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The Impact of STEM Approach in Environmental Education on Environmental Attitudes and Knowledge Levels and Students' Opinions on STEM Approach[1]

Serpil ÇÜRÜK [2]
Ministry of National Education
Halil İbrahim YILDIRIM [3]
Gazi University

Abstract

This investigation was performed to determine the impacts of the STEM approach in environmental education (EE) on environmental attitudes and knowledge levels and to examine student opinions on the STEM approach in EE. The investigation was implemented in a government school in Turkey in 12 weeks using a mixed method. A Quasi-experimental design with a pretest-posttest control group and a phenomenological research design were used in the quantitative-qualitative parts of the investigation, seriatim. Investigation data were collected using the Environmental Attitude Scale, Environmental Knowledge Test, and an Interview Form, which were also administered as follow-up tests to evaluate the permanence of the changes in attitudes and knowledge. The experimental group received EE with the STEM approach while the group under control received the 5E model. In both study groups, EE was based on reusing waste materials. The study results showed that the 5E model and STEM approach in EE had a meaningful effect on the rise in students' attitudes and knowledge levels toward the environment. However, the STEM approach in EE was more effective compared to the 5E model. In addition, pupils in the experimental group had positive opinions regarding the STEM approach used in EE. Considering the research results, it was proposed that the STEM approach be included in EE.

Keywords: STEM, STEM Education, Environmental Education, STEM Approach in Environmental Education, environmental attitudes, environmental knowledge

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[2] Teacher, Ministry of National Education, Van, Türkiye, ORCID: 0000-0002-4398-7672, serpilcrks@gmail.com, **Correspondence**: halily@gazi.edu.tr

[3] Assoc. Prof. Dr., Gazi University, Gazi Faculty of Education, Mathematics and Science Education, Ankara, Türkiye, ORCID: 0000-0002-8836-8349, halily@gazi.edu.tr

Introduction

Environmental education (EE) has a major role in solving environmental problems and aims to raise environmentally sensitive individuals with favorable attitudes and behaviors toward environmental protection (Demir & Yalçın, 2014). Only through EE can behaviors toward the environment be changed, the nature of environmental issues be understood, and solutions for them be offered (Kuvaç & Koç Sarı, 2019). EE is based on raising awareness of protecting nature and all resources in nature. The goal of EE is to raise awareness about environmental problems as well as to raise the number of individuals who are successful and eager to protect the environment (Kamacı, 2021, p. 4). EE should be implemented via proper programs, curricula, and learning approaches to accomplish these aims (Özdemir, 2023). STEM approach (STEMA) is one of the appropriate learning processes that can be used to achieve EE objectives. Fraser, Gupta, Flinner, Rank and Ardalan (2013) have highlighted the importance and need for the use of the "STEM Approach" (STEMA) in EE. While STEM is an appellation comprised of the first letters of the STEM fields, STEMA is a pedagogical method based on the application of these disciplines in teaching as a whole (Akgündüz, 2018). The STEMA provides acquisition of knowledge and skills related to life (National Research Council, 2011) and raises creative, productive individuals equipped with 21st-century skills (CS) (Bybee, 2010). STEMA is a major factor in developing students while they get ready for a future that is changing rapidly. The science, technology, mathematics, and engineering skills that students learn at school are the basis of a successful STEM career (Knezek, Christensen, Tyler-Wood & Periathiruvadi, 2013). The goal of STEMA is to guide persons into STEM disciplines in higher education (at universities) by using an interdisciplinary and holistic approach (Akgündüz, 2018). The present study aimed to develop EE outcomes with STEM, a pedagogical learning-teaching approach. Previous studies have emphasized that the STEMA contributes to 21st-CS (Bybee, 2013; Jolly, 2016), decision making (Bybee, 2010a, 2010b, 2013; Jolly, 2016), interests and abilities toward the courses and STEM disciplines (Akgündüz et al., 2015; Şahin, Ayar & Adıgüzel, 2014), quality of learning experiences (Jolly, 2016; Wang, 2012), technology literacy (Thomas, 2014), orientation toward STEM fields (Brown, Brown, Reardon and Merrill, 2011; Dugger, 2010; Çorlu, Capraro and Capraro, 2014; Sanders, 2009; Thomas, 2014), and stimulating the desire to research and produce solutions to life problems (Morrison, 2006; Wang, 2012). Considering the contributions of STEMA to learning-teaching aims, it can also facilitate achieving EE goals because the abovementioned skills are also used in EE. Similar to STEM education, EE has a conception of an interdisciplinary, holistic teaching approach.

It is a common misconception that STEM practices focus on robotics-maker activities that are not integrated with STEM disciplines, not associated with course outcomes, and can only be implemented with expensive materials. This paves the way for a misunderstanding of STEM education. However, the STEMA can be achieved using simple materials that align with the courses' outcomes, and this is necessary (Akgündüz, 2018; Kuvaç & Koç Sarı, 2019). Accordingly, "reuse", a key term in

EE and contributes to sustainable living, served as the foundation for the STEM planned in the present study.

