Implementing STEAM Activities with Biology Teachers in the Context of Ecology

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Abstract: This study investigates the impact of ecology-based STEAM (Science, Technology, Engineering, Art, and Mathematics) activities on biology teachers' ecological citizenship, STEAM awareness, and attitudes toward art education. Designed as a convergent parallel mixed-methods study, it involved 26 in-service biology teachers from diverse regions in Türkiye. Quantitative data were collected using three validated instruments: the Ecological Citizenship Scale, the STEM Awareness Scale for Secondary School Teachers, and the Attitude Toward Art Education Scale, applied as pre- and post-tests. Qualitative data was obtained through teachers' daily reflections, focus group interviews, and lesson plans developed during the training.The results showed significant improvements in teachers' ecological citizenship, STEM awareness, and attitudes toward art education. Teachers appreciated the interdisciplinary nature and classroom applicability of the 26 STEAM activities conducted over six days. While participants expressed high motivation to integrate STEAM practices, some lesson plans revealed insufficient interdisciplinary alignment, particularly in incorporating engineering, mathematics, and technology components. The findings highlight the potential of STEAM-based professional development to support both environmental awareness and pedagogical growth. However, the study also underscores the need for ongoing support in curriculum literacy and integrated instructional design to ensure the effective adoption of STEAM approaches in science education.

Keyword: STEAM education

Introduction

Human beings are constantly interacting with their environment, influencing it while simultaneously being influenced by it. This reciprocal relationship with all living and non-living components demonstrates that humans are an integral part of the ecosystem. However, ecosystems are increasingly being affected by human activities such as economic, social, artistic, and political decisions. These negative impacts have accelerated particularly since the Industrial Revolution. Humanity has now entered the Anthropocene, a new geological epoch characterized by the destructive footprint of human activities on the planet's natural systems. Despite numerous activities and projects aimed at mitigating these issues, environmental problems continue to escalate.

In this context, STEM aims to prepare students for the Fourth Industrial Revolution (the digital age). Yet these approaches often overlook global environmental crises. STEM-focused education typically fails to sufficiently address the ethical issues related to how STEM-related products are produced, consumed, and disposed of, and the environmental harm resulting from these processes. The STEAM approach, which integrates artistic disciplines into STEM, provides opportunities for learners to develop interdisciplinary knowledge and skills, strengthen creative thinking, enhance moral awareness, and cultivate a sense of environmental justice. In doing so, it supports pedagogical approaches that raise students' ethical and emotional consciousness and encourage active engagement in addressing environmental issues (Videla, et al., 2021).

STEAM education is expected to contribute to preparing human resources capable of multidimensional thinking to address current global challenges. Contemporary environmental issues require us to think differently, question more deeply, and take corrective action. Therefore, science education plays a more crucial role in educational transformation and societal adaptation than ever before, as the sustainability of our planet is ultimately at stake. Gülhan (2023) argued that STEAM education is among the most promising approaches for achieving these goals and provides a holistic and interdisciplinary perspective on environmental sustainability. This approach emphasizes that environmental sustainability exists not through linear relationships but within a complex, interconnected network, one that can only be fully understood and effectively addressed through interdisciplinary learning and practice.

Building on this perspective, the present study aims to highlight, through STEAM practices, not merely the visible “product” dimension commonly showcased in STEAM activities, but rather the process through which individuals develop their own innovative technologies by integrating mathematical and scientific knowledge with engineering and artistic thinking, while remaining attentive to environmental systems and the factors influencing them. In this regard, the EKO-STEAM project is designed to respond to 21st-century educational demands for biology teachers with fundamental knowledge, current developments, and examples of classroom/outdoor implementation on various environmental topics, including ecological systems, waste management, biodiversity, and environmental ethics. All activities were implemented through hands-on engagement in which teachers participated actively. The rationale for implementing STEAM-based instruction with biology teachers is explained below based on relevant literature and statistical evidence.

A review conducted at the TÜBİTAK Thesis Center for the years 2018–2023, using the keywords "STEM activities" and "STEAM activities", revealed that 22 studies focused on students, four on pre-service teachers, and only one on in-service teachers. Most of these studies were centered on physics and chemistry, with limited attention paid to the field of biology. Additionally, the sources of the implemented activities were not specified in many theses.

According to OECD’s *Education at a Glance 2024* data, there has been a remarkable improvement in the educational attainment of young adults aged 25–34 in Türkiye between 2019 and 2024. The proportion of young adults with below upper secondary education decreased from 41% to 28%, whereas the OECD average for the same age group was 13% in 2024. The rate of upper secondary graduation in Türkiye increased from 28% to 31%, while the OECD average reached 39% in 2024. At the higher education level, the proportion of bachelor’s degree graduates rose from 28% to 30%, and the proportion of postgraduate degree holders increased from 3% to 4%. In contrast, the OECD average for total higher education attainment reached 48% in 2024. These data indicate that although Türkiye has made meaningful progress in educational attainment, it remains significantly below the OECD average, particularly in higher education (OECD, 2024).

Supporting this situation, the 2023 AYT (Field Proficiency Test) results show that the average score on the 13-item Biology test was 2.08 among 12th-grade students and 1.887 across all candidates (OSYM, 2023). This outcome highlights the low level of academic achievement in the field of Biology. Moreover, the OECD reports that 67.1% of young people aged 18–24 in Türkiye are neither in education nor training, making Türkiye the country with the second-highest rate among OECD member states (TEDMEM, 2023). Additionally, according to 2020/21 data, the upper secondary completion rates were 70.5% for males and 76% for females (TUİK, 2023).

In the context of labor-market requirements, skills such as critical thinking, decision making, creativity, entrepreneurship, and teamwork have become increasingly important (World Economic Forum, 2019). The *Future of Jobs Report 2025* further states that technological skills will rise in importance at a faster pace than any others over the next five years. Artificial intelligence (AI) and big data are identified as the most crucial competencies, followed by network technologies, cybersecurity, and general technological literacy. Additionally, skills such as creative thinking, resilience, flexibility, agility, curiosity, and lifelong learning habits are gaining prominence (World Economic Forum, 2025).

Considering these findings and statistical indicators, it can be argued that developing competencies such as scientific literacy, environmental literacy, and health literacy among young people in Türkiye remains challenging. Educational activities play a critical role in fostering these competencies, and various instructional methods are employed. The Ministry of National Education also supports skill-oriented learning through its curriculum renewal initiatives (MEB, 2024). This study aims to contribute to the renewed curriculum through STEAM activities and teacher training focusing on the theme of ecology.

