Integrating Outdoor STEM Activities Into an Elective Course to Promote Students' STEM Literacy

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Abstract

Outdoor STEM is an instructional approach that connects the teaching of STEM subjects to the natural environmental context. This study aims to enhance students' STEM literacy through outdoor STEM activities within the elective course, and to evaluate students' satisfaction with Outdoor STEM. This research employs a quasi-experimental design involving 29 Thai eighth-grade students enrolled in a secondary school. The primary instruments utilized in this study are the STEM literacy test, which consists of seven open-ended questions, and 'The Student Satisfaction Survey Form,' which uses a 13-item Likert scale. The findings indicate that the mean post-study score for STEM literacy (M = 14.62, SD = 3.40) significantly exceeds the pre-study score (M = 8.59, SD = 3.42). Furthermore, students exhibited growth in STEM literacy across all six components and expressed a high level of overall satisfaction with their learning experience. Consequently, it is recommended that outdoor STEM activities be integrated into the school curriculum as elective courses, as they effectively promote the development of STEM literacy and foster student interest in learning STEM subjects.

Introduction

The primary goal of STEM education is to develop students' STEM literacy, which encompasses enhancing their knowledge, attitudes, and skills in identifying questions and problems encountered in daily life. It also involves the ability to explain natural phenomena, draw conclusions based on empirical evidence, understand the various aspects of science within STEM, and recognize the significance of STEM to society (Bybee, 2013). STEM literacy is recognized as a crucial objective for student development across many countries. In alignment with this global trend, the Thai government is actively promoting STEM literacy. This initiative is consistent with the overarching goals of Thailand's 20-Year National Strategic Plan (2017-2036), which aims to foster individual development by equipping citizens with knowledge and skills in STEM as a foundation for supporting research, technology, and innovations that meet increasing consumer demands (Ministry of Higher Education, Science, Research and Innovation, 2017). However, there remains a shortage of qualified STEM personnel, as evidenced by the PISA (Programme for International Student Assessment) scores, particularly in the application of STEM knowledge, which has shown a downward trend in many countries (Ross, 2012). Consequently, it is essential to inspire all students to develop an interest in STEM and to become STEM-literate (PCAST, 2010).

STEM Literacy

STEM literacy is a term that encapsulates the primary goals of STEM education, including understanding concepts, skills, procedures, and the various qualifications of individuals associated with STEM (Bybee, 2013). STEM literacy can be cultivated through learning experiences that immerse learners in real-world contexts, thereby promoting teamwork through the effective use of technology (Chamrat, M. Intanate, Nguenyuang, & Bussadee, 2021). When considering the important characteristics of STEM literacy, Chamrat et al. (2021) identified five important characteristics that are consistent with each other: 1) STEM conceptualization, 2) STEM practice, 3) STEM application, 4) STEM attitudes, and 5) STEM-related contexts. Furthermore, an analysis of each component revealed consistency with the findings of Pitiporntapin et al. (2023). Additionally, Pitiporntapin et al. (2023) proposed an extra evaluative component and emphasized the significance of integration within these characteristics. In conclusion, this research delineates the characteristics of STEM literacy as specified below:

- STEM concept: equipping with the knowledge and understanding of content and the usage of process skills in science, mathematics, technology, and engineering, which can be integrated to solve various problems
- STEM integration: connecting STEM with concepts of science, mathematics, technology, and engineering, as well as other disciplines
- STEM practice: making decisions with precise reasoning that can express STEM concepts, principles, and processes, along with using technological tools to design guidelines or to work towards solving problems and creating new items
- STEM participation: participating in the application of science, mathematics, technology, and engineering in connection with society and culture, as well as citizenship
- STEM Evaluation: evaluating to reflect the results from problem-solving using science, mathematics, technology, and engineering
- STEM Awareness: being aware of the role of STEM in daily lives in solving problems, creating innovations, and pursuing careers