A sustainable life requires establishing a balance between people's needs and the environment, which is their living space. Concepts such as recycling and upcycling have emerged and begun to be used instead of the understanding of "use-and-dispose" to minimize the adverse effects of humans on the environment, transfer today's resources to the future, and reduce the amount of waste (Dal & Cengiz Gökçe, 2019). Another recently emerging concept is "reuse," which is crucial for raising awareness about resource and environmental preservation as well as changing the mindset that "it is inexhaustible". Reuse is the practice of using usable parts of waste materials for various purposes as they are, instead of recycling them by consuming energy (Kendir Beraha, 2019). In the present study, waste materials were transformed into a product by reusing them within the scope of the STEMA. The aim here was to make use of the waste materials and reduce their damage to the environment before they turn into garbage. Thus, the study aimed to achieve EE by doing-experiencing in accordance with its purpose, allowing students to gain positive attitudes toward the environment, and providing them with an effective EE.

For effective EE, appropriate curricula should be developed and associated with the environment (Yıldırım, 2015, p. 287). STEM disciplines overlap with environmental issues, and these disciplines offer opportunities for effective EE (Kuvaç & Koç Sarı, 2019). Environmental issues have a facilitating role while implementing the STEM method (Fraser, Gupta, Flinner, Rank & Ardalan, 2013). The fact that environmental issues encourage the usage of 21st-CS (communication-collaboration-critical thinking-problem solving) and that environmental issues contribute to learning by linking the STEM disciplines with each other are among the reasons why the STEMA is used in EE (Kuvaç & Koç Sarı, 2019). Activities in which children undertake active roles in nature using their experiences or with their friends have a significant effect on developing environmentalist behaviors (Davis et al., 2008; Madden & Liang, 2017). The STEMA also includes activities in which children actively participate together. In addition, employing the STEMA in EE contributes to improving the effectiveness of EE and provides rich opportunities for STEM applications (Kuvaç & Koç Sarı, 2019). For this reason, this study also addressed the STEMA in EE.

Theoretical knowledge should be applied in solving daily life problems to make the information acquired in EE permanent. Thus, it is important to teach the topics connected to the environment using STEM to increase efficiency in environmental learning. Provision of EE with the STEMA holistically presents the opportunity for the pupils to assume proactive roles in solving the problems in the environment (Duyal, 2022). Bişkin Uygar (2022) highlighted that EE achievements are parallel with the STEMA and that this approach would contribute to raising environmental awareness. It is also crucial to provide EE with the STEMA to create solutions to environmental issues, avoid these problems, and raise environmental awareness (Tuncel, 2022). Therefore, the STEMA should be used in EE at all educational levels (Kavak, 2024; Ünver Gürsoy, 2024). EE has a multidisciplinary nature and requires interdisciplinary communication (Teksöz, 2024). This is the same for STEM education. Both STEM and EE aim to achieve common goals such as putting the student at the center, teaching by doing and experiencing, establishing a relationship with daily life, providing individuals with problem-solving skills by using an interdisciplinary approach, and creating a multidimensional perspective (Duyal, 2022). As a result, STEM and EE overlap and support each other in many aspects, which is one of the reasons for incorporating STEMA into EE.

Studies examining the use of STEM in EE are limited in the literature. Studies have examined the application of STEM in EE on decision-making and communication skills (Boran, 2024), environmental literacy (Kavak, 2024), achievement and environmental attitude (Ünver Gürsoy, 2024), environmental attitude (Demirci, 2023), conceptual understanding and students' opinions (Kayaalp, 2023), environmental attitude, environmental citizenship knowledge, and students' opinions (Özdemir, 2023), environmental literacy and students' opinions (Koçak, 2023), scientific skills and environmental attitude (Tepe, 2023), interest in science and environmental awareness (Tuncel, 2022), environmental attitude and creativity (Demir, 2021), awareness of light pollution (Tanrıverdi, 2021), environmental awareness and students' opinions (Yavuz, 2020), environmental awareness and perception of recycling (Doğru, 2020), attitude, creativity, and achievement (Kınalıkaya, 2019), environmental attitude (Çalışıcı, 2018), creativity, problem solving skills, achievement, and environmental attitude (Duyal, 2022). Some of the above investigations researched the influence of using STEMA in environmental issues on the goals of the STEMA. In addition, most of the studies have focused on a limited subject of EE and examined the efficacy of the STEMA on the outcomes of EE. The present study is distinct from previous research in a number of respects, the first of which was that this study aimed to achieve EE goals by integrating all EE subjects at the middle school level with a STEMA. Another difference was that this study was conducted over 12 weeks, a period of time that can lead to changes in affective traits, and it monitored the permanence of the development of the students' environmental attitude and knowledge. In addition, this study was based on the reuse of waste materials to achieve effective EE through doing and experiencing. Accordingly, this investigation was implemented to find out the influence of the STEMA in EE on pupils' environmental knowledge-attitudes levels and evaluate their opinions about the use of the STEMA in EE.