Globally and nationally, societies are facing environmental challenges such as climate change, air pollution, the depletion of water resources, and the loss of biodiversity. For this reason, the present study addresses ecological citizenship in education, considering both teachers' perspectives and the potential impact of the project on students. Türkiye, as one of the countries located within the Mediterranean basin, is among the regions at high risk regarding climate change. The Mediterranean region is prone to decreased precipitation during winter months. Reports published by the Intergovernmental Panel on Climate Change [IPCC] highlight several critical parameters, including changes in precipitation regimes, decreases in snowfall and rainfall, excessive and unsustainable use of water resources, and the reduction of groundwater levels. Due to growing climate concerns, it is expected that education will contribute solutions to this global problem. Educational planning must incorporate universal issues; therefore, the role of education in addressing climate change has increased significantly (Mochizuki & Bryan, 2015). Article six of the United Nations Framework Convention on Climate Change [UNFCCC] emphasizes that countries should raise awareness through education (UNFCCC, 1992). To prevent climate change from becoming an even more severe global threat, national and international educational initiatives are essential for raising public awareness (Ay & Erik, 2020).

One of the topics addressed within the ecology theme in this study is water pollution. Climate change has adverse effects on freshwater resources and the water cycle, leading to floods in some regions and severe water scarcity in others (Çapar, 2019). According to the United Nations World Water Development Report (2020), global water use has increased sixfold over the past century and continues to grow by approximately 1% annually due to population growth. The depletion of freshwater resources constitutes a major global crisis (Bildiren & Sargıncı, 2022). Therefore, the project aimed to enhance students' awareness of water-related issues through hands-on activities. Other topics emphasized within the project include air pollution and biodiversity loss—two significant ecological problems intensified by ecosystem degradation. According to the Worldwide Fund for Nature [WWF] Türkiye (2021), while more than 25% of land area in Europe is designated as protected, only 8.7% of Türkiye's land area holds protected status. For a sustainable future, this percentage must increase to at least 30% by 2030. These areas are critically important for the continuity of ecological processes, genetic diversity, and endangered species (WWF-Türkiye, 2020).

The instructional practices implemented in the current study were based on the STEAM teaching approach. The STEAM approach brings artistic practices into STEM fields, thereby fostering learners' creativity, innovative thinking, and problem-solving abilities (Hetland & Winner, 2004; Liao, 2016). It is also a multidimensional educational approach that fosters employability skills such as collaboration, communication, and adaptability, thereby contributing to career development and economic advancement (Colucci-Gray et al., 2017). The primary purpose of STEAM-based educational models is to enhance the creativity of young learners, enabling them to design products that are both aesthetically meaningful and functionally effective (Erdoğan, 2020). Research indicates that creativity tends to decline during the transition from primary to secondary school (Runco & Charles, 1997; Torrance, 1968). The primary reason for this decline is rote-based learning. In STEAM-based education, curiosity and inquiry play a central role; thus, integrating art-based activities into STEM instruction is essential for sustaining creativity. For this reason, the present study utilized art-based activities within the STEAM framework.

Nature itself is a form of art in which mathematics and science are inherently intertwined. The hexagonal structure of honeycombs exemplifies the "honeycomb conjecture," providing the most efficient use of space and serving as inspiration for technological design (Hales, 2001). Natural structures such as the wings of birds, the leg structures of insects, and the tendril curve of climbing plants have inspired technological innovations ranging from airplanes to robotic systems. Like STEAM, nature is an interdisciplinary and integrated system.

A review of the literature shows that STEM/STEAM studies conducted on environmental topics have predominantly been carried out with students and pre-service teachers and have generally produced positive outcomes (Gottfried, 2015; Kılınç, 2018). Gottfried (2015) demonstrated that STEM education increases students' inclination to select mathematics and science courses and enhances their attitudes toward the environment. Research consistently confirms that STEM activities increase environmental awareness and interest. Similarly, Kılınç (2018) found that project-based environmental education fosters environmentally friendly behaviors among pre-service science teachers. Yıldırım (2019) revealed that the integration of biomimicry practices into STEM instruction changes pre-service teachers' perspectives on nature and technology. In another study, Çilek (2019) implemented a STEM lesson plan on global warming with 5th-grade students. Through a prototype developed using Arduino, the influence of CO_2 on temperature increase was measured, and STEM instruction was found to have positive effects on students' attitudes.

Another study explored the effectiveness of a STEAM-based, space-themed learning module implemented at the elementary level, involving 180 students in the experimental group and 94 in the control group. After an eight-week intervention, findings indicated that gender and academic achievement significantly influenced the module's effectiveness; female students demonstrated the greatest increase between pre-test and post-test scores. In addition, the traditional instructional approach was found to reduce performance among some high-achieving students (Arpaci, et al., 2023). Similarly, in a study employing STEM-based instructional design for the topic "Matter Cycles and Environmental Problems," students in the experimental group developed products aimed at reducing environmental pollution (Dallı, 2019).

Videla, et al., (2021) suggested extending the scope of an active-ecological approach into STEAM learning, particularly when the goal is to understand the deep roots of the learning process. Sayuda, Kinoshita, and Pennington (2025) showed that after-school STEAM and citizen science programs promote long-term environmental engagement among both students and families. Likewise, Keum and Baek (2025) found that students' environmental competencies concerning climate change increased. A STEAM-based environmental education experience conducted with 25 primary school students resulted in a statistically significant improvement in ecological literacy levels (Ali, Ismail, & Nurfadila, 2025). Baek (2023) demonstrated that 6th-grade students in South Korea developed environmental competencies through a STEAM-based plant education program. Bulut (2024) examined the effects of STEM activities related to environmental education on middle school students' attitudes, learning responsibility, and perceptions of STEM; the findings indicated positive changes in these areas, as well as enhancements in students' cognitive structures regarding STEM.

In another study examining how STEM education influences pre-service science teachers' understanding of STEM learning, their application of chemical concepts in the production of bioplastic materials, and their design of environmentally focused STEM lesson plans, 93% of teachers reported concerns about how to develop an effective project. The authors emphasized the importance of teacher education programs that incorporate professional development, content knowledge, pedagogy, practice opportunities, reflection, and revision within collaborative and supportive environments (Hasanah, et al., 2022). Ayverdi et al. (2024) found that science teachers hold positive views toward integrating the STREAM approach with sustainable development goals and that they require interdisciplinary integration, awareness activities, and project-based applications in instructional design processes. Green, et al., (2016) reported that pre-service teachers showed increased environmental citizenship awareness, including self-efficacy, value awareness, ecological literacy, and civic literacy after participating in a targeted instructional intervention. Through a critical evaluation of local energy production systems, these teacher candidates also recognized energy conservation as a cultural issue with local and global implications and strengthened their commitment to action-oriented environmental education.

Over the past 15 years, international frameworks such as the United Nations [UN], UNESCO, and the Incheon Declaration have increasingly promoted education for sustainability and sustainable development. However, despite numerous student-centered recommendations, there is limited evidence regarding how these approaches are addressed within STEAM-based teacher education programs. Ariza and Olatunde-Aiyedun (2024) conducted a systematic literature review based on 207 studies retrieved from Scopus, Web of Science, and ERIC, following PRISMA guidelines. Their findings highlight the absence of courses integrating sustainability and STEAM disciplines in pre-service teacher programs. They also noted that interventions developed for STEAM teacher training tend to focus on mathematics and statistics and are often recommended for teachers in rural areas. In-service teachers were found to struggle with connecting theoretical concepts to real-world experiences. Instructional strategies used in these studies included problem-based learning, inquiry-based learning, escape rooms, robotics, and flipped learning. Their research contributes to the development of pre-service and in-service teacher education programs aligned with STEAM education and sustainable development goals, emphasizing the critical role of teachers.

