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THE INFLUENCE OF OUTDOOR STEM ACTIVITIES ON STUDENTS' STEM LITERACY: A STUDY OF ELECTIVE SUBJECTS, EXTRACURRICULAR ACTIVITIES, AND STUDENT CLUBS

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ABSTRACT

STEM literacy, the goal of STEM education, has shown potential for enhancement through outdoor activities in informal learning environments. However, the use of these activities in formal school settings to promote students' STEM literacy remains unexplored. This research examined the STEM literacy of students participating in formal school settings through outdoor STEM activities across various contexts: elective subjects, extracurricular activities, and student clubs. The participants in this pre-experimental study included 29 students in elective subjects, 37 students in extracurricular activities, and 48 students in student clubs. The research instrument was a STEM literacy test comprising six open-ended questions to assess six components of STEM literacy: STEM concepts, STEM integration, STEM practice, STEM participation, STEM evaluation, and STEM awareness. Data were collected from students in each group before and after engaging in outdoor STEM activities using the STEM literacy test. Means (M) and standard deviations (SD) were used for data analysis. The findings revealed that students participating in student clubs had a higher mean STEM literacy score after learning (M=15.37, SD=3.71) compared to students in elective courses (M=14.62, SD=3.34) and extracurricular activities (M=10.30, SD=3.46). These results suggest that student clubs are the most effective method for promoting students' STEM literacy. The researchers also provide recommendations for enhancing students' STEM literacy through student clubs.

Keywords: elective subject; extracurricular activities; outdoor STEM activities; STEM literacy; student club

INTRODUCTION

Technology has revolutionized the world, affecting almost every area of the economy, society, and culture. Several countries are making efforts to equip their young people with skill sets that will allow them to be successful in future workforces in the fields of science, technology, engineering, and math (STEM) to compete in the global economy (Marrero et al., 2014; Blackley & Howell, 2015; UNESCO, 2020). However, the inadequacy of a skilled workforce is exacerbated by the lack of interest in STEM disciplines and careers among younger generations, as evidenced by declining results in the PISA scores (Programme for International Student Assessment), particularly in areas that focus on the application of STEM knowledge (Ross, 2012).

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In many countries, STEM education has been considered a teaching approach to encourage students to solve real-life problems, challenge them to seek alternative solutions by integrating STEM, and increase a skilled workforce (Bybee, 2010; Marginson et al., 2013; Aktürk & Demircan, 2017; Acar, 2018; Hobbs et al., 2018; Holmlund et al., 2018; Promboon et al., 2018). Moreover, a goal of STEM education is to emphasize STEM literacy, a core competency for 21st-century workers (Bybee, 2010; Blackley & Howell, 2015). STEM literacy is thus crucial for students who will soon enter the labor market.

In this context, STEM literacy is an important goal of STEM education (Tang & Williams, 2019). STEM literacy is related to STEM concepts, which involve the ability to apply STEM concepts to examine complicated problems and innovate solutions, and STEM integration, which involves the ability to apply other disciplines along with STEM concepts to solve problems that cannot be solved within a single discipline (Washington STEM Study Group, 2011). Problem-solving thus includes STEM practice, which uses skills or processes of STEM to design solutions or create innovations (Chamrat et al., 2018, 2019). Being STEM literate also refers to STEM participation, which is the ability to engage in STEM-related issues and discourse and maintain a positive disposition toward STEM (Wilkins, 2000). Furthermore, it involves STEM evaluation, which is the ability to evaluate the use of STEM to solve problems in daily life, create innovations, and pursue careers, and STEM awareness, which focuses on design and career possibilities related to STEM. Other common aspects of STEM literacy include the ability to critique and comment on information related to STEM for relevance and accuracy (Peterson, 2017) and awareness of the importance of STEM in daily life and society (Honey et al., 2014). These aspects cover personal, societal, and economic needs as well as cognitive, affective, and psychomotor learning domains. These broad conceptualizations of STEM literacy highlight the important role that schools play.