Method

This research was implemented using the mixed method in which study data are gathered and analyzed, quantitative-qualitative research techniques are applied, findings are combined, and inferences are drawn (Tashakkori & Creswell, 2007). The phenomenological approach, which includes the examination and description of the existence of events, was used in the qualitative part of the study

(Baş & Akturan, 2013). When studying using this approach, the researcher collaborates with those who experience the phenomenon. Individuals' experiences and perceptions of the phenomenon are investigated and interpreted in depth (Creswell, 2012). This study used the phenomenological approach because the experiences of students who were given EE using STEM education were examined through interviews. The quasi-experimental technique was used in this research's quantitative part because the investigation investigated the impact of the STEMA on environmental knowledge and attitudes. The research was prepared in an experimental design with a pre-post test control group because one control group and one experimental group were selected by lot from the classes in the school.

Determining the Study's Sample

Convenience sampling was used in the current research because the investigator included students in the sample whom he/she taught, could easily conduct the study, and communicate (Büyüköztürk et al., 2016).

Participants

During the 2023–2024 academic year, 60 eighth-grade pupils from a Turkish secondary school made up the working group. There were 16 boys-14 girls in the experimental class and 15 girls-15 boys in the class under control. In each group, the proportion of male and female students was about equal. Additionally, because they shared a neighborhood, they had comparable socioeconomic features.

Data Collection Tools

Environmental Knowledge Test (EKT)

The EKT developed by Cömert (2011) was used to assess the participants' points of environmental knowledge. It was initially prepared as a test with 25 multiple-choice items with four options. The items were analyzed, and two items with a discrimination index < 0.20 were removed. The KR-20 reliability value of the 23-item EKT was 0.75 (Cömert, 2011). Before beginning the investigation, the EKT was given to 8th-grade students (n = 454), and item and reliability analyses were conducted. The EKT's mean discrimination index, difficulty index, and KR-20 reliability coefficient were 0.45, 0.55, and 0.83, seriatim.

Environmental Attitude Scale(EAS)

The EAS produced by Yücel and Özkan (2014) was implemented in the investigation to evaluate the participants' level of environmental attitude. This 5-point Likert-type scale initially included 41 items for which the responses were "never", "rarely", "sometimes", "frequently", and "always". Six items were eliminated from the scale, leaving 35 items after the exploratory factor analysis. The Cronbach's alpha coefficient for the EAS, which comprises four components (behavior, thought, emotion, and willingness to act) was 0.88 (Yücel & Özkan, 2014). Similarly, the EAS was administered to 8th-grade students (n = 454) before the study was started, and its reliability coefficient value was determined to be 0.90.

Interview Form

Student opinions about the application of the STEMA in EE were analyzed using this interview form, which was developed by Yıldırım (2020) and adapted to this study. The suitability and validity of the interview form's questions were assessed by two specialists in science education. A Turkish teacher evaluated its comprehensibility in terms of linguistic features. This form was finalized after the required changes were made based on the suggestions obtained from the experts. Before the study began, the form was also administered to students in a different public school that included STEMA in its curriculum, and the questions were revised.

Data Collection

EE topics based on the STEMA and the 5E model (the model's steps:engage/explore/explain/elaborate/evaluate) were developed before starting the study, which was conducted by the researcher in the environment course in 12 weeks. Four lessons were offered each week. As a pre-test, the EKT and EAS were applied. The subjects "Basic Concepts in EE, Environmental Pollution, Change of the Environment, Types of Environmental Pollution: Air-Water-Soil-Space-Noise-Light-Electromagnetic, Renewable Energy, Recycling, The Greenhouse Effect-The Environment for Sustainable Life-Global Warming" were taught.

Implementation in the Control Group

The 5E model, which is student-centered and based on learning by doing and experiencing, was employed to avoid the control group from being disadvantaged in terms of EE. The reuse of waste materials was considered as the basis for an effective EE while doing activities within the scope of the 5E model's stages.