Other studies in the literature also emphasize that long-term STEAM training for teachers is essential for successful implementation (Herro, et., 2019). The success of STEAM relies on interdisciplinary collaboration, which is necessary to create integrated curricula (Kelley & Knowles, 2016). Lin and Tsai (2021) argue that teachers should engage in practices that help them design activities that foster creative thinking, while Bush and Cook (2019) note that providing teachers with adequate resources to integrate art and technology into the classroom enhances student engagement. Additionally, the integration of STEAM in schools must be supported by educational policies (Herro, et., 2019).

The present study is significant in that it enables the STEAM instructional approach to be experienced at the secondary education level through both in-school (laboratory-based) and out-of-school activities. Moreover, the practices developed within the scope of the project have the potential to serve as exemplary models for the education system, thereby enhancing the originality and value of the study.

Through hands-on training conducted with Biology teachers in both natural settings and laboratory environments using a STEAM (science, technology, engineering, art, and mathematics) education approach centered on the theme of ecology, the study aims to:

- Develop Biology teachers' skills in planning STEAM activities on the theme of ecology for their lessons,
- Foster ecological citizenship among Biology teachers through STEAM-based practices,
- Raise awareness of the STEAM instructional approach among Biology teachers and promote positive attitudes toward art education through STEAM activities focused on the theme of ecology.

Accordingly, the research problems of the study are as follows:

- What are teachers' views regarding the STEAM activities implemented within the scope of the ecology theme?
- How do teachers design instructional plans for teaching ecology topics using the STEAM approach after completing the project?
- What is the effect of STEAM activities conducted within the ecology theme on teachers' ecological citizenship, STEM awareness, and attitudes toward art education?

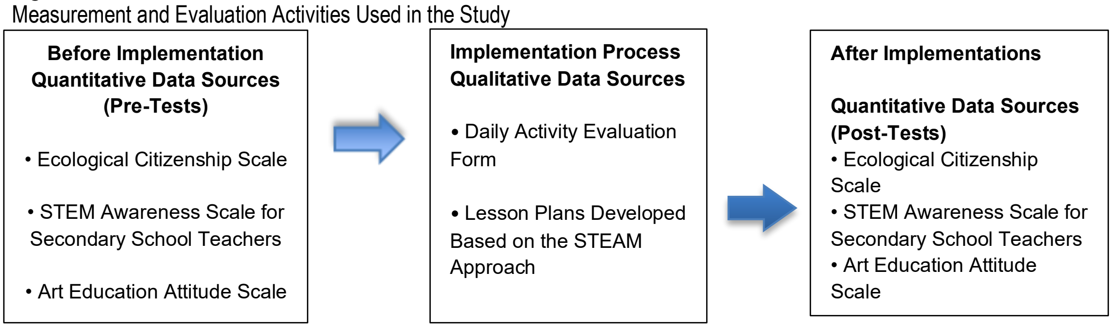
Method

This study was designed using the convergent parallel mixed-methods design, one of the mixed research method patterns. In this design, qualitative and quantitative data are collected simultaneously and analyzed separately (Creswell & Creswell, 2018). In the qualitative dimension of the study, an open-ended "Daily Activity Evaluation Form" was administered at the end of each day of the training to determine biology teachers' views regarding the activities conducted and the STEAM practices implemented.

Among qualitative data collection techniques, the focus group interview which is a method increasingly used in recent years was also employed. A focus group interview is defined as a planned series of discussions conducted with a selected group of participants to gather information on a predetermined topic. Participants are not expected to reach complete agreement, nor is divergence of views a requirement. The aim is to create a productive discussion environment that yields rich data consisting of varying perspectives, opinions, evaluations, and experiences related to the topic under investigation (Baş & Akturan, 2017).

To determine the extent to which participating teachers could design instructional plans using the STEAM approach in the teaching of ecological concepts, they were asked to develop lesson plans. In the quantitative dimension of the study, the Ecological Citizenship Scale, the STEM Awareness Scale for Secondary School Teachers, and the Art Education Attitude Scale were administered as pre- and post-tests to examine the effects of the instructional intervention on teachers' ecological citizenship, STEM awareness, and attitudes toward art education. The measurement and evaluation procedures applied in this research are summarized in Figure 1.

Figure 1.
Measurement and Evaluation Activities Used in the Study



Sample Group

As previously stated, this project was supported by TÜBİTAK; therefore, the biology teachers included in the study group were selected from various regions across Türkiye. The study group was determined using maximum variation sampling, one of the purposive sampling methods. Maximum variation sampling aims to construct a sample that reflects the broadest possible range of diversity by identifying key dimensions of variation and selecting cases that differ from one another to the greatest extent (Suri, 2011).

Within this scope, prior to determining the study group, an online announcement was published inviting biology teachers to complete an application form. The form included personal information such as gender, type of school they worked in, province/district of employment, and postgraduate education status, along with an open-ended question: “Why do you want to participate in this project?” Responses to the application forms were reviewed after the application period ended, and attention was given to ensuring an equal distribution of participants across different regions of the country. However, due to the high number of female applicants in this field, gender balance could not be fully achieved.

To enhance creativity in the development of STEAM products and to strengthen peer learning and teacher interaction during group work, attention was also paid to selecting teachers from different types of schools. As a result, a total of 26 biology teachers consisting of 5 males and 21 females were participated in the study. Teachers were coded like T1, T2.

Data Collection Instruments

To determine the biology teachers’ opinions regarding the STEAM activities implemented on ecological topics, the Daily Activity Evaluation Form, developed by the researchers, was administered at the end of each day. This form included the following open-ended questions:

1. Which of today’s activities do you think you can implement in the school where you teach? Please explain briefly.
2. Which of today’s activities do you think contributed to you the most? Please explain briefly.
3. Which dimension of the STEAM approach do you think today’s activities supported?
4. In which aspect of teaching ECOLOGY theme do you think today’s activities contributed to you?
5. Did you experience any activities or situations that you found difficult or less beneficial? Please specify briefly.

To determine biology teachers' ability to develop instructional designs for teaching ecological topics through the STEAM approach, the lesson plans they prepared at the end of the project were analyzed using descriptive analysis. Unlike content analysis, descriptive analysis relies on predefined categories, and the data are analyzed in accordance with these categories (Yıldırım & Şimşek, 2013).

To examine the effect of the intervention on teachers' ecological citizenship, the Ecological Citizenship Scale, developed by Karatekin and Uysal (2018), was administered as a pre- and post-test. The scale consists of 24 items on a 5-point Likert type and is structured under four factors. Exploratory and Confirmatory Factor Analyses revealed that the items clustered under participation, sustainability, responsibility, and rights and justice. Cronbach's alpha internal consistency coefficients for each dimension and the overall scale were calculated as .87, .76, .75, .64, and .90, respectively (Karatekin & Uysal, 2018).

