Kasetsart Journal of Social Sciences 44 (2023) 489–496

Kasetsart Journal of Social Sciences

journal homepage: http://kjss.kasetsart.org

The development of a professional development model focusing on outdoor learning resources to enhance in-service teachers' STEM literacy

Sasithep Pitiporntapin[a,*], Oraphan Butkatanyoo[b], Chatsiri Piyapimonsit[c], Thananun Thanarachataphoom[c], Sareeya Chotitham[c], Usanee Lalitpasan[c]

[a] *Division of Science Education, Department of Education, Faculty of Education, Kasetsart University, Bangkok 10900, Thailand*
[b] *Division of Early Childhood Education, Department of Education, Faculty of Education, Kasetsart University, Bangkok 10900, Thailand*
[c] *Division of Research and Evaluation Methodology, Department of Education, Faculty of Education, Kasetsart University, Bangkok 10900, Thailand*

Article Info

Article history:
Received 21 March 2022
Revised 1 August 2022
Accepted 9 August 2022
Available online 21 June 2023

Keywords:
learning resources,
professional development,
STEM literacy

Abstract

This study aimed to (1) identify the need assessment of enhancing teachers' science, technology, engineering, and mathematics (STEM) literacy; (2) develop a professional development (PD) model to enhance teachers' STEM literacy focusing on using outdoor learning resources; and (3) study the effectiveness of a PD model using outdoor learning resources to enhance teachers' STEM literacy. The research participants in this study were 320 teachers who responded to the online questionnaire to identify the need assessment of enhancing teachers' STEM literacy, nine teachers who participated in a focus group interview, 30 teachers who participated in the PD model, and five experts who approved the PD model. For data collection, the researcher employed the teachers' STEM literacy test, the satisfaction survey form, and an evaluation form for experts' approving the model. The researchers used the modified priority needs index ($PNI_{modified}$), means, standard deviations (*SD*), *t*-test dependent, and content analysis. The findings revealed that the top needs to enhance teachers' STEM literacy that most teachers identified was the connection of STEM education with other disciplines ($PNI_{modified}$ = .17 from primary school teachers and $PNI_{modified}$ = .28 from secondary school teachers). For the model, there are five components: principles, objectives, outdoor STEM activities, supported strategies, and evaluation. Finally, the experts approved this model at an excellent level (*M* = 4.62, *SD* = 0.31). Teachers increased their STEM literacy scores after participating according to the PD model, with a significant difference of .01. The findings also showed that teachers' satisfaction with the PD model was at an excellent level.

* Corresponding author.
E-mail address: fedustp@ku.ac.th (S. Pitiporntapin).

https://doi.org/10.34044/j.kjss.2023.44.2.19
2452–3151/© 2023 Kasetsart University.

Introduction

Many countries around the world have become greatly aware of the need for economic reform. In Thailand, "Thailand 4.0" is a new economic model that will help the country to step out of the middle economic income trap. It focuses on all levels of Thai people to promote creativity, new technology innovation, and the availability of effective services (Baxter, 2017). On the other hand, Thai people are lagging in mathematics and science. Consequently, they also innovate less than other countries do. Also, the Programme for International Student Assessment (PISA) score was low compared to other countries in Asia (Fernquest, 2017). Similarly, the Trends in International Mathematics and Science Study (TIMSS) average score of Thai students in mathematics was lower than in most countries. For science, the average score was low and decreased over time (Ross et al., 2012). The results showed a skilled workforce supply inadequacy. Furthermore, there are not many start-ups initiated by university graduates (Habig, 2017).

To cope with this problem, effective education will increase the quality of the workforce. Puncreobutr (2017) noted that the key achievement of economic transformation is educating people to create or innovate the products and services that come with all sustainable development goals. Therefore, science, technology, engineering, and mathematics (STEM) education was implemented in the curriculum at many schools or educational institutions in Thailand, similar to many other countries, to promote students to be innovative thinkers who would create new solutions or inventions (Honey et al., 2014; Office of the Permanent Secretary, Ministry of Education, 2016). This pedagogical approach provides the opportunity for students to solve real-life problems and challenge them to seek alternative solutions by integrating with STEM (Boonruang, 2015; Khwaengmek & Faikhamta, 2023). Also, STEM education is also for everyone to apply to daily life (Blackley & Howell, 2015).