However, applying STEM concepts in the classroom to develop STEM literacy encounters challenges, particularly regarding students' lack of perseverance and interest in STEM. A study by the American Society for Quality (ASQ) found that 85 percent of students in the United States are not interested in pursuing careers in STEM, which is further reflected in low enrollment rates in STEM subjects (Topal & Korkmaz, 2023). Moreover, when STEM is presented to students abstractly, without reference to real-world problems—such as building a water bottle rocket that fails to connect to a practical context—students struggle to relate STEM to their own life experiences. As a result, they are unable to connect STEM concepts with real-world applications (Roehrig et al., 2021; Haas, Kreis, & Lavicza, 2021). This issue is often linked to teachers' lack of content knowledge and their ability to integrate various scientific disciplines, particularly engineering, into their instructional practices (Crompton, 2020; Blackley & Howell, 2015; PCAST, 2010). These issues contribute to the development of students' STEM literacy not reaching the expected standard. This reflects that students' STEM literacy should inevitably be developed. For this reason, an important teaching method that can help students become intrinsically motivated to learn and connect their learning experiences to the natural world in environments outside the classroom is Outdoor Education (OE)

(Gilbertson, Ewert, Siklander, & Bates, 2022). This approach can be integrated into Outdoor STEM.

Outdoor STEM

Outdoor STEM is an important concept that has gained popularity recently by emphasizing hands-on learning in natural environments to enhance STEM education (Son, Mackenzie, Eitel, & Luvaas, 2017). When considering the key characteristics of STEM, Son et al. (2017) mentioned four key characteristics that are consistent with each other: 1) provide opportunities for students to practice and learn in a real environment, 2) integrate knowledge in STEM subjects, 3) work together as a team to solve problems, and 4) provide students with direct experiences. This relates to Tsinajinie, Kirboyun, and Hong (2020), who stated that outdoor STEM should provide opportunities for students to learn through hands-on methods by collaborating in teams and utilizing technology. This approach offers students direct sensory experiences—such as touching, listening, smelling, and moving—that cannot be replicated in a classroom setting.

However, Pitiporntapin et al. (2023) and Khwaengmek et al. (2020) also emphasize the importance of designing solutions through engineering design process, utilizing materials from natural learning resources, and evaluating solutions based on authentic assessment, adding to the contributions of Son et al. (2017). Both of these aspects are key characteristics of outdoor STEM. Consequently, this research has chosen to focus on five essential characteristics of outdoor STEM as follows:

- Applying engineering design process to solve problems rooted in authentic learning contexts;
- Using STEM knowledge and other disciplines to solve problems found in learning resources;
- Creating solutions and using materials in learning resources;
- Collaborating in finding innovations to solve problems in learning resources; and
- Evaluating approaches or innovations to solve problems based on actual situations in learning resources.

Outdoor STEM helps students apply their knowledge in various contexts and relate school content to real-world problems in a stress-free environment. Additionally, the outdoor setting in which students learn stimulates their interest in both learning and pursuing STEM careers (Hughes & Maaita, 2023; Ludwig, Jablonski, Caldeira, & Moura, 2020; Khwaengmek et al., 2020). Moreover, it encourages participation in adventures and physical activities, allowing students to experience nature firsthand. This enhances their knowledge, skills, and understanding and fosters their appreciation for the environment and various important competencies (Khwaengmek et al., 2020; Son et al., 2017). In other words, these characteristics indicate that learners have enhanced their STEM literacy. This aligns with the findings of Topal and Korkmaz (2023), which suggest that Outdoor STEM increases student interest in STEM careers. Although Outdoor STEM is a concept that effectively connects students to STEM learning by combining outdoor education with STEM, thereby providing real-world context and fostering interdisciplinary connections (Son et al., 2017; Crompton, 2020; Hughes & Maaita, 2023), research focusing on the integration of STEM education and outdoor education that emphasizes nature remains limited (Hughes & Maaita, 2023).

The concept of outdoor STEM education has been presented by academics from various perspectives. For example, Son et al. (2017) discuss integrating STEM education with Outdoor Adventure Education (OAE), which organizes learning in an adventure-style summer camp. This contrasts with Crompton (2020), who proposes integrating STEM education with Contextualized Outdoor Learning, focusing on technology within mathematics courses. Another example is Othman, Iksan, and Yasin (2022), who present a project that addresses problems in contexts outside the classroom. Therefore, outdoor STEM education can be utilized in core courses, elective courses, and extracurricular activities, such as STEM camps. Moreover, unlike elective courses, most research on outdoor STEM teaching focuses on extracurricular activities or STEM camps not integrated into the school curriculum (Topal & Korkmaz, 2023). In this research, the elective course was chosen because STEM in core courses often faces challenges in integrating learning standards and indicators into the curriculum, compounded by issues related to time allocation for organizing learning activities (Kaewklom, Khumwong, & Dahsah, 2018). Consequently, teachers often express dissatisfaction with implementing STEM activities in those courses (Kaewklom et al., 2018). Given this context, we were interested in designing an elective course titled "Fun Thinking…with STEM Activities," a flexible elective course focused on outdoor STEM to enhance students' STEM literacy and assess students' satisfaction with the learning experience based on outdoor STEM activities.

