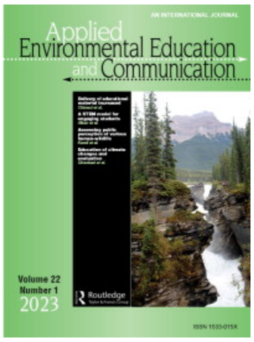

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A STEM model for engaging students in environmental sustainability programs through a problem-solving approach

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ABSTRACT

This study exemplifies a STEM model for engaging students in environmental sustainability programs through a problem-solving approach. The study employed a mixed-method approach incorporating 346 elementary students. The research findings demonstrated a significant improvement in post-test scores, revealing augmented students' understanding of environmental issues. Observations of students' tasks, and students' and facilitators' feedback illustrated enhanced students' collaborative problem-solving (CPS) attitudes. Conclusively the successful implementation of CPS skills through a week-long course has been demonstrated by a strength, weaknesses, opportunities, & threats (SWOT) analysis. Thus, this study paves the way for the future development of E-STEM-based problem-solving programs.

Introduction

Environmental education (EE) seeks to address concerns among global citizens regarding the environment and associated challenges. It aims to develop their skills, attitudes, and knowledge to effectively work toward addressing adequate present-day issues and combatting emerging and new ones (Ballantyne et al., 1998). According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO), education is a necessary instrument for environmental sustainability (Leicht et al. 2018). Not surprisingly, many countries worldwide continue to foster active environmentalism among people, especially students (Bergman, 2016; Sivamoorthy et al., 2013). For example, studies conducted in Turkey (Omran et al., 2017),

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Malaysia (Marpa et al., 2016), and the Philippines (Anilan, 2014) identify environmental awareness programs offering on-off campus waste recycling activities targeting high school and undergraduate students (Rogayan & Nebrida, 2019). Other countries, such as Tonga, prefer to focus on forming bonds between people and their nature, providing organized initiatives that employ plant projects for elementary school students to focus on plant species that are culturally and traditionally important to Tonga (Bhandari & Abe, 2000). In South Korea, EE emphasizes integrating competencies, including cognitive attitudes, into the high school EE curriculum as an approach to enhance their curriculum (Seo et al., 2020). In contrast, Japan believes that EE should begin at an earlier school stage (Mulyadi, 2020). Therefore, Japanese primary schools have incorporated EE programs, aiming to enable citizens to understand their duties and responsibilities toward the environment by promoting their positive attitudes & improving their cognitive and intellectual skills (Mulyadi, 2020). In South America, a problem-solving model is extensively employed to educate students about environmental issues. A study by Wei C. et al. has reported a framework for teaching socio-environmental problem-solving (Wei et al., 2020). In that framework, the problem-solving process is based on socio-environmental (S-E) synthesis, where an integrative, transdisciplinary approach is employed to understand and combat complex socio-environmental problems.

Literature review

EE took a significant turn when STEM education was adopted (Helvaci & Helvaci, 2019) and merged with environmental awareness. This resulted in an E-STEM approach (Environment, Science, Technology, Engineering, and Mathematics) (Garner et al., 2018). STEM education helps learners develop the problem-solving and critical thinking skills and abilities needed to cope with challenging situations and seize opportunities as they arise (Davidson et al. 2003). It is the Situated Cognition Theory (SCT) supports STEM education, which stresses that students' knowledge develops within simple actions and circumstances (Koole, 2018). STEM education can be effectively employed in developing competencies and acquiring knowledge through problem-solving in real-life situations (Holmlund et al., 2018; Williams, 2014). In general, the collaborative problem-solving (CPS) approach outlines a strategy for encouraging people within a team to address issues and solve them effectively. This is predicated on the notion that team members should employ logical problem-solving skills to obtain effective solutions (Williams, 2014). Acquiring these skills helps individuals grow and prepare themselves to manage emerging situations by finding practical solutions (Williams, 2014). CPS begins with identifying the cause of a problem and