There are education challenges for teachers to prepare STEM teachers to implement STEM education in their classroom and be STEM literate persons who have the knowledge, attitude, and skills to identify questions and problems in daily life, explain the natural and designed world, understand the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design, be aware of how STEM disciplines shape our material, intellectual, and cultural environments, be willing to engage in STEM-related issues and with the ideas, of STEM as a constructive, concerned, and reflective citizen (Bybee 2010). Zollman (2012) pointed out that teachers who have STEM literacy tend to effectively design and teach STEM activities. Therefore, it is important to prepare teachers for STEM literacy. However, teachers cannot link STEM to authentic contexts in daily life, communities, and society. Also, teachers cannot integrate content from different subject areas to design STEM activities in the classroom by themselves (Chamrat et al., 2018; Kaewklom et al., 2018). These findings show that STEM literacy should be developed.

To promote STEM literacy, there are many reports on promoting students' or pre-service teachers' STEM literacy (Jituafua, 2020; Techakosit & Nilsook, 2018). Nonetheless, the literature review showed that teachers' professional development (PD) models can support teachers in STEM literacy. Chamrat et al. (2018) provided a PD model for promoting teachers' STEM literacy with various strategies, such as workshops, professional learning communities (PLCs), knowledge management, and STEM activity design and development. Nevertheless, this study did not provide an opportunity for teachers to connect STEM with the surrounding world that is not available in the classroom. If the teacher can relate outdoor learning with STEM education, it will create something new that is active and can affect changing teachers by increasing their knowledge of STEM-related content, feeling comfortable with learning and teaching STEM content, and effectively using local outdoor spaces for STEM instruction. Their valuable and direct experiences will help them conceptualize and deliver similarly situated, authentic experiences to their students (Adams et al., 2014).

To cope with the aforementioned problems, the researchers intended to design a PD model focusing on using outdoor learning resources to develop teachers' STEM literacy. The implementation of this PD model should result in the development of teaching practices based on STEM education. This research study aimed to: (1) identify the needs assessment of enhancing teachers' STEM literacy; (2) develop a PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy; and (3) study the effectiveness of a PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy.

Literature Review

STEM Literacy

With the rise of STEM in education, the focus is often on STEM literacy (Peterson, 2017). Many educators have proposed components of STEM literacy (Bybee, 2010; Jackson et al., 2014; Peterson, 2017) to consider, such as (1) STEM concepts related to the understanding of concepts related to STEM issues; (2) STEM integration related to the overlapping STEM concepts and other disciplines to solve problems that cannot be solved with a single discipline; (3) STEM practice using skills or process of STEM for design solution or creating innovation; (4) STEM participation in STEM issues to be linked with society, culture, and citizenship; (5) STEM evaluation of the ability to evaluate of using STEM to solving problems in daily life, creating innovation and careers; and (6) STEM awareness which focuses on design and career possibilities related to STEM. Importantly, teachers are the main factor that affects quality STEM teaching, as they must have STEM literacy (Jituafua, 2020). Teachers who have STEM literacy tend to effectively design and teach related activities (Zollman, 2012).

Outdoor Learning Resources for STEM

Providing opportunities to teach using outdoor activities can promote positive teacher development. Jituafua (2020) found that using authentic outdoor activities that focused on real-life contextual situations, community participation combined with a STEM camp, engineering design process tasks, hands-on practices, collaborative work, the application of technology to find solutions, reflection on developed STEM lesson plans, and STEM teaching could promote pre-service teachers' STEM literacy. To support this idea, Vasquez et al. (2013) noted that STEM activities in outdoor environments are important for three reasons: (1) providing an opportunity to connect with the natural environment where learners can pose questions and investigate problems based in real-world contexts, which opens up the chance to explore plants, animals, and natural phenomena that are not available in the classroom; (2) completing activities that are too messy to conduct inside can be performed outside; and (3) promoting learners to use their whole bodies helps them understand the physical properties of objects in new ways.