Implementation in the Experimental Group

The group under experimentation received EE with the STEMA. In other words, STEM education, a pedagogical approach, was incorporated in the EE process, in which course plans developed in line with STEM were used. These plans included learning outcomes associated with environmental issues and those with science/technology/engineering/mathematics. At the beginning of the lesson, a presentation titled "Knowledge-Based Life Problem" (KBLP) was delivered using visual materials, including multimedia elements, news, videos, and animations, to attract interest in each EE topic and motivate the students for learning. Students were encouraged to brainstorm by asking questions related to the KBLP, and their prior knowledge and thoughts regarding the problem were determined. Then, they were asked to think about the KBLP created for the environmental subject that was aimed to be taught and to identify the problem. In addition, they were expected to decide which professional group they would collaborate with to solve KBLP. At this stage, the students began conducting research on the KBLP. They were informed about the limitations of the KBLP, and the professions, duties, and responsibilities were introduced. The pupils were split up into groups, and they were instructed to share tasks within the group. In the information acquisition stage, students were asked whether they wanted to undertake additional tasks and responsibilities, and the students in the groups shared these tasks and responsibilities. The students were also asked to research the occupational group they chose and the problem in the KBLP phase. Herein, questions such as “What is the problem”, “How has the problem emerged”, “How has the environmental problem changed over the years”, “How will it affect life over time”, and “What measures can be taken” were asked to the students and they were instructed to discussed and answer them in groups. In the idea development phase, students’ ideas for resolving the environmental problem in the KBLP were taken, and these ideas were discussed. The pupils were asked to draw the design on paper, aligning with the agreed-upon idea. In the product development phase, group members shared their work based on their professions and made the first design in three dimensions, considering the drawings on paper. In the testing phase, whether the designs created by the groups found a resolution to the environmental trouble in the KBLP and their compliance with the limitations were checked by the students. Students examined whether the design worked or not, and whether it was a solution to KBLP based on the occupational distribution within the group. If there was an issue with the design, the product development stage was revisited, and the design was redeveloped and improved. If a problem or deficiency with the product existed, how to redevelop and improve the product was discussed, and which professions in the group would handle this issue. Each group presented the product they designed in the classroom in the sharing and reflection stage. The KBLP, the environmental problem and related concepts in KBLP, and the product developed as a resolution to the trouble were discussed in the classroom, and the results were concluded and generalized. The drawings on the paper and the product that the groups developed were compared and evaluated.

Upon completion of the research, the EKT and EAS were applied as the post-test; they were also administered as follow-up tests: EKT 4 weeks and EAS 12 weeks after the end of the research. At the conclusion of the investigation, conversations were implemented with the experimental group about the STEMA in EE.

Quantitative Data Analysis

Table 1 demonstrates the analysis conclusions of the distribution of the investigation data.

Table 1. Conclusions of the Normality Analysis of the EKT and EAS Data

	Control			Experiment		
	Skewness	Kurtosis	Shapiro W.	Skewness	Kurtosis	Shapiro W.
EKT Pre-test	0.15	-0.21	0.80	-0.18	0.05	0.92
ÇYT Posttest	-0.26	-0.38	0.87	-0.84	0.76	0.40
ÇYT Follow-up Test	-0.37	-0.31	0.56	-0.89	-0.24	0.19
EKT Pre-test	-0.07	0.10	0.89	0.07	-0.90	0.55
EKT Posttest	0.28	-0.71	0.16	-0.69	-0.17	0.24
EKT Follow-up Test	0.10	-0.93	0.58	-0.29	-0.63	0.43

The significance value of Shapiro-Wilk results was > 0.05, and the skewness-kurtosis coefficients ranged from -1.5 to +1.5 (Table 1). These findings demonstrated the normal distribution of the EKT and EAS data. Therefore, the data were analyzed using parametric tests. The pre-, post-, and follow-up data of the study groups were compared using the independent groups *t*-test. Changes in the EKT and EAS scores of the groups were analyzed using one-factor ANOVA for repeated measures (Büyüköztürk, 2016; Kalaycı, 2018; Tabachnick & Fidell, 2013). The effect size was measured using eta squared (η^2). Based on the value ranges, the effect size was interpreted as follows: low if $0.01 < \eta^2 < 0.06$, medium if $0.06 \leq \eta^2 < 0.14$, and high if $0.14 \leq \eta^2$ (Cohen, 1988).

Analysis, Validity, and Reliability of the Qualitative Data

The qualitative material was analyzed using content analysis, in which data were analyzed, divided into meaningful sections, and coded, and the correlations between codes were grouped as themes. In the present study, semi-structured conversations were held with the pupils in the experimental group. Voice recordings were recorded to prevent loss of qualitative data, and they were transcribed. Codes and themes were created based on the analysis of students' opinions and in line with the literature. To ensure internal validity, the data acquired as a conclusion of the interview were analyzed in detail, and expert opinion was received for the study results. Students' confirmation was obtained from the students regarding their opinions to examine the authenticity of their opinions and whether these opinions conformed with the results (Yıldırım & Şimşek, 2018). The speech records of the conversations were transcribed to prove the reliability of the qualitative data. They were reviewed by the other investigator, besides the investigator, and codes-themes were created, and the similarity between these codes-themes was determined using the correlation ($\frac{\text{Consensus}}{\text{Consensus+Disagreement}}$) formulated by Miles and Huberman (1994). The similarity values were 0.90 and 0.95 for codes and themes, respectively. The fact that these values were > 0.70 proved the reliability of qualitative data. The two investigators discussed the differences between the codes and themes and reached a consensus.