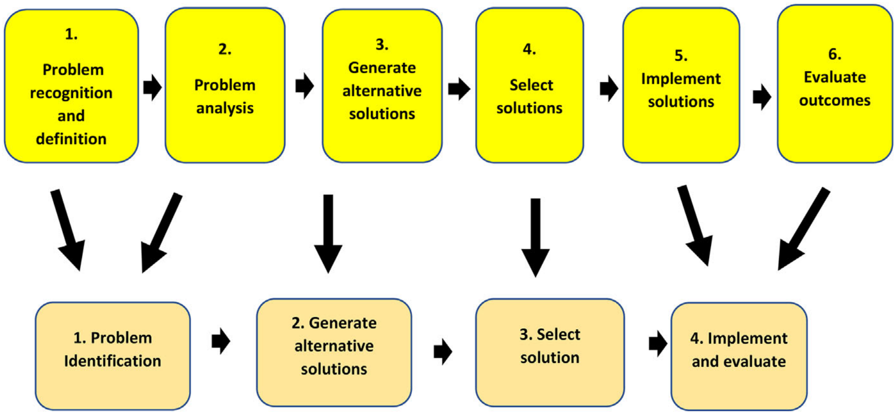

Figure 1. Illustrates the Rational Problem-Solving Approach, proposed by John Dewey in 1910. It shows the six extended steps of the problem-solving approach. These steps were shortened by the course facilitators to 4 steps.

comprehending it entirely by obtaining information from various sources and then analyzing and developing possible solutions that may aid in solving the identified problem. (Fiore & Schooler, 2005).

The integrated nature of STEM education means the utilization of two or more STEM disciplines (i.e. science, technology, engineering, and mathematics) to educate scientific and logical facts (Ortiz-Revilla et al., 2020). Such an integrated approach is extensively employed, and there is a significant volume of scientific production on the topic (Brown, 2012; Mizell & Brown, 2016). Therefore, given the integrated character of STEM education, previous studies have suggested that CPS offers advantages such as incorporating diverse views, expertise, and experiences (Hesse et al., 2015). The problem-solving program was designed employing the four basic steps: (1) Identifying the problem, (2) Suggesting solutions to the problem, (3) Choosing the best solution, and (4) Testing and evaluating. The problem-solving steps were modified and developed from the previous studies of Martorella, 1978 and (Kim et al., 2019; Martorella, 1978). Figure 1 shows the modified problem-solving steps.

Research objectives

The study was based on a 'Problem-Solving' (PS). The study emphasized the program's execution by successfully integrating various STEM activities into challenges to help solve and address environmental problems via an E-STEM model. The research objective was solely focused on acquainting the participants with problem-solving skills and their relevance in daily life by solving environmental problems. The research questions addressed in this study were:

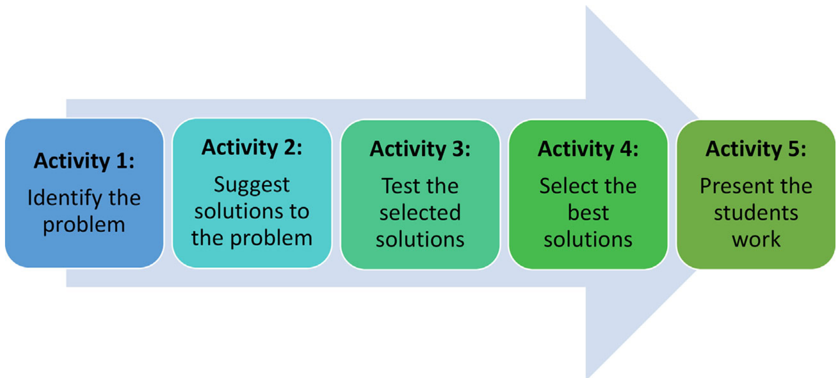

Figure 2. Schematic diagram of the methodology of the "Problem-solving" program. The framework is given for all workshops, showing the activities of each day of the program; W-1, W-2, W-3, and W-4 were directed to acquire students with knowledge regarding pollution, waste challenge, wasting of water, and global warming, respectively.

1. Did the program improve the students' understanding of environmental issues?
2. Were the students able to acquire problems solving skills?
3. Were the program's design and delivery successfully integrating students' collaborative problem-solving (CPS) skills with an E-STEM program?