Professional Development Model

PD is a way to develop teachers' STEM literacy (Chamrat et al., 2018). There are many facets regarding the development of effective PD, such as providing basic knowledge or theory and good examples for application in their own STEM teaching (Avery & Reeve, 2013; Thammaprateep & Chartisathian, 2007), applying knowledge and skills of STEM and other disciplines to solve problems in learning resources (Custer et al., 2007), using engineering design processes to drive activities (Avery & Reeve, 2013; Jituafua, 2020), delivering materials (Burgstahler, 2006), doing hands-on teamwork activities (Jituafua, 2020), authentic tasks, and assessments (Chamrat, et al., 2021; Jackson et al, 2014), following up on the workshop (Loucks-Horsley et al., 2009), and promoting inspiration on teaching according to STEM education (Chamrat et al., 2018; Thammaprateep & Chartisathian, 2007). Also, a good PD model should provide continual reflection and evaluation of working tasks (Gulamhussein, 2013; Guskey, 2000) using various technologies (Haas et al., 2021), collaborative (Thammaprateep & Chartisathian, 2007) feedback (Gottesman, 2000; Loucks-Horsley et al., 2009), and coaching and mentoring support (Loucks-Horsley et al., 2009; Thammaprateep & Chartisathian, 2007).

Methodology

The methodology of this research study was research and development (R&D), which was divided into three phases, as follows:

Phase I: Needs Assessment for Enhancing Teachers' STEM Literacy

The aims of the first phase were: (1) to identify the needs assessment of enhancing teachers' STEM literacy; and (2) to analyze the cause of their needs of enhancing STEM literacy. These data will be used to design the PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy in the second phase. The researchers collected data from 320 teachers who were teaching at a basic educational level (159 teachers teaching at primary level and 161 teachers teaching at secondary level) in any subject area with accidental sampling using online questionnaires via Google form. The content of the questionnaire was divided into three parts: nine items of respondents' background, 15 items of a set of five-scale and dual-response format of the teachers' perceived level of STEM literacy and the expected STEM literacy ability, and one item of interest for participating in the PD program for enhancing teachers' STEM literacy using outdoor learning resources. The item-objective congruence index (IOC) of this questionnaire was 0.80–1.00. The data were analyzed with means, percentages, and SDs, and the orders of importance were prioritized by the modified priority needs index (PNImodified).

For a cause analysis of their need to enhance STEM literacy, the nine teachers were asked to participate in an online focus group interview via Zoom. They teach in many kinds of schools, such as those under the Office of the Basic Commission, the Bangkok Metropolis Administration, the Office of the Private Education Commission, the Department of Local Administration, the National Defense Studies Institute, and the Ministry of Higher Education, Science, Research, and Innovation. The research instrument in this phase was a focus group interview protocol regarding the cause of the teachers' needs in enhancing STEM literacy. Content analysis was employed for the data analysis. First, the researchers read and interpreted the raw data. Then, all data were constructed as categories to capture the relevant characteristics of the content. Finally, coding was validated by a panel of researchers.

Phase II: The development and tryout of the PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy

The goal of this phase is to create a PD model focusing on using outdoor learning resources to improve teachers' STEM literacy. The researchers employed the data from the first phase and from the literature review related to the PD model, outdoor learning resources, and enhancing STEM literacy to synthesize the framework of the PD model, focusing on using outdoor learning resources to enhance teachers' STEM literacy. They purposively asked seven experts (three science educators, one mathematics educator, and three STEM teachers) and conducted focus group interviews related to the model's goals. The first draft of the model was validated by seven experts using the evaluation form. Analysis was performed using descriptive statistics, which consist of the findings from mean and standard deviation (*SD*), and identifying the quality level with the following score criteria: 1.00–1.49 = unsatisfactory, 1.50–2.49 = fair, 2.50–3.49 = moderate, 3.50–4.49 = good, and 4.50–5.00 = excellent. For data from the focus group interview protocol, the researchers employed content analysis to analyze their comments and suggestions. As a result, the experts validated the PD model at an excellent level ($M = 4.71$, $SD = 0.49$). Then, the researchers revised the PD model according to their comments about the appropriation of time in each activity before implementing it with a small group of teachers. The researcher recruited the participants by announcing the PD model via social media and asked teachers who were interested in participating in the PD model to complete a Google form. Finally, in November 2021, 21 teachers from various subject areas were selected by voluntary sampling to participate in the activities according to the developed PD model, and data were used to revise the components of the PD model before implementing it with the target group of teachers.