Findings

Table 2. Analysis of the Study Groups' EAS Points

Test	Group	N	$\bar{x}$	S	df	t	p	η2
Pre	Control	30	122.73	15.84	58	0.46	0.65	-
	Experiment	30	121.10	11.08				
Post	Control	30	132.57	18.23	58	-4.24	0.001	0.24
	Experiment	30	149.07	11.06				
Follow-up	Control	30	131.17	16.52	58	-4.37	0.001	0.25
	Experiment	30	148.53	14.19				

Pupils in the experimental and control classes did not significantly differ in their EAS pre-test points ($t_{(58)}$=0.46; p>.05). However, the posttest ($t_{(58)}$= -4.24; p<.05) and follow-up test points ($t_{(58)}$= -4.37; p<.05) of the class under experimental were significantly greater than those of the group under control. Table 2 demonstrates that the η2 values were greater than 0.14, indicating a large effect size.

Table 3. One-Factor ANOVA for Repeated Measures of the Control Group's EAS

Source of Variance	Sum of Square	df	Mean Square	F	p	η2	Difference
Between Subjects	17254.489	29	594.982	6.51	0.003	0.18	Post-Pre, Follow up-Pre
Measurement	1697.756	2	848.878				
Error	7566.911	58	130.464				
Total	26519.16						

A meaningful differentia was found among the EAS pre-test and post-test of the class under control in favor of the post-test and between the EAS pre-test and follow-up test in favor of the follow-up test ($F_{(2-58)}$=6.51; p<.05). According to the table, a value of η2 bigger than 0.14 indicates a high effect size (Table 3).

Table 4. One-Factor ANOVA for Repeated Measures of the Experimental Group's EAS

Source of Variance	Sum of Square	df	Mean Square	F	p	η2	Difference
Between Subjects	9396.767	29	324.026	125.633	0.001	0.81	Post-Pre, Follow up-Pre
Measurement	15350.067	2	7675.0.33				
Error	3543.267	58	61.091				
Total	28290.100						

There was a significant difference between the EAS pre-test and post-test in favor of the post-test and between the EAS pre-test and follow-up test in favor of the follow-up test ($F_{(2-58)}$=125.633; p<.05). The η^2 value was > 0.14, which indicated the high effect of the experimental procedure (Table 4).

Table 5. Analysis of the Study Groups' EKT

Test	Group	N	$\bar{x}$	S	df	t	p	η2
Pre	Control	30	9.23	2.91	58	0.55	0.58	-
	Experiment	30	8.80	3.18				
Post	Control	30	13.93	2.56	58	-4.94	0.001	0.30
	Experiment	30	17.37	2.82				
Follow-up	Control	30	12.23	3.55	58	-4.98	0.001	0.30
	Experiment	30	16.43	3.00				

The differentia among the EKT pretest points of the class under experimentation and the class under control was not significant ($t_{(58)}$=0.55; p>.05). There was a meaningful differentia among the EKT post-test ($t_{(58)}$= -4.94; p<.05) and follow-up test points ($t_{(58)}$= -4.98; p<.05) in favor of the class under experimentation. The η^2 values showed a high effect of the experimental procedure (Table 5).

Table 6. One-Factor ANOVA for Repeated Measures of the Control Group's EKT

Variance's Source	Sum of Square	df	Mean Square	F	p	η2	Difference
Between Subjects	505.733	29	17.439	33.419	0.001	0.54	Post-Pre, Follow up-Pre, Post-Follow up
Measurement	339.801	2	169.900				
Error	294.867	58	5.084				
Total	1140.401	89					

A meaningful differentia was observed among the EKT pretest and posttest of the group under control in favor of the posttest, among the EKT pretest and the follow-up test in favor of the follow-up test, and among the EKT posttest and the follow-up test in favor of the posttest ($F_{(2-58)}$=33.419; p<.05). The η^2 value > 0.14 showed a high level of effect size (Table 6).

Table 7. One-Factor ANOVA for Repeated Measures of the Experimental Group's EKT

Variance's Source	Sum of Square	df	Mean Square	F	p	η2	Difference
Between Subjects	404.400	29	13.945	100.95	0.001	0.78	Post-Pre, Follow up-Pre
Measurement	1325.267	2	662.633				
Error	380.733	58	6.564				
Total	2110.400	89					

There was a meaningful difference among the EKT pretest and posttest in favor of the posttest and among the EKT pretest and follow-up test in favor of the follow-up test $F_{(2-58)}$= 100.95; p<.05). Since the η2 value is higher than 0.14, the impact size is high (Table 7).

The analysis results of "Could you please explain your thoughts on the STEMA in EE?" are displayed in Table 8.

