their own knowledge but also contributed to their PD. For instance, T02 had previously planned a lesson to teach students about energy concepts, which involved creating a model with YouTube clips for narrative purposes. However, when he realised that he needed to demonstrate the lesson to community science teachers, he returned to the Facebook group, used it as a source of guidance, and amended his lesson plan to incorporate more active learning sections. 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 summarise the data by creating a model. On this, he noted that:

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

6. Discussions

This study examines the important impacts of a PD program that utilises digital resources and blends theory with practice to enhance teachers' knowledge and experience in teaching science literacy. The program includes theory-focused activities, such as lectures, discussions, and integration, while also incorporating practice-oriented activities, such as lesson planning and improvements. The data analysis indicates that a majority of teachers are now successfully linking their knowledge to develop science literacy lessons through feedback from the researchers, the digital self-directed learning resources, and community workshops for practical applications.

The first finding of this study supports the views by Carlson et al. (2019) that transforming teachers' pedagogical content knowledge in the classroom depends on the level of practice. The knowledge received from other teachers or the wider community cannot be implemented into teaching practices without actions taken to re-plan, re-teach, and re-reflect on lessons. In this study, the teachers who have science education backgrounds and at least of five-year experience in science teaching appear to have prior knowledge about teaching for science literacy through the framework of the PISA (OECD, 2017). Additionally, they have the chance to refresh their knowledge based on the PISA framework that has been incorporated into the PD program; however, they are unable to fully create effective lesson plans. Their ineffective lessons frequently involve the use of passive learning activities, such as the memorisation of scientific concepts or a teacher-centred approach. Consequently, the knowledge acquired from prior experiences and formal training during the three phases of the PD program is considered their public knowledge, or what Carlson et al. (2019) refer to as collective pedagogical content knowledge (cPCK). Teacher PD programs that primarily focus on theoretical lectures and emphasise knowledge renewal, as well as passive teacher roles, do not facilitate the application of contextual pedagogical content knowledge in practice, thus impeding the development of effective lessons (Carlson et al., 2019; Faikhamta et al., 2018; Kaptan & Timurlenk, 2012).

This study supports the findings of Bom et al. (2019) and Hanfstingl et al. (2023) which reveal that giving teachers feedback on their lesson plans improves their understanding and ability to identify both global and local contexts that have connections to scientific concepts, as well as their ability to include a range of scientific competencies in the lessons. With positive and productive feedback by the researchers, who are university specialists, teachers trust and place high regard on the suggestions by using them to reflect on the lesson plans (Hudson, 2014; Kleinknecht & Gröschner, 2016). Furthermore, the PD program's three cycles of feedback and the self-reflection elements during the practice phase of lesson improvement allow the teacher to first transform cPCK into the notion of Carlson et al. (2019) of personal pedagogical content knowledge (pPCK) and subsequently achieve enacted pedagogical content knowledge (ePCK) level. The teachers can modify their own lessons to accommodate unplanned situations, i.e., the workshop for the science teacher community.

This study also supports the survey findings of Poonputta and Nuangchalerm (2024) which reveal that teacher development programs in the twenty-first century need to encourage successful teachers to share their methods with others and establish varied online learning communities for knowledge exchange. In this study, the provision of online learning resources, specifically the Facebook group known as the Sharing Tank within the PD program, facilitated the distribution of improved lesson plans with feedback. This approach helps teachers with limited time and limited experience in teaching science literacy to advance their self-directed learning by viewing and criticising their peers' lesson plans: it makes clearer the own issues with their lessons plans and the feedback they have received (Knowles et al., 2020). Mavuso et al. (2022) additionally support the belief that teacher PD programs cannot completely promote the development of lesson planning without effective online learning resource support.

Furthermore, the establishment of a community workshop focused on practical applications serves as a progressive goal for teachers in the PD program, significantly encouraging them to further develop their lesson plans in a clearer and more effective manner (Farnsworth et al., 2016). To achieve the workshop's objectives, teachers engage in developing effective lesson plans to share their expertise and experiences beyond the PD program. The community workshop empowers teachers to engage with the PD program and their school community, thereby positioning them as authorities in teaching science literacy. Consequently, they will acknowledge the importance of incorporating PD experience into their classroom teaching practices to sustain their community membership (Barr & Askell-Williams, 2020).

7. Conclusions and Implications

This research implemented a teacher PD program via the Zoom platform for ten science teachers from ten public schools in the northern educational region of Thailand. The PD program comprised four phases: 1) Knowledge of science literacy and its assessment according to the PISA framework; 2) Knowledge of pedagogical approaches for science literacy and the curriculum; 3) Integration of science literacy within a science lesson; and 4) Practice with enhancing science lesson effectiveness. As results, the teachers previously viewed science literacy as aligned with the PISA framework and improved their learning and practical experience in lesson planning for science literacy. This was accomplished via feedback, a knowledge-sharing platform, and a community workshop in which experiences were exchanged among teachers and school communities. To effectively implement the PD program, researchers must 1) cultivate positive relationships with teachers prior to and throughout the PD activities to foster trust and confidence in the feedback; 2) offer online learning resources to facilitate teachers' self-directed study following PD meetings; and 3) design an unexpected situation to prompt teachers to enhance their specific knowledge levels that influence their practices in teaching science literacy. Finally, the creation of a new PD program for specific purposes should integrate both theoretical knowledge updating and practical cycles to ensure effective teacher development and sustainability. This pertains to the learning outcomes in science literacy for students.

8. Limitations

This study employs a qualitative research paradigm that does not aim to generalise or validate data collection instruments. This study reinforces the findings by augmenting the trustworthiness of the data analysis method, particularly by triangulation. This study proposes the utilisation of reflective journals to collect information from teachers that may not be captured in interview questions, together with classroom observations to determine and sustain teaching approaches that promote students' progress in science literacy within authentic school environments.

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Appendix 1

Guided questions of the focus group interview:
1) What is science literacy?
2) How have Thai students performed in the Program for International Student Assessment (PISA)'s science literacy assessment?
3) In the classroom, what evidence or performance confirms the science literacy of your students?
4) How do you teach science literacy in the classroom?
5) What are the factors that influence the teaching of science literacy?

Appendix 2

Guided topics in the lesson template:
1) Title and time for teaching.
2) Relevant science learning indicators/standards/curriculum
3) Students' competencies in science literacy (Based on the Program for International Student Assessment (PISA)'s framework)
4) Teaching and learning objectives
5) Science concepts
6) Scientific issues and information in global/social contexts
7) Teaching models/approaches
8) Student learning activities
9) Student learning materials and resources
10) Student learning assessment

Appendix 3

Guided questions in the individual interview:
1) Could you explain your experience of participating in the professional development (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 science literacy in a classroom, and could you provide examples?
5) What additional information would you like to share about the PD program?