Phase III: The Effectiveness of the PD Model for Enhancing Teachers' STEM Literacy Using Outdoor Learning Resources and Final Revision of the PD Model

In this phase, the researchers studied the effects of using the developed PD model to enhance teachers' STEM literacy using outdoor learning resources with 30 teachers in December 2021. The teachers in this phase were selected from voluntary sampling via social media, but they were not the same group of teachers from Phase II. On the first day, they were asked to complete the STEM literacy test before and after completing the activities according to the PD model. Its IOC was 0.80–1.00, and the teachers' satisfaction form for the PD model focused on using outdoor learning resources to enhance teachers' STEM literacy. The researchers then analyzed the data from the STEM literacy test by finding mean, *SD*, and a dependent t-test. For the STEM literacy level, the researchers compared teachers' mean scores of STEM literacy before and after participating in the activities with these criteria: (1) below three scores = unsatisfactory; (2) 3–8 = fair; (3) 9–14 = moderate; (4) 15–20 = good; and (5) 21–24 = excellent. Considering each component of STEM literacy, the researchers compared the mean score of each item with the following criteria: (1) 0.00–0.80 = unsatisfactory; (2) 0.81–1.60 = fair; (3) 1.61–2.40 = moderate; (4) 2.41–3.20 = good; and (5) 3.21–4.00 = excellent. For data from teachers' satisfaction form for the PD model focusing on using outdoor learning resources for enhancing teachers' STEM literacy, the researchers analyzed such data by finding means, *SD*, and identified the quality level with these criteria: (1) 1.00–1.49 = unsatisfactory; (2) 1.50–2.49 = fair; (3) 2.50–3.49 = moderate; (4) 3.50–4.49 = good; and (5) 4.50–5.00 = excellent.

After that, the researchers finally revised the PD model to enhance teachers' STEM literacy using outdoor learning resources and asked five experts (two science educators, one mathematics educator, and two STEM expert teachers) to complete the evaluation form to approve the PD model and participate in the focus group interview. The researchers analyzed data from the evaluation form by descriptive statistics, which consist of the findings from mean, and *SD*, and identified the quality level with these criteria: 1.00–1.49 = unsatisfactory, 1.50–2.49 = fair, 2.50–3.49 = moderate, 3.50–4.49 = good, 4.50–5.00 = excellent. For data from the focus group interview protocol, the researchers employed content analysis to analyze their comments and suggestions.

Results and Discussion

According to the aforementioned data analysis, the researchers discuss three main areas to serve the research objectives: (1) a needs assessment to enhance teachers' STEM literacy; (2) the development of a PD model for enhancing teachers' STEM literacy using outdoor learning resources; and (3) the effectiveness of the developed PD model.

The Needs Assessment for Enhancing Teachers' STEM Literacy

The top needs to enhance teachers' STEM literacy that most teachers identified was the connection of STEM education with other disciplines. The level of index from teachers who teach at primary level and secondary level were $PNI_{modified}$ = .17 and $PNI_{modified}$ = .28 respectively. According to the cause analysis of their needs for enhancing STEM literacy, nine teachers were asked to participate in an online focus group interview. They pointed out that the cause of the need to connect STEM education with other disciplines was the policy of support STEM of their school focuses on STEM disciplines, not link to other disciplines such as home economy, agriculture, and social studies. To solve these problems, they need to train their teachers in every subject to have basic knowledge of STEM education, and they need to complete STEM activities together and design activities that apply knowledge and skills from every subject to cope with STEM problems.