Table 8. Themes-Codes Generated from Students' Opinions on the STEMA

Theme	Code	f	%	Theme	Code	f	%
STEMA Process	Research-Investigation	26	86.66	Contribution	Useful-Developing (For Learning)	28	93.33
	Problem Solving	23	76.66		Permanent Learning	23	76.66
	Experimentation	18	60.00		Ease of Understanding	25	83.33
	Creative Thinking	27	90.00		Contribution to Life	22	73.33
	Project Preparation	24	80.00		Contribution to The Lesson	25	83.33
	Designing	27	90.00				
	Product Creation	26	86.66				
	Reuse	24	80.00				
	Interesting	28	93.33				
	Fun	27	90.00				
	Imagination	24	80,00				

The codes in Table 8 were grouped under two themes: STEMA process and contribution. The majority of the students expressed the STEMA as research-investigation, problem solving, experimentation, creative thinking, project preparation, designing, product creation, reuse, interesting, fun, imagination, useful-developing (for learning), permanent learning, ease of understanding, contribution to life, and contribution to the lesson.

The results of the analysis, "Do you have any positive or negative effects of teaching using the STEMA? Are there any skills and characteristics that it develops or reduces?" are presented in Table 9.

Table 9. Theme and Codes Generated from the Students' Opinions on the Benefit of the STEMA to Students

Theme	Code	f	%	Code	f	%
Skills Developed in Individuals	Self-Expression	27	90.00	Working Together	24	80.00
	Communication	26	86.66	Research-Examination	18	60.00
	Patience	17	56.66	Manual Skills	19	63.33
	Creative Thinking	23	76.66	Designing	24	80.00
	Problem Solving	22	73.33	Ability to Use Materials	25	83.33
	Cooperation	27	90.00	Generating Idea	20	66.67

The codes in Table 9 were grouped under the theme of skills developed in individuals. Overall, the students expressed the contribution of the STEMA to themselves as self-expression, communication, patience, creative thinking, problem solving, cooperation, working together, research-examination, manual skills, designing, ability to use materials, and generation of ideas.

The analysis results of "Did the STEMA have an impact on your feelings and thoughts about the environment and learning about environmental issues? Could you please explain?" are displayed in Table 10.

Table 10. Themes-Codes Generated from the Students' Opinions on Their Feelings and Thoughts about the STEMA

Theme	Code	f	%	Code	f	%
Contribution to EE	Loving The Environment	26	86.66	Taking Responsibility	17	56.66
	Being Interested in The Environment	28	93.33	Learning Environmental Issues	24	80.00
	Attitude Toward The Environment	27	90.00	Permanent Learning of Environmental Issues	24	80.00
	Research on Environmental Issues	21	70.00	Creative Thinking	25	83.33
	Environment Course Self-Efficacy Belief	19	63.33	Reusing	22	73.33
	Problem Solving	26	86.66	Designing (For Environmental Issues)	26	86.66
	Motivation For The Environment Course	25	83.33			

The codes in Table 10 were grouped under the theme of contribution to EE. The majority of the students stated their views as loving the environment, being interested in the environment, attitude toward the environment, research on environmental issues, environment course self-efficacy belief, problem solving, motivation for environment course, taking responsibility, learning environmental issues, permanent learning of environmental issues, creative thinking, reusing, and designing.

The result of the analysis, "Did the STEMA used in EE have any impact on your daily life?", is shown in Table 11.

Table 11. Theme and Codes Generated from the Students' Opinions on the Impact of the STEMA on Students' Daily Lives

Theme	Code	f	%	Code	f	%
Contribution to Daily Life	Communication	17	56.66	Public Speaking	22	73.33
	Problem Solving	25	83.33	Learning About Environmental Issues	23	76.66
	Self-Confidence	19	63.33	İnterest in The Environment	22	73.33
	Loving The Environment	24	80.00	Reusing	24	80.00
	Protecting The Environment	28	93.33	Career Choice (Being a Scientist)	16	53.33
	Environmental Awareness	27	90.00	Saving Energy	15	50.00
	Concern for The Environment	25	83.33			

The codes in Table 11 were grouped under the theme of contribution to daily life. According to the majority of the pupils' opinions, the following were determined: communication, problem solving, self-confidence, loving the environment, protecting the environment, environmental awareness, concern for the environment, public speaking, learning about environmental issues, interest in the environment, reusing, career choice, and saving energy.