Methodology

Context and participants

The context of this study is related to a professional development (PD) model focusing on outdoor learning resources to enhance in-service teachers' STEM literacy. The first author participated in this PD model, which was developed by the second author (Pitiporntapin et al., 2023), and was also involved in the follow-up process to implement outdoor STEM activities in formal school settings (Pitiporntapin et al., 2024). Ethical approval for this follow-up research involving human subjects was obtained from a university in Bangkok, Thailand (COA65/064).

In this study, the first author served as the teacher of the elective course "Fun Thinking… with STEM Activities," while the second author acted as the teaching advisor. The aim was to enhance students' STEM literacy, in alignment with the school's emphasis on fostering innovative creators. Permission was obtained to use secondary data on the STEM literacy of students participating in outdoor STEM activities as part of the elective course. The study employed a quasi-experimental design involving 29 eighth-grade students (17 male and 12 female), aged 13 to 14, from a secondary school. The participants were selected through purposive sampling, consisting of students enrolled in the elective course. Permission to collect data was granted, and participants were assured of confidentiality. All participants provided fully informed and voluntary consent to participate in the research.

Data collection

The researcher collected data on STEM literacy prior to the outdoor STEM learning intervention by administering the STEM literacy test as a pre-test. Following this, students participated in outdoor STEM activities as outlined in the lesson plans over fifteen-weeks, guided by a single teacher. During this learning process, students were asked to write reflective learning documents. Afterward, they completed a post-test, which included an assessment of satisfaction through the student satisfaction survey form and an informal interview.

The outdoor STEM lesson plans

The researcher reviewed documents and studies related to outdoor STEM and designed lesson plans for the course "Fun Thinking… with STEM Activities," a one-credit elective course that meets twice a week. Subsequently, the lesson plans were evaluated by three experts—two with expertise in STEM education and one specializing in science education—to assess content validity. The Index of Item Objective Congruence (IOC) values ranged from 0.67 to 1.00 and were refined based on the experts' recommendations. In the next step, the lesson plans were tested with eighth-grade students who were not part of the sample group, and adjustments were made to enhance their appropriateness.

The main learning outcome of this course is for students to develop STEM knowledge and the ability to integrate this knowledge to solve problems related to real-world contexts. After revisions by the experts, the activities were categorized into four distinct tasks. In each activity, students will solve problems outside the classroom using the seven-step engineering design process, following the guidelines of the TeachEngineering STEM Curriculum for K-12 (2018). The details of these activities are presented in Table 1.

Table 1. Details of activities in the elective course "Fun and thinking...with STEM activities"

Week	Activity	Task	Materials/Equipment	Learning Resources
1		Pre-test		
2-5		STEM orientation		
6-7	The Glider	A glider designed to achieve the longest duration and greatest distance in flight.	- straws - scissors - papers - tapes	Greenward
8-9	The Turbine Generating Electricity	Water turbines designed to generate electricity with the highest voltage and suitable for installation at a faucet.	Various equipment that students acquire using virtual currency, along with materials sourced from natural learning resources.	Faucets in the canteen
10-11	The Shockproof Packaging	Three pieces of equipment designed to prevent chicken eggs from breaking, tested by dropping the eggs from a specified height within a building.	Various equipment that students acquire using virtual currency, along with materials sourced from natural learning resources.	The balcony up in the school building
12-13	The Cargo Ship	A boat designed to hold the maximum weight while remaining no larger	Various equipment that students acquire using virtual currency, along with materials sourced	The school's pond

Week	Activity	Task	Materials/Equipment	Learning Resources
		than the dimensions of the school's pond.	from natural learning resources.	
14	Summary of the lesson			
15	Post-test			

From the table, during weeks 2-5, students will explore the concept of STEM and the engineering design process through simple STEM activities conducted in the classroom. From weeks 6 to 13, outdoor activities will be integrated into the curriculum to further enhance learning. Students will create tasks using the engineering design process, applying contexts beyond the classroom. For example, students will measure the height of the faucet to inform their turbine design, which aligns with the key characteristics of outdoor STEM, specifically solving problems related to authentic contexts in their learning resources. Following this, students will test their designs in a real-world setting. Additionally, students can choose to utilize natural waste materials, such as leaves, plastic bottles, and rocks, in their projects, which further supports the essential characteristics of outdoor STEM , as shown in Figure 1.