The Development of a PD Model Focusing on Using Outdoor Learning Resources to Enhance Teachers' STEM Literacy

The researchers employed the data from the guideline of solving problems guideline regarding connecting STEM education with other disciplines, as well as the literature review about the components of the PD model (Chamrat et al. 2021; Thammaprateep & Chartisathian, 2007). This PD model was approved by the experts at an excellent level (*M* = 4.62, *SD* = 0.31). Finally, the model for enhancing teachers' STEM literacy using outdoor learning resources consists of five components: principles, objectives, outdoor STEM activities, supported strategies, and evaluation (Chamrat et al., 2018; Thammaprateep & Chartisathian, 2007), as shown in Figure 1.

There are seven principles of the PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy, including: (1) using various methods and strategies for promoting teachers' STEM literacy (Loucks-Horsley et al., 2009); (2) offering on-going professional support (Thammaprateep & Chartisathian, 2007); (3) focusing on applying knowledge and skill of STEM and other disciplines to solve problems in learning

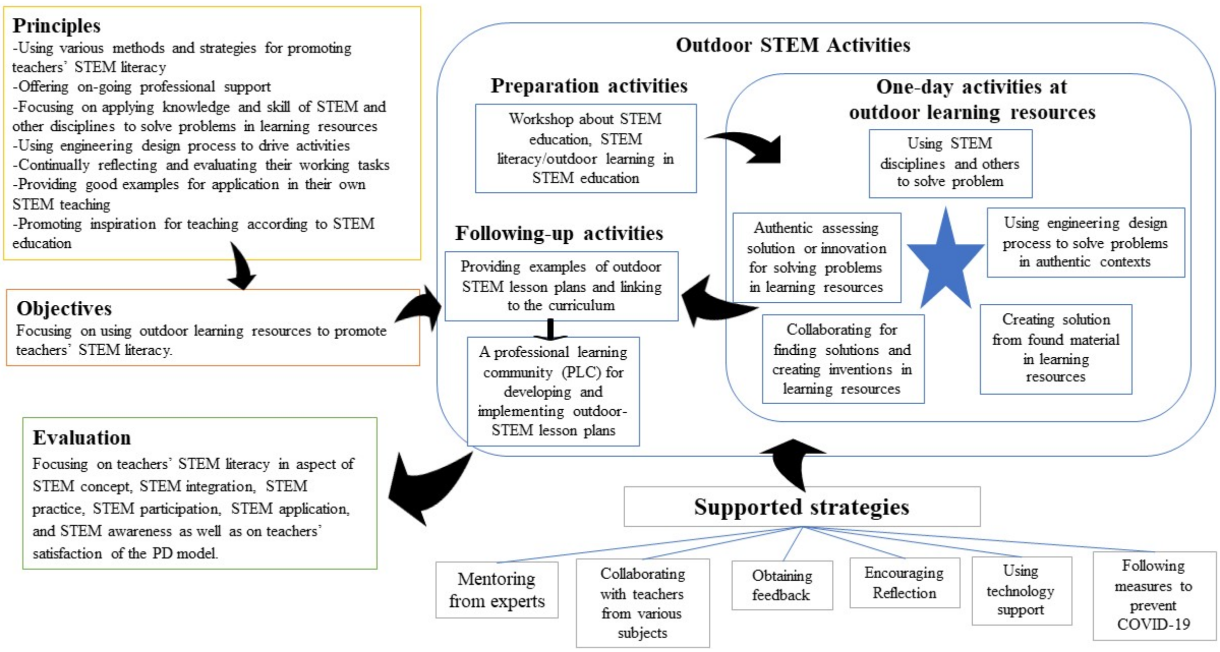

Figure 1 The final version of the PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy

resources (Custer et al., 2007); (4) using engineering design process to drive activities (Avery & Reeve, 2013; Jituafua, 2020); (5) continually reflecting and evaluating their working tasks (Guskey, 2000); (6) providing good examples for application in their own STEM teaching (Avery & Reeve, 2013; Thammaprateep & Chartisathian, 2007); and (7) promoting inspiration for teaching according to STEM education (Chamrat et al., 2018; Thammaprateep & Chartisathian, 2007). To achieve the objectives of the model, the researchers focused on using outdoor learning resources to promote teachers' STEM literacy.