Methodology

We used a mixed-method approach, where the data was collected & analyzed qualitatively & quantitatively (Creswell, 1998; Yin, 2009). Our study has been developed with reference to the mixed-method case study by Palupi et al., which aimed at studying the students' attitudes in a guided inquiry and problem-solving model (Palupi et al., 2020). In this study, the case was the implementation of environmental sustainability programs through a problem-solving approach for elementary students of Qatar. The study employed a one-group pre-post design on different groups of elementary students for a week (1.5 hours/day). The workshops offered five activities aligned with the CPS approach (Figure 2). Thus, our study intended to understand the common phenomena (Problem-solving skills) during the implementation of the problem-solving-based STEM model (Yin, 2009).

Participants

The present study involved 346 elementary (Grade 4; aged 9-10 years) school students, including 144 males and 202 females, who participated in a four-workshop problem-solving program over two years, from 2018 to 2019. The study was conducted on four batches of students from 14 schools, as shown

Table 1. Student distribution, by year, gender, workshop and school.

		Total Number of Students				Schools	
Year	Workshops	F	%	M	%	F	M
2018	**W-1** Environmentally-Friendly Challenge	**52**	**65**	**28**	**35**	**2**	**1**
2019	**W-2** Waste Challenge	**73**	**63**	**43**	**37**	**3**	**2**
	W-3 Water Problems	**46**	**64.8**	**25**	**35.2**	**2**	**1**
	W-4 Rise of Earth Temperature	**31**	**39.2**	**48**	**60.8**	**1**	**2**
2018-2019	**Total**	**202**	**58.4**	**144**	**41.6**	**8**	**6**

Table 2. Student distribution, by workshop, group and gender.

Year	Workshop	Participants No.	Groups No.	Gender (School)
2018	**W-1**	28	5	Males
		26	5	Females
		26	5	Females
2019	**W-2**	27	5	Females
		20	5	Females
		25	5	Males
		18	5	Males
		26	5	Females
	W-3	21	5	Females
		25	5	Females
		25	5	Males
	W-4	31	6	Females
		25	5	Males
		23	5	Males

in Table 1. The students were first introduced to the concept of STEM education before the start of the workshop. Table 2 shows that students were grouped randomly to accommodate the variety of group-based activities and establish the CPS approach, resulting in approximately five groups per school. Table 2 illustrates the problem-solving workshop conducted in different schools (Brame & Biel, 2015).

Facilitators

The program was designed and delivered by eight STEM professional facilitators, each with more than eight years of experience in designing and developing STEM workshops. The data collection tools (like student feedback form, facilitators' feedback form, and students' pre-posttests) were also developed by the facilitators. They were also responsible for conducting the SWOT analysis.

Program workshops

The four workshops were developed using a similar framework of activities based on the four steps of problem-solving skills, as illustrated in Figure 2.

W-1, W-2, W-3, and W-4 were titled 'Environmentally Friendly Challenge,' 'Waste Challenge,' 'Water Problems,' and 'The Rise of Earth Temperature,' respectively. These workshops were designed and developed through diverse activities by integrating STEM subjects. The activities (refer to Figure 2) carried out to satisfy the program objectives are detailed below:

Activity 1: Identify the problem—the workshops began with an ice-breaking activity where students engaged in various activities like puzzle solving, videos, and hands-on experiments.

Activity 2: Suggest solutions—After the students knew the causes and effects of the problem presented to them, they brainstormed possible solutions.

Activity 3: Test suggested solutions—After students became familiar with the problem and its consequences on the environment, they offered possible solutions and tested them. Refer to Figure S2.

Activity 4: Choose the best solution—Students understood the significance of their suggested solutions by developing their cognitive capabilities via comparing, analyzing, interpreting, observing, critical thinking, decision-determination, and problem-solving skills.

Final Project: The students interpreted the information they obtained and applied it throughout the project. Thus, the program included two types of projects: a poster (for W3 & W4) and a prototype design (for W1 & W2). Refer to Figure S3. The evaluation was held on a public platform to help improve students' oration, body language, public speaking confidence, and vocabulary by the facilitators using pre-designed rubrics (Figure S5).