Figure 1 : Students were measuring the distance of a faucet outside of class to gather information for designing a turbine.

The STEM Literacy Test

The STEM literacy test for students is a subjective assessment composed of seven open-ended questions based on given situations, covering all six components of STEM literacy. The researcher evaluated the quality of the test by consulting five external experts: two with expertise in STEM education, two in science education, and one specializing in educational evaluation. The Index of Item Objective Congruence (IOC) value was 1.00. Subsequently, the test was revised based on the experts' suggestions before being administered to the sample. Following this, the researcher conducted a trial of the test, which yielded an internal consistency reliability value of .81.

The Student Satisfaction Survey Form

The student satisfaction survey form is an assessment of satisfaction with elective courses, using a 13-item Likert scale. The quality of the tool was reviewed by three experts: the first expert specializes in STEM education, the second in science education, and the third in educational evaluation. The Index of Item Objective Congruence (IOC) values ranged from 0.67 to 1.00. Subsequently, the survey was revised based on the experts' suggestions before being administered to the sample. Following this, the researcher conducted a trial of the test, which yielded an internal consistency reliability value of .98.

Data Analysis

The STEM literacy data was analyzed using the average scores for each component, categorizing the quality of STEM literacy into five levels: (1) 0.00-0.80 = Unsatisfied (U); (2) 0.81-1.60 = Fair (F); (3) 1.61-2.40 = Moderate (M); (4) 2.41-3.20 = Good (G); and (5) 3.21-4.00 = Excellent (E). The evaluation criteria for each item are as follows: 0 for irrelevant responses or blank answers; 1 for answers showing minimal detail that only partially address the definition of each STEM literacy component; 2 for answers providing moderate detail that adequately cover the definition of each STEM literacy component; 3 for answers demonstrating substantial detail that mostly covers the definition of each STEM literacy component; and 4 for answers presenting precise details that comprehensively cover the definition of each STEM literacy component. For example, in the STEM integration component, students received a score of 0 if their answers reflected no correlation between STEM and other disciplines, 1 if they integrated with only one discipline in an unclear manner, 2 if they clearly integrated with one discipline, 3 if they demonstrated integration with more than one discipline but with some ambiguity, and 4 if they clearly showed integration with multiple disciplines. Additionally, the researcher conducted informal interviews and analyzed students' responses to supplementary learning materials. This analysis was complemented by qualitative data from students' learning reflections, as well as reports from the student satisfaction survey.

Findings

The Students' STEM Literacy

The results of the analysis of the mean STEM literacy scores (n = 29) for six components in the pre-test and post-test, based on the outdoor STEM activities, indicate that the average STEM literacy score after the learning process was higher than before in every component. This information is presented in Table 2.

Table 2: Basic statistics between the STEM literacy scores before and after the study

Time	*M*	*SD*	Level	Quality level (people)				
				U	F	M	G	E
Pre-test	8.59	3.42	F	4	14	10	1	0
Post-test	14.62	3.40	G	0	3	9	17	0

From Table 2, it was observed that all 29 participants had an average score of 14.62 on the post-test (Good level), which is higher than the average score of 8.59 on the pre-test (Fair level). Additionally, there was an increase in the number of students achieving higher scores. The classification of scores for each component is illustrated in Figure 2.