Outdoor STEM activities were completed and comprised of three parts: (1) preparation activities; (2) one-day activities at outdoor learning resources; and (3) follow-up activities to link with curriculum and design learning activities for students. In Part I, teachers were trained to prepare themselves before visiting outdoor learning resources, introducing outdoor STEM education in a two-day online meeting that covered: (1) the definition of STEM education; (2) the importance of STEM education; (3) the role of outdoor learning in STEM education; (4) and STEM literacy. In Part II, the teachers completed outdoor STEM activities in urban gardens, such as using a DIY mango picker, leaf plates, a solar oven for a dried banana challenge, environmentally friendly floating baskets, and a Hello Kitty beverage. These activities were in line with outdoor STEM education, which consists of (1) using STEM disciplines and other disciplines to solve problems; (2) using engineering design processes to solve problems in authentic contexts; (3) creating solutions from found material in learning resources; (4) collaborating for finding solutions and creating inventions in learning resources; and (5) authentic assessing solutions or innovations for solving problems in learning resources (Jackson & Mohr-Schroeder, 2018; Jituafua, 2018; Vasquez et al., 2013). In Part III, the researcher provided examples of outdoor STEM lesson plans and links to the curriculum. The teachers were also asked to join a professional learning community (PLC) for developing and implementing outdoor STEM lesson plans. This part took a three-day online meeting.

There were six strategies supporting the effectiveness of this model: mentoring from expert, collaborating with teachers from various subjects, encouraging reflection, obtaining feedback, mentoring from experts, using technology support (Loucks-Horsley et al., 2009), and following measures to prevent COVID-19.

For the evaluation of the PD model, the whole idea focuses on teachers' STEM literacy and satisfaction with the PD model. The researchers used various instruments, such as the STEM literacy test, teachers' satisfaction form, and focus group interview protocol, to collect data from the teachers in six components of STEM literacy: STEM concept, integration, practice, participation, evaluation, and awareness.

The Effectiveness of the PD Model, Focusing on Using Outdoor Learning Resources to Enhance Teachers' STEM Literacy

Teachers' STEM literacy

The researchers found that the post-test scores of STEM literacy were 15.17 (good level), and had increased when compared with the pre-test score of 12.37 (moderate level), with a significant difference at .01, as shown in Table 1.

When considering each component of STEM literacy, STEM concept and STEM integration, were developed to the higher level. For the rest of the components of STEM literacy (STEM practice, STEM participation, STEM evaluation, and STEM awareness), their levels were the same, as shown in Table 2.

Table 1 Statistics test of the difference between pretest and posttest of STEM literacy

Score	*M*	*SD*	D	*SD*	*t*	*df*	*p*
Pretest	12.37	3.90	2.80	3.50	4.39	29	.00
Posttest	15.17	3.22					

Table 2 The comparison of mean score and level of each STEM literacy component from pretest and posttest

STEM Literacy Components	Pretest		Posttest	
	M	Level	*M*	Level
1. STEM concept	1.83	Moderate	2.90	Good
2. STEM integration	2.77	Good	3.47	Excellent
3. STEM practice	3.40	Excellent	3.50	Excellent
4. STEM participation	1.73	Moderate	1.87	Moderate
5. STEM evaluation	1.77	Moderate	2.40	Moderate
6. STEM awareness	0.87	Fair	1.27	Fair

Teachers' satisfaction of the PD model focusing on using outdoor learning resources to enhance teachers' STEM literacy

The data from the teachers' satisfaction form for the model to enhance teachers' STEM literacy using outdoor learning resources showed their overall satisfaction at an excellent level (M = 4.87, SD = 0.35). They also had overall satisfaction at an excellent level in preparation activities before participating in, while doing, and following up on activities after learning in outdoor learning resources.

Conclusion and Recommendations

The results of the research study revealed the significant outcome that most teachers needed to develop STEM literacy in terms of connecting STEM education to other disciplines. Similarly, Kaewklom et al. (2018) noted that teachers cannot analyze and integrate content from different subject areas to design learning activities in the classroom by themselves. However, the PD model in the current study provides collaboration among teachers in STEM and non-STEM disciplines to solve problems in outdoor learning resources. Consequently, teachers increased their STEM literacy scores after participating in the PD program. In particular, scores on connecting STEM education to other disciplines changed from a good to an excellent level.