Data collection methods

Students' pre-post tests were used to evaluate the students' environmental understanding. The open-ended questions comprised diagrammatic representations of environmental issues, where students were required to correctly identify the problem, and its cause and propose solutions. These three open-ended tests were designed to offer participants a chance to feel free to give a wide range of responses without limiting them to specific options (Hyman & Sierra, 2016). These tests were quantitatively assessed to evaluate the possible developments in students' understanding of environmental problems. The reliability test was also conducted, and the Cronbach Alpha value was found to be 0.76 and 0.77 for the pre and post-tests, respectively. For the quantitative evaluation of the data, the pre-post open-ended questions were coded as '1' and '0' for correct and incorrect answers, respectively. While the t-test was conducted to reveal the statistical significance of the pretest and post-test scores.

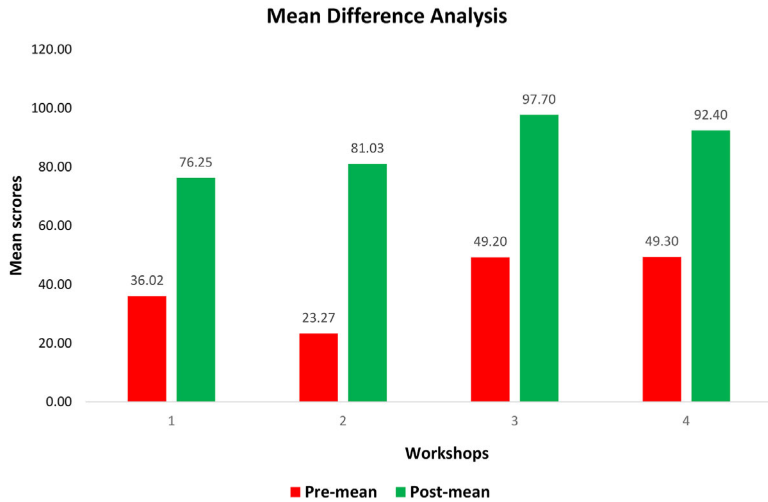

Figure 3. Mean difference analysis, revealing t-test of pretest and post-test scores.

Bloom's taxonomy (affective, cognitive, and psychomotor domain) has been followed to map the learning outcomes (Bloom & Krathwohl, 2020). To evaluate the students' problem-solving skills, qualitative analysis of facilitators' feedback forms (Table S2) and students' artifacts/videos/pictures (Figure S1-S5) were used. To gauge the programs' efficiency, qualitative analysis of facilitators' feedback forms, students' daily feedback forms, and SWOT analysis by facilitators were used. The students' feedback form included three questions (what did you like the most, what did you like the least, and suggestions)

Results

In this part, we have presented the findings of the study, including the qualitative and quantitative evaluations.

Did the program improve the students' understanding of environmental issues?

Analysis of students' pre-posttests

The quantitative assessment of pre-and post-tests was performed to address the first research question. Results showed a substantial difference between the two data sets (pre-and post-scores), indicating significant improvement in students' understanding of the environmental issues following the program (Figure 3). The pre-and post-test scores were statistically computed and evaluated using the t-test statistical calculator via SPSS (Statistical Package for The Social Sciences) software. Binary coding for the acceptable and unacceptable responses was used as indicators, executing the t-test analysis. The p-value for the t-test for all four workshops was less than 0.05, indicating its statistical significance. Refer to Table S1-8 for calculations.

The qualitative analysis of pretests reveals that only 40% of students could correctly identify the presented global issues and write two possible solutions. While, in the post-tests, nearly 90% of the could address the same question more appropriately. Proposed solutions were more descriptive and clearer in the post-tests than in the pretests.

Were the students able to acquire problems solving skills?

Analysis of the facilitator's feedback (on students' attitudes)

The program facilitators witnessed the development of students' problem-solving skills from the beginning of the program. The daily written facilitators' feedback (refer to Table S2) was a crucial tool in analyzing the progress of students' problem-solving skills. The problem-solving skills were assessed based on the affective, behavioral, and cognitive (ABC) theory of attitudes (Ostrom, 1969). The facilitators observed students' ABC attitudes by witnessing their creativity, effective collaboration, engagement, satisfaction, interest, critical thinking skills, reasoning skills, understandability of the problem, etc., while performing the various tasks and designing their final projects (referring to Bloom's Taxonomy).