However, Suriyabutr and Williams (2021) pointed out that many students exhibit low engagement in STEM activities and lack interest in STEM disciplines and careers. This may affect their STEM literacy. To address this problem, outdoor contextualized learning is a pedagogical method that can bridge the gap between difficult STEM concepts and the real world, making learning more meaningful (Evans et al., 2014; Halton & Treveton, 2017; Crompton, 2020; Jituafua, 2020; Demir & Kose, 2022), especially using school gardens or playgrounds to promote students' learning (Putnam, 2015; Weiser, 2022). Outdoor STEM activities may provide opportunities to engage with complex problems where the environment serves as a learning resource for pedagogies that support contextualized STEM learning (Denson et al., 2015; Baran et al., 2016; Ayotte-Beaudet et al., 2017; Wiedel-Lubinski, 2019; Christenson, 2022; Willig, 2022). Research in informal learning environments suggests that outdoor STEM activities could promote students' STEM literacy (Cavalcanti, 2017).

In the formal school setting, Son et al. (2017) identified that engaging students in STEM subjects through outdoor adventure education could enhance high school students' interest, engagement, enjoyment, and learning in STEM, and foster career aspirations. Other studies have explored outdoor STEM activities through extracurricular activities (Paulsen & Andrews, 2019) and student clubs (Van Anh et al., 2022). However, these studies did not directly focus on students' STEM literacy.

In the academic year 2021, the researchers developed a professional development (PD) program focusing on using outdoor learning resources to promote STEM literacy (Pitiporntatpin et al., 2023). Thirty teachers participated in this PD program. In the academic year 2022, the researchers followed up with these teachers about their intention to implement outdoor STEM education in their schools. They found three main approaches: elective subjects, extracurricular activities, and student clubs. There was no implementation in core subjects, possibly due to the number of indicators that teachers had to follow (Kaewklom et al., 2018). Therefore, the researchers selected one teacher for each approach—elective subjects, extracurricular activities, and student clubs—and asked them to develop outdoor STEM activities. These activities were validated by the research team before implementation.

The objective of this research was to examine the STEM literacy of students who learned through outdoor STEM activities in a formal school context: elective subjects, extracurricular activities, and student clubs. For elective subjects, these courses foster deeper cognitive engagement by allowing students to explore areas of interest more intensively (Jones et al., 2021). Extracurricular activities emphasize experiential learning and performance, which can help develop practical skills and social competencies (Darling et al., 2005). Student clubs provide a flexible environment for students to pursue their interests autonomously, enhancing their skills and building social connections (Lee et al., 2023). The research questions formulated for this study are as follows: What was the STEM literacy of students who learned through outdoor STEM activities in elective subjects, extracurricular activities, and student clubs?

METHODS

This study used pre-experimental research to examine the STEM literacy of students who learned through outdoor STEM activities in different contexts: elective subjects, extracurricular activities, and student clubs. The researchers asked the teachers who taught outdoor STEM in each context to collect students' STEM literacy data before and after applying outdoor STEM activities.

The participants of this study were three groups of students: 29 students (17 males, 12 females) in elective subjects, 37 students (19 males, 18 females) in extracurricular activities, and 48 students (21 males, 27 females) in a student club. The researchers purposively selected them from students who were studying with teachers who participated in the outdoor STEM PD program, volunteered to provide information, completed the STEM literacy test, and attended at least 80% of the scheduled class hours.

All procedures for data collection performed in this study were reviewed and approved by the Ethical Committee of the university in Bangkok, Thailand. The procedures were as follows:

1. Before implementing outdoor STEM activities, students who participated in elective subjects, extracurricular activities, and student clubs were asked to complete a STEM literacy test. This test was based on a STEM problem scenario related to creating a plant hanging basket: "Aunt Mali is a gardener. Customers regularly visit Aunt Mali's garden to learn how to grow plants. Aunt Mali wants to devise a way to hang plants using the banana rope available in the garden. This method can help people who live in small spaces grow plants in addition to using pots placed on the ground. (If there is no banana rope, use 10 strands of hemp rope or yarn instead and a pair of scissors.)" The test included six open-ended questions to measure the students' STEM concept, STEM integration, STEM practice, STEM participation, STEM evaluation, and STEM awareness.