Also, teachers' STEM literacy increased, which might be because this PD model focuses on outdoor learning activities. Teachers can investigate problems based on authentic real-world contexts that are not available in the classroom (Vasquez et al., 2013). Similarly, Jituafua (2020) found that using outdoor activities that focused on real-life contextual situations, community participation combined with a STEM camp, engineering design process tasks, hands-on practices, and collaborative work could promote pre-service teachers' STEM literacy.

However, teachers in this study developed STEM literacy-related awareness of STEM in solving problems in daily life, creating innovation, and career less than other aspects. Confirming this finding, Chamrat et al. (2018) also found that teachers who participated in the PD program for promoting STEM literacy did not change much in STEM awareness when compared with other aspects because they needed STEM experts, learning materials, and funding support for designing STEM activities in real-world situations.

Regarding recommendations, teachers who participated in this PD model came from both STEM-related subjects and non-STEM-related subjects, which affected their increased STEM literacy and effectiveness in designing outdoor STEM activities. Thus, teacher PD to enhance STEM literacy should provide opportunities for teachers who teach various subjects in the same school or in other schools to work together to solve problems or create inventions in outdoor learning resources, as well as to design STEM activities for enhancing students' STEM literacy. Also, they develop less awareness of STEM for solving problems in daily life, creating innovation, and careers, so the activities should provide them with more opportunities to work with *STEM* professional's expertise, partner together to solve problems in real-world contexts, support funding, and provide them with learning materials that are easy to find in local areas. The context of the learning resources in this study was only urban farms in Bangkok. In future study, the researchers hope such is done in other contexts, such as rice fields, seas, forests, etc. Thus, the researchers will be able to compare teachers' STEM literacy with other effective models.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgements

The Faculty of Education, Kasetsart University, Thailand, is the sponsor for this research project.

References

Adams, A. E., Miller, B. G., Saul, M., & Pegg, J. (2014). Supporting elementary pre-service teachers teach STEM through place-based teaching and learning experiences. *Electronic Journal of Science Education*, *18*(5), 1–22. https://eric.ed.gov/?id=EJ1188278

Avery, Z. K., & Reeve, E. M. (2013). Developing effective STEM professional development programs. *Journal of Technology Education*, *25*(1), 55–69. https://eric.ed.gov/?id=EJ1020199

Baxter, W. (2017). *Thailand 4.0 and the future of work in the Kingdom*. International Labour Organization. http://tinyurl.com/mkhf5r5

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), 102–112. http://doi.org/10.14221/ajte.2015v40n7.8

Boonruang, S. (2015). *A STEM education: New method of teaching science, technology, engineering and mathematics in an applied approach is being promoted by IPST*. http://www.bangkokpost.com

Burgstahler, S. (2006). *Equal access: Universal design of Instruction*. https://www.washington.edu/doit/equal-access-universal-design-instruction

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35. https://eric.ed.gov/?id=EJ898909

Chamrat, S., Manokarn, M., & Thammaprateep, J. (2018). *The development of STEM literacy for basic education teachers through the learning materials and activities: STEM for life, economy and society*. Research Report of National Research Council of Thailand. [in Thai]

Chamrat, S., Manokarn, M., Intanate, N., Nguenyuang, S., & Bussadee, N. (2021). Development for pre–service teachers' stem literacy through the maker concepts and field experiences in stem education. *Journal of Research Unit on Science, Technology and Environment for Learning*, *12*(1), 15–37. https://doi.org/10.14456/jstel.2021.2

Custer, R. L., Daugherty, J., Zeng, Y., Westrick, M., & Merrill, C. (2007). *Delivering core engineering concepts to secondary level students*. http://ncete.org/flash/pdfs/Delivering_ Core_Concepts_Merrill.pdf

Fernquest, J. (2017). *Educational inequality in Thailand: The challenge*. https://www.bangkokpost.com/learning/advanced/1259777/educational-inequality-in-thailand- the-challenge.