To measure the effect of the intervention on teachers' STEM awareness, the STEM (FeTeMM) Awareness Scale for Secondary School Teachers, developed by Çevik (2017), was administered as a pre- and post-test. The scale consists of 15 items on a 5-point Likert type. The items were found to form three subdimensions: "Impact on Students," "Impact on the Course," and "Impact on the Teacher." Cronbach's alpha coefficients for each subdimension and the full scale were reported as .81, .71, .72, and .82, respectively.

To examine the effect of the project activities on teachers' attitudes toward art education, the Attitude Toward Art Education Scale (Aykanat, 2018) was used. The scale consists of 23 items on a 5-point Likert type distributed across four factors: Enjoyment of Art and Contribution of Art Education, Negative Attitudes toward Art, Communication-Enhancing Role, and Role of Importance. The Cronbach's alpha coefficients for these factors were calculated as .94, .95, .89, and .81, respectively (Aykanat, 2018).

All scales and permissions for their applications were obtained.

Implementation of the Study

Within the scope of the project, a total of twenty-six activities were implemented over six days in both laboratory settings and various out-of-school learning environments, including the Çanakkale Municipality Biological Wastewater Treatment Plant, the Çanakkale Municipality Solar Power Plant, Ayazma Spring located on the foothills of Mount Ida, the ancient city of Troy, the Troy Museum, the Gallipoli Historical Site Martyrs' Memorial Area, and the University's Herbarium.

The activities conducted throughout the project included: What is STEAM?; Developing a Project-Based STEAM Activity Plan for Biodiversity Conservation in the New Biology Curriculum; Assessment and Evaluation Methods and Techniques in the STEAM Instructional Model; Designing an Ecosystem; Global Warming–STEAM; Changes in Water Quality Along a Stream; Water Ecosystems with STEAM; What Lives in an Aquatic Ecosystem?; Attention—Do Not Let Them Disappear; Insect Collector: The Naturalist in Me; Plant Biodiversity of Türkiye; Plant Biodiversity of Türkiye—Herbarium and Field Study; Innovative Approaches in Biology Classrooms: Teaching Ecology with Web 2.0 Tools; Planning Biology Instruction Using the STEAM Approach; From Nature to Fashion: Designing My Own Hat; In the Footsteps of Troy: Visualizing the Transformation of an Ancient City Through Artificial Intelligence; Climate Change and Ancient Cities: The Case of Troy; Visual Ecology: Visualizing the Effects of Ecosystems on Plant Species Using NVIDIA Canvas; The Language of Plants; Inquiry-Based Ecology Education

Enriched with Simulations; Assessment and Evaluation Methods for Use in the STEAM Approach; Calculating My Water Footprint—Çanakkale Municipality Biological Wastewater Treatment Plant; Renewable Energy: Çanakkale Municipality Solar Power Plant; Collecting Solar Energy for Greenhouses; Biomimicry and STEAM: Protecting Pelicans; Factors Affecting Plants in the Ecosystem; and The Impact of War on the Ecosystem: Gallipoli Historical Area.

Since the sample was intended to include teachers working in different types of high schools across various geographical regions of Türkiye, the activities were diversified accordingly and planned to ensure that they would be applicable in school contexts, particularly within STEAM and ecology themes and skill-oriented learning. The implementation lasted six days, with nine hours of training per day. The sample activities were placed in article video.

Data Analysis

In the analysis of the data, the teachers' views on the STEAM activities implemented within the scope of the project were examined using content analysis of the daily activity evaluation reports. Through content analysis, similar data are grouped together within specific concepts and themes and organized in a way that is understandable to the reader. A descriptive analysis technique was employed to evaluate the lesson plans. This method interprets data by structuring it around themes established prior to the analysis. This process involves the following steps: (1) coding the data, (2) identifying themes, (3) organizing codes and themes, and (4) describing and reporting the findings (Yıldırım & Şimşek, 2016). Within this framework, the daily activity evaluation reports were first grouped separately for each day, read individually by the researchers, and codes and themes were developed. In the final stage, findings were reported by providing illustrative quotations under the identified themes.

To investigate teachers' ability to design instructional activities for teaching ecological concepts through the STEAM approach, they were asked to prepare a lesson plan addressing a learning outcome of their choice related to the ecology theme at the 10th-grade level. A descriptive analysis technique was employed to evaluate the lesson plans. This method interprets data by structuring it around themes established prior to the analysis (Yıldırım & Şimşek, 2016). The themes used in the analysis of the lesson plans were: *"Alignment of Learning Outcome and Instructional Design"* and *"Alignment of Instructional Design with the STEAM Approach."* The lesson plans were examined and interpreted within these thematic categories.

To examine the effect of the STEAM activities implemented within the project on teachers' ecological citizenship, STEM awareness, and attitudes toward art education, the significance of the differences between pre-test and post-test scores was tested. To determine the appropriate statistical test, the normality of the difference scores was checked, and the results are presented in Table 1.

Table 1.
Descriptive Statistics of Pre- and Post-Test Difference Scores

Variable	n	Minimum Value	Maximum Value	Mean ($\bar{x}$)	SD (s)	Skewness	Skewness SE	Kurtosis	Kurtosis SE
Ecological Citizenship Difference Score	25	-.42	1.21	.31	.44	.17	.46	-.41	.90
STEM Awareness Difference Score	25	-.53	1.60	.42	.54	.41	.46	-.17	.90
Art Education Attitude Difference Score	25	-.48	1.09	.19	.40	.18	.46	-.56	.90

An examination of table 1 shows that the skewness and kurtosis coefficients of the difference scores fall between –1 and +1, suggesting that the distributions are normal. Accordingly, since the normality assumption for the difference scores was met, the paired-samples t-test, one of the parametric tests, was deemed appropriate for the analysis. A paired-samples t-test allows for the comparison of data collected from the same sample at two different points in time to determine changes in the same variable (Livingston, 2014).In this context, the data obtained from the Ecological Citizenship Scale, the STEM Awareness Scale, and the Attitude Toward Art Education Scale, administered to teachers before and after the project, were compared.

Ethical Considerations

This research was carried out as part of the TÜBİTAK-funded project numbered 123B837. Prior to the study, ethical approval was obtained from the Ethics Committee of Çanakkale Onsekiz Mart University (Approval No: E-84026528-050.01.04-2300301751). In addition, the necessary legal permissions were obtained from the Provincial Directorates of National Education to which the participants were affiliated and where the implementation took place. The procedures for determining the sample group were explained under the "Participant Group" section. Informed consent was obtained from all participants, and participation in the study was entirely voluntary.