2. Each teacher conducted outdoor STEM activities according to their plans: 2.1 The teacher implemented outdoor STEM activities in STEM elective subjects for grade 8 (13-14 years old). This subject lasted 14 weeks, with double periods per week (100 min). There were four outdoor STEM activities in this subject: (1) Glider at the playground, where students built a glider aiming for the furthest distance to send messages and save time walking messages from one side of the playground to the other; (2) Water turbine at the school garden, where students created a small-scale water turbine model to optimize voltage generation; (3) Protective packaging, an activity set on the building's balcony where students devised a cost-effective packaging solution to prevent eggs from breaking when dropped from a tall building; and (4) Cargo vessel, an activity set at the school pool where students constructed a miniature cargo vessel model designed to carry the maximum number of plastic basins, testing this small-scale model in the school's pool area.

2.2. The teacher implemented outdoor STEM activities in extracurricular activities for grade 4 (9-10 years old). These activities lasted 20 weeks, with students engaging in activities 5 days per week, 25 minutes per session, totaling 125 minutes per week. There were three outdoor STEM activities in these extracurricular sessions: (1) DIY roller coaster at the playground, where students constructed small-scale model roller coasters using a bike inner tube and marbles to see which could make the marble travel the furthest; (2) Paper airplane launcher at the playground, where students built a launcher to send paper airplanes from one side of the playground to the other; and (3) Leaf plates at the school garden, where students aimed to replace foam plates with plastic plates by finding leaves in the school garden to create leaf plates capable of holding up to 1 kg of food.

2.3. The teacher implemented outdoor STEM activities in a STEM club for grades 7-12 (12-18 years old). Students enrolled in this club based on their interests. This club lasted 20 weeks, with students engaging in activities once per week for 1 hour and 20 minutes. The club featured four outdoor STEM activities: (1) Leaf plates at the school garden, where students created leaf plates capable of holding up to 1 kilogram of food and featuring colorful exteriors; (2) Solar house at the football field, where students developed house models to reduce heat inside during the summer using solar cells as the energy source for a roof drip system, tested on the school football field to identify the most effective design; (3) Mango picker at the school garden, where students created a mango picker using provided materials to bring down mangoes from a height of 2 meters; and (4) Bamboo gun, where students created a gun from bamboo in the school garden that uses paper bullets to expel pigeons from a distance of 2 m.

3. The teachers asked students to complete the STEM literacy test again after finishing the outdoor STEM activities.

4. The researchers analyzed the data from the STEM literacy test by evaluating the students' answers to each item representing each component of STEM literacy. Answers were scored on a 5-level scale: 0 - irrelevant/unclear responses or blank, 1 - answers showing less detail, 2 - answers showing some detail, 3 - answers showing most detail, and 4 - answers showing full detail covering the definition of each STEM literacy aspect. For example, in the STEM concept component, students received a 0 score if their answers were irrelevant/unclear or blank, a 1 score if their answers showed less detail and did not clearly cover four STEM disciplines, a 2 score if their answers explained the ability to apply two STEM disciplines to examine complicated problems and innovate solutions, a 3 score if their answers explained the ability to apply four STEM disciplines but were not entirely clear, and a 4 score if their answers clearly explained the ability to apply four STEM disciplines to examine complicated problems and innovate solutions.

Considering each component of STEM literacy, the researchers compared the mean score of each item using the following criteria: 0.00–0.80 = unsatisfied (U); 0.81–1.60 = fair (F); 1.61–2.40 = moderate (M); 2.41–3.20 = good (G); and 3.21–4.00 = excellent (E). The researchers calculated the mean (M) and standard deviation (SD) from the pretest and posttest scores of students in each group (Kirk, 2013; Montgomery, 2012). Additionally, the researchers compared teachers' mean scores of STEM literacy before and after participating in the activities using these criteria: below 3 = unsatisfied (U); 3–8 = fair (F); 9–14 = moderate (M); 15–20 = good (G); and 21–24 = excellent (Pitiporntapin et al., 2023).