Gottesman, B. (2000). *Peer coaching for educators*. Rowman and Littlefield Publishing.

Gulamhussein, A. (2013). *Teaching the teachers: Effective professional development in an era of high stakes accountability.* http://www.centerforpubliceducation.org

Guskey, T. (2002). Professional development and teacher change. *Teachers and Teaching*, *8*(3), 381–391. https://doi.org/10.1080/135406002100000512

Habig, T. (2017). *Six steps to achieve Thailand 4.0.* https://moderndiplomacy.eu/2017/10/03/six-steps-toachieve-thailand-4-0/

Haas, B., Kreis, Y., & Lavicza, Z. (2021). Integrated STEAM approach in outdoor trails with elementary pre-service teachers. *Educational Technology & Society*, *24*(4), 205–219. https://eric.ed.gov/?id=EJ1318685

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research engineering*. The National Academies Press.

Jackson, C. D., & Mohr-Schroeder, M. J. (2018). Increasing STEM literacy via an informal learning environment. *Journal of STEM Teacher Education*, *53*(1), 4. https://doi.org/10.30707/JSTE53.1Jackson

Jackson, C., Mohr-Schroeder, M. J., & Little, D. L. II. (2014). Using informal learning environments to prepare preservice teachers. *Teacher Education and Practice*, *27*(2–3), 445–463. https://eric.ed.gov/?id=EJ1044969

Jituafua, A. (2020). The development of science student teachers' STEM literacy through the community participation combined with local resource STEM education camp in Surat Thani. *Journal of Education Naresuan University*, *22*(2), 302–316. thaijo.org/index.php/edujournal_nu/article/view/124357. [in Thai]

Kaewklom, W., Khumwong, P., & Dahsah, C. (2018). Current situation, problem and needs for stem learning of primary science teacher. *Veridian E-Journal Silpakorn University*, *11*(3), 2092–2112. https://he02.tci-thaijo.org/index.php/Veridian-E-Journal/article/view/159293 [in Thai]

Khwaengmek, V, & Faikhamta, C. (2023). Perceptions of pre-service science teachers toward teaching STEM from suburb University in Thailand. Kasetsart Journal of Social Sciences, *44*(1), 223–230. https://doi.org/10.34044/j.kjss.2023.44.1.25

Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and mathematics.* The National Institute for Science Education.

Office of the Permanent Secretary, Ministry of Education (2016). *Educational Development Plan of Ministry of Education B.E. 2560–2564 (2017–2021)*. http://www.mua.go.th/users/bpp/main/download/plan/EducationPlan12.pdf

Peterson, B. (2017). Exploring STEM literacy. *Children's Technology and Engineering*, *22*(1), 22–24. https://www.academia.edu/37928637/Exploring_STEM_literacy

Puncreobutr, V. (2017). The policy drive of Thailand 4.0. *St. Theresa Journal of Humanities and Social Sciences*, *3*(1), 91–102. http://www.stic.ac.th/ojs/index.php/sjhs/ article/view/114

Ross, T., Kena, G., Rathbun, A., KewalRamani, A., Zhang, J., Kristapovich, P., & Manning, E. (2012). *Higher education: Gaps in access and persistence study (NCES 2012–046). U.S. Department of Education, National Center for Education Statistics.* Government Printing Office.

Techakosit, S., & Nilsook, P. (2018). The development of STEM literacy using the learning process of scientific imagineering through AR. *International Journal of Emerging Technologies in Learning*, *13*(1), 230–238. https://doi.org/10.3991/ijet.v13i01.7664

Thammaprateep, J., & Chartisathian, C. (2007). STEM collaborative professional development for early childhood teachers. *STOU Education Journal*, *10*(2), 35–53. https://so05.tci-thaijo.org/index.php/edjour_stou/article/view/123454 [in Thai]

Vasquez, J. A., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3–8: Integrating science, technology, engineering, and mathematics*. Heinemann.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics*, *112*(1), 12–19. https://eric.ed.gov/?id=EJ957607