Figure 2 : Comparison of STEM literacy scores by component (Full Score: 4 Points)

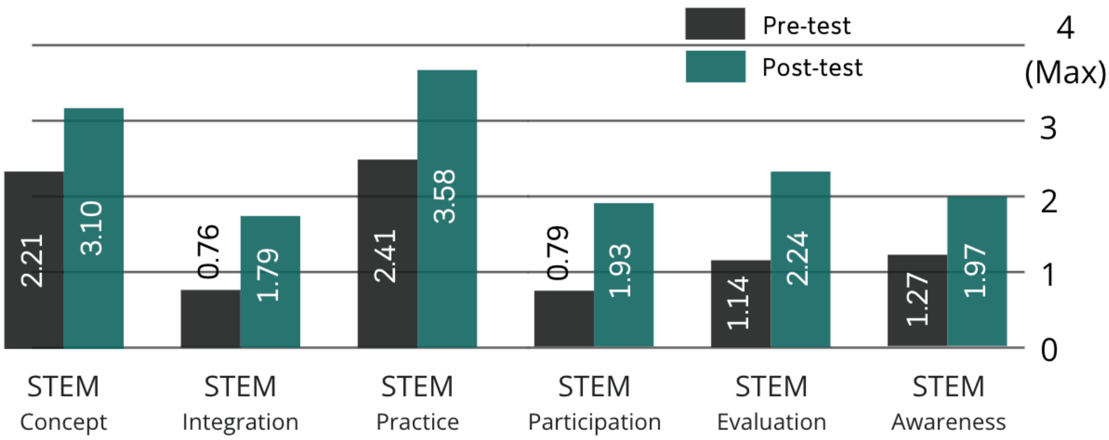

Figure 2 shows that all 29 participants demonstrated an increase in their average scores across every component. The greatest improvement component was STEM participation, which increased by 1.14 points. Conversely, the component that required the most improvement in the pre-test and post-test was STEM integration. However, every component in the post-test reached a moderate or higher level.

When analyzing students' answers for each question, it was evident that their responses regarding each component of STEM literacy had changed. For instance, in the STEM concept component, students' scores increased from M = 2.21 (Fair level) to M = 3.10 (Good level). This improvement reflects students' ability to solve problems using valid and clear knowledge and their understanding of the content, supported by applying STEM process skills across all four disciplines. An example of a student's response on the STEM literacy test in addressing a problem is as follows: *"I was able to solve this problem by integrating sciences, for example, gravity, moment, and air resistance, technology for applying knowledge to make materials for tying knots, engineering for designing plant pot handles and space-saving designs, also with mathematics for calculating the weight of the pot or space."* (Student No. 6)

In the STEM integration component, students' scores increased from M = 0.76 (Unsatisfied level) to M = 1.79 (Moderate level). During the pre-study period, most students recognized that STEM education integrates only the four aspects of disciplines, and some struggled to provide answers. However, in the post-study assessment, several students understood connections to other disciplines, with many referencing "art." An example of a student's response is as follows: *"There is another discipline, namely the art of designing beautiful pieces"* (Student No. 3) Furthermore, some students provided responses that indicated a higher level of understanding, suggesting that more than one discipline can be integrated. For example, they mentioned connections to fields such as agriculture or economics.

In the STEM practice component, students' scores improved from M = 2.41 (Good level) to M = 3.58 (Excellent level). While most students could identify some problems during the pre-study period, they struggled to articulate the detailed steps for solving them. In the post-study period, however, most students could outline the steps required to address the problems. An example of a student's response is as follows: *"Step 1: Design the task with a drawing. Step 2: Find information about the equipment required. Step 3: Assemble the task. Step 4: Test and evaluate the task. Step 5: Modify and improve the task. Step 6: Try it yourself. And step 7: put it into practice"* (Student No. 10)

In the STEM participation component, students' scores increased from *M* = 0.79 (Unsatisfied level) to *M* = 1.93 (Moderate level). During the post-study period, most students expressed that they could engage in problem-solving but still struggled to connect with other participants. An example of a student's response is as follows: *"I will participate because planting trees improves the environment, which will affect me in the future."* (Student No. 8)

In the STEM evaluation component, students' scores improved from *M* = 1.14 (Fair level) to *M* = 2.24 (Moderate level). This change indicates that students could select effective solutions based on testing. However, they still struggled to identify more than one testing method. An example of a student's response is as follows: *"I am confident that the approach chosen is effective because there is an experimental process as well as improvements to make it more efficient."* (Student No. 17)

In the STEM awareness component, students' scores increased from *M* = 1.27 (Fair level) to *M* = 1.97 (Moderate level). This improvement suggests that students were able to articulate the value of STEM in addressing everyday problems; however, their understanding was still not fully developed. An example of a student's response is as follows: *"STEM is important because if STEM is used to solve problems in daily lives, it will help to make the problem solving more systematic and can find the best solution."* (Student No. 9)

The Students' Satisfaction in Outdoor STEM Learning

The analysis of student satisfaction regarding outdoor STEM learning, conducted with 29 participants, revealed that most students expressed high satisfaction. The results are presented in Table 4.