Discussion

There was a meaningful improvement in the EAS grades of the study groups at the completion of the investigation, and this improvement was retained after 12 weeks. The fact that the 5E applied in this group is a student-centered application model of constructivist learning theory can account for the significant increase in the EAS scores of this group. Similarly, the rise in the EAS points of the experiment group can be attributed to the fact that the STEMA is also a student-centered pedagogical learning and teaching approach, and that it was designed based on the reuse of waste materials in the study. The EAS scores of both groups were the same at the beginning of the investigation; however, those of the group under experimentation were meaningfully greater compared with the group under control at the finishing and 12 weeks after the end of the investigation. In other words, the STEMA was more efficient than the 5E model in raising EAS scores. Although a student-centered learning and teaching approach was applied in both groups, the EAS grades of the pupils in the class under experimentation were greater than those of the class under control at the end of the investigation. This consequence can be clarified by the fact that a KBLP which included interesting and multimedia elements was used in the STEMA, how the environmental issue would affect life in the STEMA was discussed, the students worked as an individual with a profession of their choice to resolve the issue, and a product was created to resolve the issue. This result can also be explained by the use of EE in real life by reusing and transforming waste substances into a new product. The literature includes studies that support the result of the present study. For example, Bulut (2024), Kavak (2024), Kuvaç (2018), Ünver Gürsoy (2024), Demirci (2023), Özdemir (2023), Demir (2021), Çalışıcı (2018) reported that STEM applications improved environmental attitudes.

Even though the research backs up the findings of this study, there are also differences. Kuvaç (2018), Demirci (2023), and Kavak (2024) used a one-group pretest-posttest experimental design in their studies. Bulut (2024), Alkan (2024), Ünver Gürsoy (2024), Demirci (2023), Kayaalp (2023), Yavuz (2020), and Çalışıcı (2018) gave STEM education on a limited topic of EE in 4–6 weeks. However, in this study, all of the EE topics at the secondary school level were addressed, the implementation was carried out in 12 weeks, a quasi-experimental method including the control group was applied, and the maintenance of the changes in the students' EAS and EKT levels was examined using a follow-up test. Duyal (2022) determined that STEM applies did not contribute to the development of environmental attitude, which contradicts the conclusion of the current research. This contradiction might be because Duyal (2022) addressed a limited number of topics related to EE, the study was completed in 5 weeks, and attitude is an affective trait that can change in a long time. There are also studies showing no significant difference in attitude scores as a result of short-term teaching interventions (Belhan & Laçin Şimşek, 2012; Ebren Ozan & Karamustafaoğlu, 2020).

According to the conclusions of the study, there was a meaningful increase in the EAS grades of the control and experimental groups, and this rise was preserved for 4 weeks after the study was completed. This can be explained by the fact that the teaching applied in both groups was student-centered and based on learning by doing and experiencing. The EAS levels of both study groups were alike at the start of the research; nevertheless, those of the class under experimentation were meaningfully greater than the group under control both at the finishing and 4 weeks after the end of the research. In other words, the STEMA was more effective than the 5E model in the development of the EAS level. This consequence might be clarified by the truth that the STEMA was employed to motivate students to learn environmental issues, environmental problems and concepts in the STEMA were examined, the students undertook an active role to solve the STEM problem, the students developed a product for the resolution of the environmental issue in the STEMA, how this product could offer a resolution to the environmental issue was shared and discussed in the class, and a conclusion was reached. According to Kayaalp (2023), researching the issue in the STEMA, developing resolutions, choosing the most suitable resolution, designing the resolution, developing a prototype, analyzing and assessing the resolution, and sharing the resolution contribute to the development of students' understanding levels. Additionally, teaching by integrating information from different fields and allowing students to be active would yield more efficient results than presenting it with a single discipline (Swapna, 2022). Some studies have found similar results to those of the present study. For example, Kuvaç (2018), Kavak (2024), Ünver Gürsoy (2024), Kınalıkaya (2019), Çalışıcı (2018) reported that STEM applications contributed to environmental knowledge. Kayaalp (2023) found that the STEMA contributed to conceptual understanding of the environment, Özdemir (2023) to environmental citizenship knowledge, and Koçak (2023) to the increase of environmental-literacy levels. The results of these studies support those of the present study. However, these studies differ from the present study in that they were conducted for 4–6 weeks, they taught a part of the subjects of EE, and did not apply a follow-up test.

Students' opinions about the use of the STEMA in EE were mostly grouped under the code of interesting and useful/developing. It can be argued that other codes (research, examination, problem solving, creative thinking, designing, and product creation) reflected the steps of the STEMA process in EE. The opinions about the effect of STEMA in EE on students mostly seemed to be under the code of self-expression. Considering the other codes (communicating, creative thinking, problem solving, and using materials), the STEMA contributed to cognitive, affective, and kinesthetic characteristics. The codes were grouped under the theme of skills developed in the individual. Students' opinions about the effect of the STEMA on their feelings and thoughts toward the environment mostly clustered under the code of being interested in environmental issues. Considering the other codes (loving the environment), it can be argued that the STEMA process in EE played a role in developing cognitive, affective, and kinesthetic characteristics toward the environment. The opinions of the students about the effect of the STEMA in EE on their daily lives mostly clustered under the codes of environmental protection, environmental awareness, and concern for the environment. Considering the other codes (communicating, loving the environment, and protecting the environment), it can be said that the use of the STEMA in EE positively contributed to daily life. The codes and themes obtained from the qualitative findings might be clarified by the truth that KBLP, which included multimedia elements that were interesting and motivating to learn environmental issues was used in STEMA, students collaborated to resolve the STEM issue and in the product development process, communicated with their groupmates, designed a product for the solution of the STEM problem, presented and discussed the product in the classroom. In addition, students used 21st CS (creative thinking-problem solving-teamwork-innovation-problem solving) in the process of generating solutions and product design for KBLP.