Results

Findings Related to Teachers' Views on the STEAM Activities

During the research process, teachers were asked to complete a daily activity evaluation report at the end of each day to assess the activities carried out. Analysis of the qualitative data revealed that most teachers found most of the activities useful:

> T13: "All of them contributed a lot. I have read many articles and attended seminars on STEAM before, but this is the first time I have felt so close to actual practice. (Day 1 activities)

> T25: "They were full, enjoyable, meaningful, and sufficiently beneficial activities that could easily be used in the classroom." (Day 1 activities)

> T19: "My purpose in coming here was to learn different ecological activities to apply with my students. I am learning something new every day. Wonderful." (Day 2 activities)

> T18: "The inquiry-based instruction enriched with simulations contributed the most." (Day 4 activities)

> T22: "Seeing the waste treatment and solar energy facilities in our environment contributed greatly. I was lucky to see them for the first time. I should also bring my students. Greenhouse-related activity helped in finding solutions to problems. Each activity was of very high quality." (Day 5 activities)

Teachers also reported that the activities contributed to teaching ecology-related topics such as *ecosystems, sustainability, protection of natural life,* and *environmental pollution*:

> T3: "Factors affecting the ecosystem, matter and energy flow, sustainability." (Day 1)

> T20: "It contributed to the topics of environmental pollution, biodiversity, and sustainability." (Day 2)

> T5: “It contributed to topics such as the importance of diversity, environmental pollution, and disruption of natural balance.” (Day 3)

> T19: “Plant systematics, how the environment transforms cities (Troy visit), and using technology while teaching ecology.” (Day 4)

Furthermore, teachers stated that they could apply most of the activities in their classrooms:

> T6: “I plan to implement the aquarium activity as a project performance task in 9th-grade biology.” (Day 1)

> T12: “I can apply the tower activity in the Support and Movement Unit, and the floating house and terrarium in the ecology unit. Materials are easy to find, and students’ creativity will lead to good outcomes.” (Day 1)

> T18: “Collecting samples in aquatic ecosystems and measuring changes in water quality along a stream are applicable. Although outdoor activities may be challenging, they can be implemented with proper permissions.” (Day 2)

> T2: “I can do the clay house, Web 2.0 tools, and artificial intelligence activities with my students. I previously created a story using AI in my school. All are applicable.” (Day 3)

> T5: “I can apply the ‘Collecting Solar Energy for the Greenhouse’ and ‘Effects of Environmental Factors on Plants’ activities in my school. Both activities allow learning outcomes to be achieved effectively.” (Day 5)

Only one activity—the *“Language of Plants”* activity conducted on Day 4—was criticized by many teachers for not being suitable for secondary school students’ readiness levels, being too long, and not fully aligned with the STEAM approach:

> T22: “The Language of Plants activity was too long and too simple.” (Day 4)

> T5: “I think the activity was not appropriate for students’ readiness levels and that its purpose was lost due to being unnecessarily prolonged.” (Day 4)

> T2: “I believe the contribution level of the Language of Plants activity was lower.” (Day 4)

Teachers also stated that the activities exemplified an interdisciplinary perspective by integrating science, mathematics, technology, art, and engineering in biology teaching:

> T12: “Engineering, art, and science.” (Day 1)

> T26: “I think it contributed to all areas—mathematics, engineering, art, and technology.” (Day 1)

> T20: “Science, art, engineering, mathematics.” (Day 2)

> T18: “It contributed to the dimensions of science, technology, engineering, art, and mathematics.” (Day 3)

> T5: “Effects of environmental factors on plants – Science, technology
> Wastewater treatment plant – Science, technology, engineering
> Solar greenhouse activity – Engineering, science, technology, art.” (Day 5)

Teachers also stated that they gained experience in planning ecology teaching based on the STEAM approach:

> T2: "…the planning activities were helpful." (Day 3)

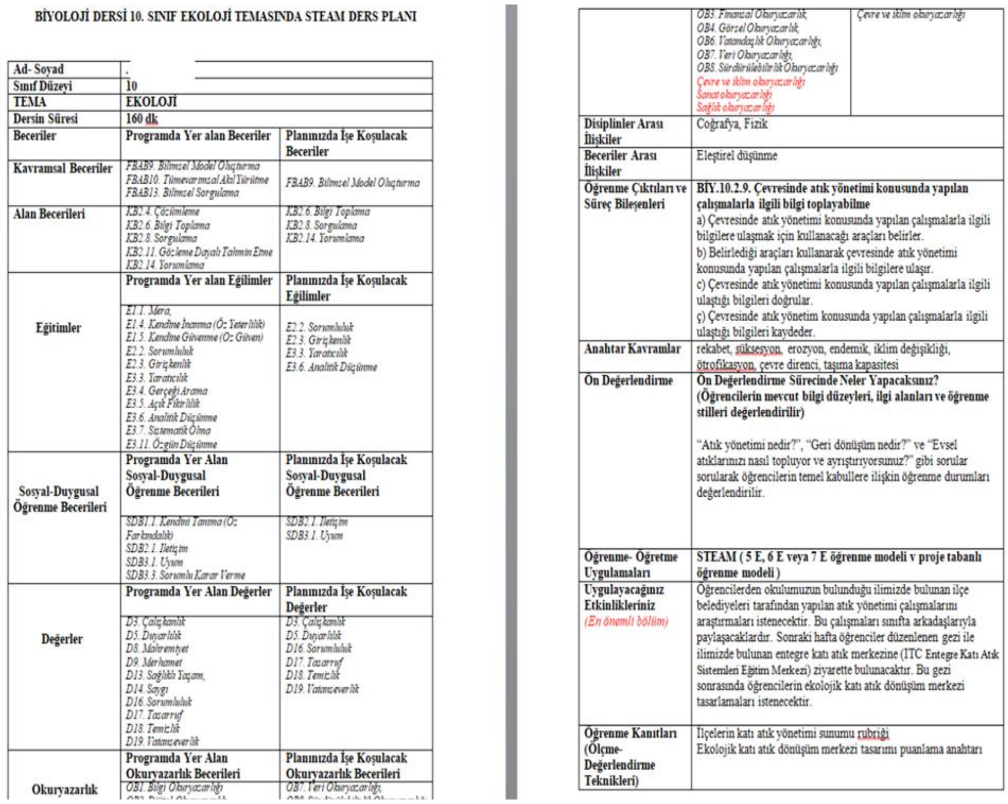
> T26: "I realized once again that plans are more meaningful when put into practice rather than remaining on paper." (Day 3)

Considering these findings, it can be concluded that participating teachers gained knowledge about planning and implementing STEAM-based activities suitable for classroom use. Except for a single activity, teachers found all activities included in the project useful and appropriate for teaching ecology topics in secondary school biology classes. Moreover, most teachers stated that they could implement the majority of the activities in their own classrooms.

Findings Regarding Teachers' Development of Instructional Designs for Teaching Ecology Topics Through the STEAM Approach

During the study, teachers were asked to prepare a lesson plan aligned with a learning outcome of their choice related to the ecology theme at the 10th-grade level. Eight participants completed their lesson plans during the implementation process. The eight completed lesson plans (prepared by T2, T4, T5, T8, T9, T14, T18, and T19) were analyzed through descriptive analysis under the categories of "Alignment of Learning Outcome and Instructional Design" and "Alignment of Instructional Design with the STEAM Approach.". Examination of the data revealed that several teachers developed instructional designs that were appropriate for the selected learning outcomes.