The qualitative analysis of the facilitators' feedback revealed the students' eagerness to solve different environmental problems. They also noted students' enthusiasm during the hands-on activities and project design challenges. Indeed, facilitators observed positive responses from the participants with improved ABC attitudes.

Analysis of projects

As students presented their projects, they were carefully assessed for their presentation, organization, execution, sustainable solution generation, and problem-solving skills (Figure S6). Finally, the students' artifacts were collected and qualitatively analyzed for their problem-solving skills (Figure S8). The innovative ideas represented via the creative posters/prototypes revealed the students' attainment of problem-solving skills and their ability to generate sustainable solutions. Some of the students' projects/ideas involve the sustainable use of plastic containers in making planters, concrete materials for roads, hydroponics, drip irrigation, recycled cloths/papers as useful materials, vermicomposting, etc.

Was the program design and delivery successfully integrating CPS skills with an E-STEM program?

Analysis of Students' feedback

Students' feedback was analyzed to evaluate the program's design and delivery success. The students' feedback revealed their perceptions of the

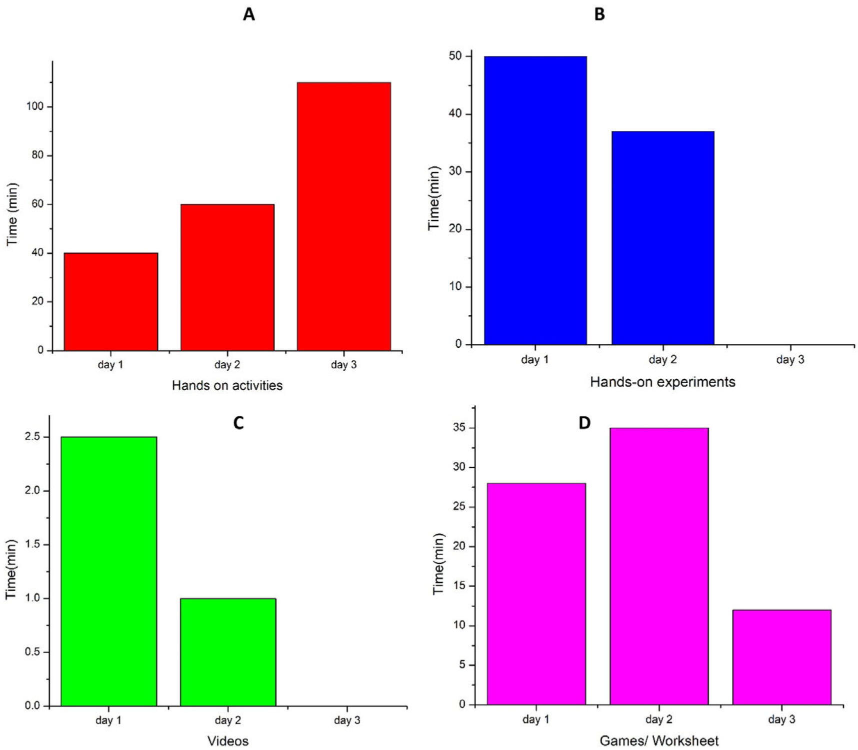

Figure 4. A schematic illustration of the duration of the various educational tools utilized throughout each workshop of the problem-solving program daily. (A) hands-on activities; (B) Hands-on experiments (C) videos, and (D) games/workshops.

workshop's most and least-liked aspects, along with their suggestions. During the qualitative analysis of students' feedback, the facilitators witnessed positive feedback, revealing the program's success.

Such a feedback mechanism has helped the facilitators to evaluate and modify the workshop in a student-centered manner. Therefore, the selection of tools and the average time allotted for each tool were determined based on the facilitators' previous experiences. The diversity of the educational tools (videos, hands-on activities, experiments, games/worksheets) employed in the program was finalized by carefully considering the learning objectives. Figure 4 illustrates a graphical representation of the educational tools allocated that displays the usage patterns of various tools throughout the workshop. Figure 4(a) and (b) demonstrate the graphical representation of the usage of 'videos' and 'hands-on experiments' during the workshops. Both showed a similar pattern, where both (videos and hands-on experiments) were executed the most on day 1. The videos and hands-on experiments were employed to brainstorm with the students about environmental issues and related challenges. Its usage significantly decreased on day 2. While on day 3, there were no video depictions or hands-on experiments because the

Table 3. Facilitators address a SWOT analysis matrix that lists the programs' strengths, weaknesses, opportunities, and risks.