Table 4: Results of students' satisfaction with outdoor STEM learning

Items	*M*	*SD*	*Results*
1. The outdoor STEM course helps students integrate STEM knowledge to solve daily-life problems.	4.33	0.68	Excellent
2. The outdoor STEM course helps students understand the importance of various subjects in STEM.	4.26	0.86	Excellent
3. The outdoor STEM course helps students work effectively as a team.	4.41	0.64	Excellent
4. The outdoor STEM course helps students solve problems creatively.	4.33	0.78	Excellent
5. The content is appropriate and interesting.	4.41	0.69	Excellent
6. The outdoor STEM activities are appropriate and engaging.	4.37	0.69	Excellent
7. The outdoor STEM activities encourage students to solve problems through practice.	4.41	0.69	Excellent

Items	*M*	*SD*	*Results*
8. The outdoor STEM activities encourage students to communicate and discuss.	4.11	0.75	good
9. The outdoor STEM activities are appropriate for the available time.	4.07	0.78	good
10. Learning materials are appropriate and engaging.	4.48	0.64	Excellent
11. Teaching publications are appropriate and engaging.	4.19	0.83	good
12. Measurements are clear and accurate.	4.37	0.79	Excellent
13. The assessment measures are diverse and consistent with objectives.	4.30	0.82	Excellent

From Table 4, the survey results indicate that students demonstrated an excellent level of satisfaction with outdoor STEM learning across most assessment items (M = 4.26–4.48), except items 8, 9, and 11, which received ratings at the good level. Furthermore, the results from interviews revealed that students learned scientific principles through hands-on activities outside the classroom, fostering the development of various skills, as illustrated in the following excerpt:

> *"I have developed scientific knowledge such as gravity, electricity generation, or Buoyant force. In addition, I learned to work together as a team, how to craft a step-by-step problem-solving process, and tried out some equipment I had never used before. So, it made me have a more positive view of STEM. I used to think that STEM was a boring course, but after studying outdoor STEM activities, I think STEM is the fun and is an interesting course."* (Student No. 9)

Discussion

The research results indicate that outdoor STEM activities significantly enhance students' STEM literacy, as they engage in hands-on learning and collaborative problem-solving within real-world contexts. As Crompton (2020) noted, outdoor STEM activities facilitate the connection between problem-solving and the environment in which students live. This approach makes learning meaningful and encourages the development of skills that foster the generation of knowledge grounded in authentic experiences, thereby further advancing learners' STEM literacy. Additionally, outdoor STEM activities contribute to the development of students' STEM literacy across various components.

In the STEM concept component, outdoor STEM activities encourage students to explore connections between STEM content and real-world problems in the natural environment. This approach allows students to integrate their knowledge and understanding better, enabling them to apply this knowledge to solve problems in authentic contexts drawn from their learning resources (Speldwinde, 2022). This aligns with Worsley and Heredia (2023), who assert that students learn science most effectively when it is linked to direct experiences in their daily lives, which are often absent in formal classroom settings. Observations of students during these activities revealed that they actively utilized contextual information in their design solutions. For instance, students measured the area around a faucet to inform their turbine designs and employed a protractor to measure building height for design tasks. This behavior reflects the key characteristics of Outdoor STEM, which emphasize problem-solving in relation to authentic contexts within learning resources. Additionally, it was noted that during the pre-study period, students frequently relied on internet searches for solutions without considering their real-world relevance. In contrast, during the post-study period, students demonstrated a greater capacity to apply various forms of knowledge to solve problems in a manner that was more consistent with real contexts.

When examining the STEM integration component, it was observed that initially, students understood STEM as the integration of only four disciplines. However, after engaging in outdoor STEM learning, students demonstrated an ability to connect with additional disciplines beyond the classroom and apply this knowledge to problem-solving. For instance, some students creatively used leaves to enhance their projects. This observation aligns with Hughes and Maaita (2023), who propose that outdoor STEM activities facilitate the integration of various disciplines found in the natural environment into the learning process. Such activities encourage students to utilize materials from their surroundings for decoration or the creation of projects, consistent with the characteristics of Outdoor STEM, which emphasizes the use of diverse learning resources and the importance of disciplines beyond STEM. Despite these advancements, the post-test scores in this component remained relatively low, indicating that students still struggle to connect multiple disciplines. Most responses primarily referenced art, with limited emphasis on other areas such as social studies, agriculture, or economics in their project development. Therefore, it is essential for educators to encourage students to broaden their perspectives and consider a wider array of disciplines when designing their tasks.