Figure 1.
Lesson Plan Prepared by T4



BİYOLOJİ DERSİ 10. SINIF EKOLOJİ TEMASINDA STEAM DERS PLANI

Ad- Soyad	.	
Sınıf Düzeyi	10	
TEMA	EKOLOJİ	
Dersin Süresi	160 dk	
Beceriler	**Programda Yer alan Beceriler**	**Planınızda İşe Koşulacak Beceriler**
Kavramsal Beceriler	*FBAB9. Bilimsel Model Oluşturma* *FBAB10. Tümevarımsal Akıl Yürütme* *FBAB13. Bilimsel Sorgulama*	*FBAB9. Bilimsel Model Oluşturma*
Alan Becerileri	*KB2.4. Çözümleme* *KB2.6. Bilgi Toplama* *KB2.8. Sorgulama* *KB2.11. Gözleme Dayalı Tahmin Etme* *KB2.14. Yorumlama*	*KB2.6. Bilgi Toplama* *KB2.8. Sorgulama* *KB2.14. Yorumlama*
Eğitimler	**Programda Yer alan Eğilimler**	**Planınızda İşe Koşulacak Eğilimler**
	E1.1. Merak, *E1.4. Kendine İnanma (Öz Yeterlilik)* *E1.5. Kendine Güvenme (Öz Güven)* *E2.2. Sorumluluk* *E2.3. Girişkenlik* *E3.3. Yaratıcılık* *E3.4. Gerçeği Arama* *E3.5. Açık Fikirlilik* *E3.6. Analitik Düşünme* *E3.7. Sistematik Olma* *E3.11. Özgün Düşünme*	*E2.2. Sorumluluk* *E2.3. Girişkenlik* *E3.3. Yaratıcılık* *E3.6. Analitik Düşünme*
Sosyal-Duygusal Öğrenme Becerileri	**Programda Yer Alan Sosyal-Duygusal Öğrenme Becerileri**	**Planınızda İşe Koşulacak Sosyal-Duygusal Öğrenme Becerileri**
	SDB1.1. Kendini Tanıma (Öz Farkındalık) *SDB2.1. İletişim* *SDB3.1. Uyum* *SDB3.3. Sorumlu Karar Verme*	*SDB2.1. İletişim* *SDB3.1. Uyum*
Değerler	**Programda Yer Alan Değerler**	**Planınızda İşe Koşulacak Değerler**
	D3. Çalışkanlık *D5. Duyarlılık* *D8. Mahremiyet* *D9. Merhamet* *D13. Sağlıklı Yaşam,* *D14. Saygı* *D16. Sorumluluk* *D17. Tasarruf* *D18. Temizlik* *D19. Vatanseverlik*	*D3. Çalışkanlık* *D5. Duyarlılık* *D16. Sorumluluk* *D17. Tasarruf* *D18. Temizlik* *D19. Vatanseverlik*
Okuryazarlık	**Programda Yer Alan Okuryazarlık Becerileri**	**Planınızda İşe Koşulacak Okuryazarlık Becerileri**
	OB1. Bilgi Okuryazarlığı	*OB7. Veri Okuryazarlığı,*

	OB3. Finansal Okuryazarlık, *OB4. Görsel Okuryazarlık,* *OB6. Vatandaşlık Okuryazarlığı,* *OB7. Veri Okuryazarlığı,* *OB8. Sürdürülebilirlik Okuryazarlığı* *Çevre ve iklim okuryazarlığı* *Sanat okuryazarlığı* *Sağlık okuryazarlığı*	*Çevre ve iklim okuryazarlığı*
Disiplinler Arası İlişkiler	Coğrafya, Fizik	
Beceriler Arası İlişkiler	Eleştirel düşünme	
Öğrenme Çıktıları ve Süreç Bileşenleri	**BİY.10.2.9. Çevresinde atık yönetimi konusunda yapılan çalışmalarla ilgili bilgi toplayabilme** a) Çevresinde atık yönetimi konusunda yapılan çalışmalarla ilgili bilgilere ulaşmak için kullanacağı araçları belirler. b) Belirlediği araçları kullanarak çevresinde atık yönetimi konusunda yapılan çalışmalarla ilgili bilgilere ulaşır. c) Çevresinde atık yönetimi konusunda yapılan çalışmalarla ilgili ulaştığı bilgileri doğrular. ç) Çevresinde atık yönetim konusunda yapılan çalışmalarla ilgili ulaştığı bilgileri kaydeder.	
Anahtar Kavramlar	rekabet, süksesyon, erozyon, endemik, iklim değişikliği, ötrofikasyon, çevre direnci, taşıma kapasitesi	
Ön Değerlendirme	**Ön Değerlendirme Sürecinde Neler Yapacaksınız? (Öğrencilerin mevcut bilgi düzeyleri, ilgi alanları ve öğrenme stilleri değerlendirilir)** "Atık yönetimi nedir?", "Geri dönüşüm nedir?" ve "Evsel atıklarınızı nasıl topluyor ve ayrıştırıyorsunuz?" gibi sorular sorularak öğrencilerin temel kabullere ilişkin öğrenme durumları değerlendirilir.	
Öğrenme- Öğretme Uygulamaları	**STEAM (5 E, 6 E veya 7 E öğrenme modeli v proje tabanlı öğrenme modeli)**	
Uygulayacağınız Etkinlikleriniz *(En önemli bölüm)*	Öğrencilerden okulumuzun bulunduğu ilimizde bulunan ilçe belediyeleri tarafından yapılan atık yönetimi çalışmalarını araştırmaları istenecektir. Bu çalışmaları sınıfta arkadaşlarıyla paylaşacaklardır. Sonraki hafta öğrenciler düzenlenen gezi ile ilimizde bulunan entegre katı atık merkezine (ITC Entegre Katı Atık Sistemleri Eğitim Merkezi) ziyarette bulunacaktır. Bu gezi sonrasında öğrencilerin ekolojik katı atık dönüşüm merkezi tasarlamaları istenecektir.	
Öğrenme Kanıtları (Ölçme-Değerlendirme Teknikleri)	İlçelerin katı atık yönetimi sunumu rubriği Ekolojik katı atık dönüşüm merkezi tasarımı puanlama anahtarı	

When Figure 1 is examined, it is seen that T4 designed an instructional plan aligned with the learning outcome “Collect information about the waste management practices carried out in one’s local environment.” In this plan, students are first asked to investigate solid waste management practices in the province and district where their school is located, followed by a planned visit to a solid waste facility. In the final stage of the plan, students are tasked with designing their own solid waste treatment plant. As observed, all the activities designed by T4 contribute directly to achieving the selected learning outcome.