RESULTS AND DISCUSSION

The findings showed that most students who participated in outdoor STEM activities tended to develop all components of STEM more than before engaging in outdoor STEM education. For students who studied in student clubs, the average mean scores after learning were at a good level (Table 1).

Table 1. The Pretest and Posttest Scores of Students Who Learned from the Student Club

STEM Literacy Components	Pretest			Posttest		
	M	SD	Level	M	SD	Level
1. STEM concept	0.54	0.50	U	3.52	0.91	E
2. STEM integration	0.52	0.58	U	3.54	1.00	E
3. STEM practice	0.58	0.49	U	2.79	1.32	G
4. STEM participation	0.31	0.46	U	1.94	1.09	M
5. STEM evaluation	0.19	0.39	U	1.85	0.91	M
6. STEM awareness	0.17	0.37	U	1.71	1.12	M
Total	2.38	1.44	U	15.37	3.71	G

Students who participated in student clubs showed significant development in STEM literacy, particularly in terms of STEM concepts and STEM integration. This improvement may be attributed to the nature of student clubs, which cater to students' interests in STEM and foster creativity in design engineering (Van Anh et al., 2022). Highly motivated students consistently engage in learning, leading to effective learning development (De Loof et al., 2021). Additionally, the diversity among learners in these clubs, with different ages, contributes to effective problem-solving collaboration (Chittum et al., 2017). For students who studied in elective subjects, the average mean scores after learning were also at a good level (Table 2). These students achieved higher scores in STEM practice and STEM concepts, likely due to their interest in outdoor STEM activities and the focus on the engineering design process within this subject. Puchongprawet and Chantraukrit (2022) identified that STEM education emphasizing the engineering design process helps develop STEM skills and practices, though it requires time.

Table 2. The Pretest and Posttest Scores of Students Who Learned from Elective Subject

STEM Literacy Components	Pretest			Posttest		
	M	SD	Level	M	SD	Level
1. STEM concept	2.21	1.00	G	3.10	0.96	G
2. STEM integration	0.76	0.86	U	1.79	1.19	M
3. STEM practice	2.41	0.97	G	3.59	0.77	E
4. STEM participation	0.79	0.61	U	1.93	0.78	M
5. STEM evaluation	1.14	0.68	F	2.24	1.01	M
6. STEM awareness	1.28	0.74	F	1.97	0.93	M
Total	8.59	3.36	M	14.62	3.34	G

In contrast, students who participated in extracurricular activities had average mean scores at a medium level after learning (Table 3). The findings revealed that these students showed the most development in STEM practice compared to other STEM aspects. This may be due to the frequency of learning sessions. However, the limited time per session resulted in lower scores compared to those in student clubs and elective courses. Kaewklom et al.(2018) also found that a main problem when implementing STEM activities in the classroom is insufficient time, which affects the effectiveness of students' learning.

Table 3. The Pretest and Posttest Scores of Students Who Learned from Extracurricular Activities

STEM Literacy Components	Pretest			Posttest		
	M	SD	Level	M	SD	Level
1. STEM concept	1.00	0.46	U	2.30	0.83	M
2. STEM integration	0.68	0.52	F	1.78	0.78	M
3. STEM practice	0.89	0.51	F	2.41	0.91	G
4. STEM participation	0.41	0.49	U	1.30	0.65	F
5. STEM evaluation	0.38	0.48	U	1.27	0.64	F
6. STEM awareness	0.38	0.48	U	1.32	0.66	F
Total	3.73	2.11	F	10.30	3.46	M

When examining students' answers to each component of STEM literacy, the researchers discovered that posttest scores were higher than pretest scores across all groups for STEM concepts. Particularly in the student club, mean scores improved from an unsatisfactory level to an excellent level. Most students effectively integrated and applied STEM concepts to tackle diverse problems, adeptly elucidating how problem-solving is interconnected with each specific STEM discipline. Hammerman et al. (2001) identified that learning outside the classroom expands students' learning experiences into the real world, which acts as a laboratory allowing them to learn about nature and their surrounding environment.