Regarding the STEM practice component, most students initially demonstrated an ability to outline problem-solving guidelines; however, they struggled to justify and sequence the steps in the problem-solving process appropriately, achieving only a good level of proficiency. Following the outdoor STEM activities, students improved significantly in their ability to identify and organize the steps involved in problem-solving, demonstrating a more systematic approach through the engineering design process. Observations during the activities indicated that students were able to tackle problems in a more structured manner. This finding aligns with Andrews, van Lieshout, and Kaudal (2023), who noted that students perceive meaningful learning as most likely to occur during hands-on sessions, particularly through the application of knowledge, problem-solving, and interaction with peers and educators. Additionally, Grubbs and Strimel (2015) emphasized that the engineering design process facilitates problem-solving within constraints, such as time, resources, safety, materials, and equipment, enhancing design efficiency and minimizing errors. Furthermore, engaging in outdoor learning environments provides students with a wider range of options and materials for solving problems, leading to more creative solutions (Son et al., 2017).

In the STEM participation component, students demonstrated increased engagement in addressing social problems, as they recognized the relevance of STEM to societal issues and its potential impact on their futures, as reflected in the post-test results. This observation aligns with the findings of Speldwinde (2022) and Khwaengmek et al. (2020), who noted that outdoor STEM activities foster a strong connection between students and nature. Moreover, these activities enhance students' awareness of environmental and social challenges, encouraging them to consider their roles in addressing these issues.

In the STEM evaluation component, the results indicated that students felt confident in the effectiveness of their chosen solutions, as they had followed the engineering design process, which included performance testing and iterative improvements. Furthermore, the characteristics of Outdoor STEM activities emphasize the evaluation of approaches or innovations in solving problems based on authentic situations in their learning environments. This hands-on practice enables students to achieve tangible results that are closely linked to real-world contexts. This aligns with Campbell and Speldewinde (2019), who asserted that outdoor STEM learning empowers students to utilize their environment to create and evaluate new strategies, ultimately fostering creative problem-solving skills. However, it was noted that students typically engaged in only one performance assessment. Therefore, teachers should encourage students to assess their performances multiple times to ensure that their solutions are as effective as possible.

In the final component, concerning STEM awareness, the results indicated that students developed a greater appreciation for the importance of STEM in their daily lives, as reflected in the post-test. This aligns with Crompton's (2020) assertion that outdoor STEM activities motivate students and help them recognize the relevance of STEM by connecting it to real-world problems.

Additionally, the analysis of the questionnaire results indicated that students' satisfaction with outdoor STEM learning was at an excellent level. This finding aligns with Son et al. (2017), who noted that outdoor STEM activities foster a positive attitude towards learning science and mathematics, particularly among students who are generally less motivated. These activities effectively engage students in STEM education. However, three specific items—1) The outdoor STEM activities encourage students to communicate and discuss, 2) The outdoor STEM activities are consistent with time, and 3) Teaching publications are appropriate and interesting —were rated at a good level. These items highlight a common issue: insufficient teaching time for each topic, which limits students' opportunities for in-depth discussions and full utilization of learning resources. Therefore, future implementations of outdoor STEM should consider and allocate time more effectively. It is also important to note that the data from this study are based solely on elective courses, which may limit their applicability to other contexts. In addition, STEM education should emphasize integrating other subjects to encourage students to develop STEM integration.

Conclusion

These results demonstrate that outdoor STEM activities enhance STEM literacy and significantly boost student satisfaction in STEM learning. Therefore, integrating outdoor STEM activities into the school curriculum as elective courses is recommended, as they are flexible and well-suited for developing STEM literacy while fostering student interest in STEM subjects. This study serves as a guideline for teachers to implement similar approaches in their classrooms. However, it is important to note that this research was conducted in an urban school context with limited green spaces for activities, leading to most activities being conducted within the school building. Future research could explore integrating outdoor activities with available green areas or developing guidelines for incorporating outdoor STEM activities into core courses aligned with established standards and indicators.

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