Similarly, T5 developed an instructional plan aligned with the learning outcome “Interpret the importance of ecological sustainability,” which includes organizing a field trip to the Mamak Landfill, examining how methane gas released at the site is utilized, and designing a modern landfill. Although T5’s activities resemble T4’s design and are related to ecological sustainability, they are more directly connected to waste management. In this regard, T4’s instructional design is more closely aligned with the targeted learning outcome.

Figure 2.
Lesson Plan Prepared by T8

Sınıf Düzeyi	**10**	
TEMA	**EKOLOJİ**	
Dersin Süresi	**40+40 dk**	
Beceriler	**Programda Yer alan Beceriler**	**Planınızda İşe Koşulacak Beceriler**
Kavramsal Beceriler	*FBAB9. Bilimsel Model Oluşturma FBAB10. Tümevarımsal Akıl Yürütme FBAB13. Bilimsel Sorgulama*	*FBAB9. Bilimsel Model Oluşturma FBAB10. Tümevarımsal Akıl Yürütme FBAB13. Bilimsel Sorgulama*
Alan Becerileri	*KB2.4. Çözümleme KB2.6. Bilgi Toplama KB2.8. Sorgulama KB2.11. Gözleme Dayalı Tahmin Etme KB2.14. Yorumlama*	*KB2.4. Çözümleme KB2.6. Bilgi Toplama KB2.8. Sorgulama KB2.11. Gözleme Dayalı Tahmin Etme KB2.14. Yorumlama*
Eğitimler	**Programda Yer alan Eğilimler**	**Planınızda İşe Koşulacak Eğilimler**
	E1.1. Merak E1.4. Kendine İnanma (Öz Yeterlilik) E1.5. Kendine Güvenme (Öz Güven) E2.2. Sorumluluk E2.3. Girişkenlik E3.3. Yaratıcılık E3.4. Gerçeği Arama E3.5. Açık Fikirlilik E3.6. Analitik Düşünme E3.7. Sistematik Olma E3.11. Özgün Düşünme	*E1.1. Merak E1.4. Kendine İnanma (Öz Yeterlilik) E1.5. Kendine Güvenme (Öz Güven) E2.2. Sorumluluk E2.3. Girişkenlik E3.3. Yaratıcılık E3.4. Gerçeği Arama*
Sosyal-Duygusal Öğrenme Becerileri	**Programda Yer Alan Sosyal-Duygusal Öğrenme Becerileri**	**Planınızda İşe Koşulacak Sosyal-Duygusal Öğrenme Becerileri**
	SDB1.1. Kendini Tanıma (Öz Farkındalık) SDB2.1. İletişim SDB3.1. Uyum SDB3.3. Sorumlu Karar Verme	*SDB1.1. Kendini Tanıma (Öz Farkındalık) SDB2.1. İletişim SDB3.1. Uyum SDB3.3. Sorumlu Karar Verme*
Değerler	**Programda Yer Alan Değerler**	**Planınızda İşe Koşulacak Değerler**
	D3. Çalışkanlık D5. Duyarlılık D8. Mahremiyet D9. Merhamet D13. Sağlıklı Yaşam, D14. Saygı D16. Sorumluluk	*D3. Çalışkanlık D5. Duyarlılık D14. Saygı D16. Sorumluluk*

Beceriler Arası İlişkiler	*KB3.3. Eleştirel Düşünme*	
Öğrenme Çıktıları ve Süreç Bileşenleri	***BİY.10.2.4. Madde döngüleri ile ilgili bilimsel model oluşturabilme*** *a) Madde döngülerinin işleyişini modeller. b) Madde döngülerinin işleyişi ile ilgili gerektiğinde birden fazla model oluşturur. c) Madde döngülerinin işleyişi ile ilgili oluşturduğu modeli bilimsel modellerle karşılaştırır. ç) Karşılaştırma sürecinde elde ettiği kanıtlarla modelini yeniden yapılandırır.*	
Anahtar Kavramlar	*Sürdürülebilirlik, çevre*	
Ön Değerlendirme	**Ön Değerlendirme Sürecinde Neler Yapacaksınız? (Öğrencilerin mevcut bilgi düzeyleri, ilgi alanları ve öğrenme stilleri değerlendirilir)** *Ekolojik kavramlarla ilgili kısa cevaplı sorular (ön test-son test uygulanır) sorulur.* *Biyoloji öz-yeterlik ölçeği uygulanır (Biyoloji, ekoloji, madde döngüleri, problem çözme, model oluşturma-yorumlama-analiz etme vs. konularında öğrencinin yeterliği ölçülür.)*	
Öğrenme- Öğretme Uygulamaları	**STEAM (5 E, 6 E veya 7 E öğrenme modeli v proje tabanlı öğrenme modeli)**	
Uygulayacağınız Etkinlikleriniz	*Öğrencilerin çember olmaları ve üç gruba ayrılmaları sağlanır.* *Öğretmen tarafından hazırlanmış su, karbon ve azot döngüsüyle ilgili kavramların(solunum, fotosentez, nitrifikasyon, denitrifikasyon, saprofit, amonyak, nitrit, nitrat, ...) ve canlılara ait görsellerin(ölmüş canlılar, bitki, hayvan, bakteri, mantar,....) olduğu zarflar öğrencilere kura ile seçtirilir.* *1. etkinlikte zarfların içinde bulunan kavramları öğrencilerin araştırması sağlanır. Grupların ihtiyaç duyduğu zamanlarda geri bildirim sağlanır.* *Öğrenciler kavramları öğrendikten sonra 2. etkinliğe geçilir. 2. etkinlikte öğrencilere gerekli malzemeler(tahtakalemi, renkli kartonlar, makas, yapışıcı, renkli elişi kağıtları, boyalar,....) dağıtılır. Bu malzemeleri kullanarak öğrencilerin su, karbon ve azot döngüsüyle ilgili poster hazırlaması istenir. Süre sonunda hazırlanan çalışmalar sınıfla sunulur. Sunumu bitiren öğrenci diğer gruba 'madde döngüsünün bir basamağının gerçekleşmemesi durumunda doğada ne gibi değişimler olabileceğini' sorar. Çalışma ile ilgili öğrencilerin görüşleri alınır.* *Doğru hazırlanan çalışmalar sınıfın panosunda sergilenir.*	
Öğrenme Kanıtları	*Hazırlanan posterler ve yapılan sunum bütüncül dereceli puanlama anahtarı*	

In the lesson plan prepared by T8 (Figure 2), the learning outcome and the activities appear to be aligned. Students are expected to research concepts related to matter cycles and collaboratively design a poster on the matter cycles. T9, on the other hand, designed activities aligned with the learning outcome “Evaluate the measures taken to protect natural resources and biodiversity and identify additional precautions that could be implemented.” In this plan, students are required to investigate national measures taken in Türkiye regarding natural resource and biodiversity conservation, evaluate these measures, and propose further actions. Implementing these activities can be considered supportive of achieving the intended learning outcome.