Regarding STEM integration, students in elective subjects, extracurricular activities, and student clubs also had higher posttest scores compared to pretest scores, with the student club showing the most improvement. Students demonstrated an increased ability to connect STEM education with concepts from science, mathematics, technology, and engineering, bridging these with other subjects to address problems, such as creating hanging plant baskets. Tuffy (2011) pointed out that outdoor learning naturally integrates various disciplines rather than separating them into distinct subjects like science, mathematics, art, and social studies. Educators can consider connecting students' outdoor learning experiences to curriculum content to make the learning more meaningful.

In the realm of STEM practice, students in elective subjects, extracurricular activities, and student clubs had higher posttest scores compared to pretest scores. Especially in student clubs, their mean score improved from an unsatisfactory level to a good level. For STEM evaluation, students in all groups showed improved posttest scores, with student clubs showing the most notable improvement from unsatisfactory to moderate levels. Students used the engineering design process in creating plant hanging baskets and effectively assessed the results to demonstrate the effectiveness of their solutions. This aligns with Loucks-Horsley's (2013) assertion that effective professional development for teachers should provide hands-on practice and good examples that can be translated into the classroom.

In terms of STEM participation, students in elective subjects, extracurricular activities, and student clubs all showed higher posttest scores. Particularly in the student club, the mean score increased from unsatisfactory to moderate levels. Students increasingly identified their ability to actively engage in applying STEM in connection to society, culture, and informed citizenship. Tsinajinie et al. (2021) found that students engaged in STEM activities through project-based learning outside the classroom actively participated, collaborated with peers, gained direct knowledge and skills from experienced individuals, enjoyed the process, gained self-confidence, and learned meaningfully.

Regarding STEM awareness, students in all groups showed higher posttest scores, with student clubs showing a notable improvement from unsatisfactory to moderate levels. Students demonstrated a better understanding of the role of STEM in everyday life, problem-solving, innovation, and career pursuits. Ludwig et al. (2020) noted that students who learn through outdoor STEM education can direct their learning, take ownership, and see pathways for future careers while recognizing the value of the community and natural environment.

These findings support existing literature suggesting that outdoor STEM activities can enhance students' STEM literacy (Cavalcanti, 2017; Jackson, 2018; Paulsen & Andrews, 2019). Outdoor STEM activities enable students to access and integrate STEM disciplines to solve problems, use engineering design processes in authentic contexts, create solutions from found materials, collaborate, and assess solutions or innovations authentically (Pitiporntatpin et al., 2023). Peterson (2017) highlights that students' STEM literacy can be enhanced both in school and outside the classroom through active learning and application of STEM concepts to analyze complex problems and devise innovative solutions. Educators play a crucial role in facilitating these learning experiences, incorporating activities like engineering design challenges centered on real-world issues.

Students in the student club demonstrated the most development in STEM literacy, especially in integration aspects, likely due to the social connections fostered within the club (Lee et al., 2023). These activities promoted interaction with the outdoor learning environment, integrating various disciplines. Moomaw (2013) also notes that outdoor STEM learning integrates knowledge from multiple disciplines to solve real-life problems effectively, fostering observation, interdisciplinary problem-solving, and innovation.

However, the aspect of STEM awareness showed less development, possibly because teachers primarily used learning resources within the school for outdoor STEM activities. Consequently, students may not have had ample opportunities to understand how their skills and knowledge could be applied in real-world professional settings, hindering their awareness of the relevance and applications of their learning (Cohen et al., 2013). To address this, teachers could use outdoor learning areas both inside and outside the school, fostering connections with the community and careers. Nevertheless, this study underscores the positive impact of outdoor STEM activities in various school contexts, particularly in school gardens and playgrounds (Putnam, 2015; Weiser, 2022), and calls for further exploration of how teachers can use outdoor learning areas outside the school to enhance students' STEM literacy.

CONCLUSION

The findings of this study highlight that students participating in the student club exhibited the most significant development in STEM literacy compared to those in elective subjects and other extracurricular activities. To foster and sustain growth in students' STEM literacy, we recommend that teachers incorporate outdoor STEM activities both inside and outside school, particularly within student clubs.

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