Strength	Weakness	Opportunities	Threats
• Successful implementation of CPS skills through a week-long workshop • Various hands-on experiments • Student-centered. • Qualitative analysis of the development of students' problem-solving skills. • Quantitative analysis of pre-post questionnaire for students' understanding of environmental issues. • High population size in a 2-year program • Feedback-driven mechanism	• Limited school time, as it was an informal program	• Online problem-solving programs • Opportunity to cover/discuss other problems (social, personal, economical issues) • Development of project prototypes • Self-directed learning	• Limited experiments due to the nature of school laboratories.

students were primarily employed in hands-on activities and project designing. Figure 4 (c) showed that the usage of hands-on activities peaked on day 3, as the students were involved in poster/model designing after passing the experimental stages. At the same time, Figure 4 (d) illustrates the usage of games and worksheets that peaked on day two as students were enthused about understanding the proposed problem. Then, it dropped correspondingly toward project design implementation on day 3.

Strength, weakness, opportunities, and threats (SWOT) analysis

The facilitators thoroughly investigated the program techniques and outcomes to create a SWOT analysis matrix. The SWOT analysis outlined the study's strengths, weaknesses, and prospects by investigating the students' & teachers' feedback forms, students' artifacts & pre-post-tests. The SWOT analysis has been illustrated in Table 3. The foremost strengths include the successful implementation of a 3-week long course of the environmental sustainability program, incorporating a STEM-based, problem-solving approach. Along with student-centered & feedback mechanisms to enhance students' CPS skills. The opportunities are the execution of online problem-solving programs, and covering/discussing other real-life problems (social, personal, and, economical issues). On contrary, some of the major limitations have been the restricted school timings for such informal courses and the nature of school laboratories for experimentation.

Discussion

This study has been conducted to investigate the impacts of environmental sustainability programs on elementary students through a STEM-based problem-solving approach. The findings have suggested that environmental education improves students' behavior and attitude toward the environment (Ural & Dadli 2020). Using traditional methods for environmental education might not provide the desired outputs. Therefore, it is imperative to upgrade the instructional mode according to the students' requirements.

In the recent literature, many studies have illustrated the success of problem-solving models in implementing environmental education (Ural & Dadli 2020). The problem-solving models in combination with other approaches such as scientific e-projects-based (Keskin et al., 2020), project-based with productive failure (Song, 2018), inquiry & video-based virtual reality (Wu et al., 2021), mobile-based (Cheng et al., 2019), etc. have been employed successfully. All of these nontraditional models have reported better cognitive, affective, or/and behavioral gains in the environmental context. Whereas this study has been a combination of diverse approaches and was analogous to the study by Helvaci S.C. et al., employing an interdisciplinary STEM approach for environmental education (Helvaci S.C. et al., 2013). Furthermore, this study also incorporated a student-centered and feedback-driven instructional mode which is critical in any pedagogical intervention (Bos-Nehles et al., 2022).

Conclusion

In recent years, environmental problems have been one of the global challenges. The implementation of environmental problem-solving programs is almost a mandatory requirement. Therefore, educating students with knowledge and skills to solve environmental problems in real life is very important. The present study's objective was to develop a unique program that combines E-STEM learning with a collaborative problem-solving approach. Students were self-engaged in a collaborative environment, thus boosting their proficiencies toward the environmental challenge addressed through project design. The problem-solving program focused on the students' eagerness to save the environment by engaging them in an inquiry-driven learning mechanism that helped them acquire problem-solving skills. The quantitative findings of pre-post tests revealed improvements in the students' understanding of environmental issues. Qualitative analysis of facilitators' feedback along with the student's artifacts revealed the gain in problem-solving skills among the students. The SWOT analysis matrix and students' feedback aided in outlining the strengths and shortcomings of the program, which provided opportunities for expansion through designing new workshops and exploring new environmental problems for which STEM education and problem-solving abilities would provide novel solutions.

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