No negative code emerged as a result of the interviews, an outcome showing that pupils had favorable opinions about the use of the STEMA in EE. Bulut (2024), Alkan (2024), Kayaalp (2023), Özdemir (2023), Duyal (2022), and Koçak (2023) reported that students in their studies had positive views toward employing the STEMA in EE. In addition, students have positive opinions about the use of STEMA in science courses (Adams, Miller, Saul & Pegg, 2014; Akdağ & Güneş, 2017; Bozkurt & Ercan, 2016; Erdoğan & Çiftçi, 2017; Ercan, Bozkurt, Taştan & Dağ, 2016; Özçakır-Sümen & Çalışıçı, 2016). According to previous studies, participating students have reported that providing EE using the STEMA contributes to environmental awareness, making EE fun, designing products (Özdemir, 2023), meaningful learning, psychomotor, abilities, 21st century-higher order thinking skills (Koçak, 2023), group work and learning (Bulut, 2024), imagination, creative thinking, working together, designing, environmental awareness (Alkan, 2024), group work (Kayaalp, 2023), enabling EE to be useful, environment, learning, and facilitating learning (Duyal, 2022). These investigations support the conclusions of the current investigation. Some studies have also shown that the STEMA process is fun and enjoyable. Some studies have also shown that the STEMA process is fun and enjoyable (Erdoğan & Çiftçi, 2017) and contributes to the development of interest, motivation, and 21st-CS (Eroğlu & Bektaş, 2016).

Conclusions and Recommendations

The use of the 5E model and STEMA in EE made a significant contribution to the increase in environmental attitude and environmental knowledge levels. Although both are based on student-centered learning and learning by doing and experiencing, the STEMA was more effective than the 5E model in the development and maintenance of environmental attitude and knowledge. Students generally had positive opinions about using the STEMA in EE. Moreover, they thought that the STEMA contributed positively to their cognitive characteristics (e.g., learning and understanding environmental issues), affective characteristics (e.g., interest, attitude, love, and anxiety toward the environment), and their daily lives. The students' positive opinions supported the result of the positive effects of the STEMA on environmental attitude and environmental knowledge that were obtained in the quantitative section of the investigation. Based on the students' opinions, the STEMA also conduced to the growth of 21st-CS.

Based on the fact that EE subjects are interdisciplinary fields such as STEM education and are suitable for the STEM education process, the STEMA, as a pedagogical learning and teaching approach, should also be included in EE. In addition, it is recommended that effective EE that includes the recycling and reuse of waste materials through learning by doing and experiencing be provided.

Policy Implications

The results acquired in this research provide evidence that the STEMA in EE contributes to the growth of attitudes and knowledge levels towards the environment and that pupils have positive views regarding the environment at the end of the EE in which the STEMA is applied. EE aims to raise individuals with awareness-knowledge-attitudes-behaviors towards the environment. EE should be implemented using suitable learning-teaching methods in order to accomplish these objectives. The results obtained in this study show that STEMA is an appropriate learning-teaching approach that can be used in EE. This situation provides evidence for teachers, prospective teachers, and education policy makers that STEMA can be used not only in science education but also in EE. In this context, a more effective EE can be realized by including the STEMA in EE curricula. Thus, it can contribute to achieving EE goals and protecting the environment.

EE designed with the STEMA presented in this study constitutes a concrete application example for teachers, pre-service teachers and researchers. EE lesson plans designed with the STEMA produced by the investigators in this investigation will also contribute to the implementation of an effective EE and achieving EE goals. Thus, the EE application example and lesson plans designed with the STEMA developed in this study can be taken as a model by educators and education policy makers, and the application of the STEMA in EE can be made widespread. In addition, the STEMA in this research is based on the reuse of waste materials. This situation shows that STEMA can be done not only with robotics-maker-arduino studies but also with waste materials. Additionally, the application of the STEMA with waste materials proves that the STEMA can be applied at low costs. This situation can spread the implementation of STEMA in schools in low socioeconomic regions.

Conflict of Interest

Each of the investigators has no conflicts of interest.

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Ethical Statement

This investigation was examined at the meeting of the Gazi University Ethics Committee dated 07.12.2021, numbered 19, and found ethically appropriate with the decision numbered 2021-1123.

Credit Author Statement

Each author made an equal contribution to the study.

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