Aside from these examples, it was observed that T18 designed an instructional plan without specifying a learning outcome, whereas T2, T14, and T19 wrote their own learning outcomes. For instance, T14 formulated the learning outcome as “To help students recognize the components of an ecosystem (abiotic and biotic elements).” As shown in Figure 3, T2 wrote the learning outcome as: “Students will be able to identify the components and functioning of an ecosystem; select appropriate organisms and plants for an aquarium; and present and justify their designs and plans.”

When the instructional activities designed by the teachers were examined in terms of their alignment with the STEAM approach, it was observed that most of the activities did not require a connection among the science, mathematics, technology, art, and engineering disciplines. Except for the virtual aquarium activity included in T14’s plan and the presentation on endangered species prepared by T9, there was almost no integration of technology in the activities. In T9’s instructional design, the statement “Students are also asked to prepare a visual presentation about endangered species” appears, yet details regarding how the visual presentation should be created are not provided. However, it can be inferred that preparing a presentation would likely involve the use of technology.

Similarly, there were other activities in the lesson plans that lacked detailed explanation and could have been better structured to incorporate interdisciplinary interaction, as required by the STEAM approach. For example, T4 included the activity of designing a solid-waste recycling center, while T5 included designing a modern landfill. Although these activities could inherently require the use of technology, engineering design, and even artistic design, the details of these steps were not included in the teachers’ plans, as seen in Figures 1 and 4.

Figure 3.
Lesson Plan Prepared by T2

Sınıf Düzeyi	10	
TEMA	**EKOLOJİ AKVARYUM EKOSİSTEMİ OLUŞTURMA**	
Dersin Süresi	**40 + 40 dakika**	
Beceriler	**Programda Yer alan Beceriler**	**Planımızda İşe Koşulacak Beceriler**
Kavramsal Beceriler	*FBAB9. Bilimsel Model Oluşturma FBAB10. Tümevarımsal Akıl Yürütme FBAB13. Bilimsel Sorgulama*	*FBAB9. Bilimsel Model Oluşturma FBAB10. Tümevarımsal Akıl Yürütme FBAB13. Bilimsel Sorgulama*
Alan Becerileri	*KB2.4. Çözümleme KB2.6. Bilgi Toplama KB2.8. Sorgulama KB2.11. Gözleme Dayalı Tahmin Etme KB2.14. Yorumlama*	*KB2.6. Bilgi Toplama KB2.8. Sorgulama KB2.11. Gözleme Dayalı Tahmin Etme*
Eğitimler	**Programda Yer alan Eğilimler**	**Planımızda İşe Koşulacak Eğilimler**
	E1.1. Mera, E1.4. Kendine İnanma (Ö: Yeterlilik) E1.5. Kendine Güvenme (Ö: Güven) E2.2. Sorumluluk E2.3. Girişkenlik E3.3. Yaratıcılık E3.4. Gerçeği Arama E3.5. Açık Fikirlilik E3.6. Analitik Düşünme E3.7. Sistematik Olma E3.11. Özgün Düşünme	*E1.4. Kendine İnanma (Ö: Yeterlilik) E1.5. Kendine Güvenme (Ö: Güven) E2.2. Sorumluluk E2.3. Girişkenlik E3.3. Yaratıcılık E3.6. Analitik Düşünme E3.7. Sistematik Olma E3.11. Özgün Düşünme*
Sosyal-Duygusal Öğrenme Becerileri	**Programda Yer Alan Sosyal-Duygusal Öğrenme Becerileri**	**Planımızda İşe Koşulacak Sosyal-Duygusal Öğrenme Becerileri**
	SDB1.1. Kendini Tanıma (Ö: Farkındalık) SDB2.1. İletişim SDB3.1. Uyum SDB3.3. Sorumlu Karar Verme	*SDB1.1. Kendini Tanıma (Ö: Farkındalık) SDB2.1. İletişim SDB3.1. Uyum SDB3.3. Sorumlu Karar Verme*
Değerler	**Programda Yer Alan Değerler**	**Planımızda İşe Koşulacak Değerler**
	D3. Çalışkanlık D5. Duyarlılık D8. Mahremiyet D9. Merhamet D13. Sağlıklı Yaşam, D14. Saygı D16. Sorumluluk D17. Tasarruf D18. Temizlik D19. Vatanseverlik	*D3. Çalışkanlık D5. Duyarlılık D16. Sorumluluk D17. Tasarruf D18. Temizlik*
Okuryazarlık Becerileri	**Programda Yer Alan Okuryazarlık Becerileri**	**Planımızda İşe Koşulacak Okuryazarlık Becerileri**
	OB1. Bilgi Okuryazarlığı OB2. Dijital Okuryazarlık	*OB8. Sürdürülebilirlik Okuryazarlığı OB4. Görsel Okuryazarlık*

	Çevre ve İklim okuryazarlığı Sanat okuryazarlığı Sağlık okuryazarlığı	
Disiplinler Arası İlişkiler	**Bilim:** Ekosistem dinamikleri, biyolojik çeşitlilik. **Matematik:** Su test sonuçlarının analizi ve grafiklerin oluşturulması. **Teknoloji:** Su arıtma ve filtreleme teknolojileri. **Sanat:** Akvaryum düzenlemesi ve estetik yerleştirme. **Mühendislik:** Akvaryum kurulumu ve su sirkülasyon sistemleri.	
Beceriler Arası İlişkiler	**Analitik Düşünme**: Su kalitesini değerlendirmek için veri toplama ve analiz yapma. **Yaratıcı Düşünme:** Estetik ve fonksiyonel bir akvaryum tasarlama. **Problem Çözme:** Su kalitesi sorunlarını tanımlama ve çözüm geliştirme. **İletişim:** Bilgi paylaşımı ve proje sunumu.	
Öğrenme Çıktıları ve Süreç Bileşenleri	Öğrenciler, ekosistem bileşenlerini ve işleyişini tanımlayabilecekler. Akvaryum için uygun canlıları ve bitkileri seçebilecekler. Tasarımlarını ve planlarını sunacak ve savunacaklar.	
Anahtar Kavramlar	Ekosistem, biyolojik çeşitlilik, su kalitesi, filtrasyon, akvaryum	
Ön Değerlendirme	**Ön Değerlendirme Sürecinde Neler Yapacaksınız? (Öğrencilerin mevcut bilgi düzeyleri, ilgi alanları ve öğrenme stilleri değerlendirilir)** Ön Değerlendirme Süreci: Öğrencilerin mevcut bilgi düzeyleri, ilgi alanları ve öğrenme stillerini değerlendirmek için kısa bir anket veya tartışma yapılır. Bu süreç, öğrencilerin ekosistem bilgisi, su kalitesi konusundaki anlayışları ve akvaryum kurulumuna dair önceki deneyimlerini anlamaya yönelik olacaktır.	
Öğrenme- Öğretme Uygulamaları	**STEAM(5 E, 6 E veya 7 E öğrenme modeli ve proje tabanlı öğrenme modeli) 5E modeli**	
Uygulayacağınız Etkinlikleriniz *(En önemli bölüm)*	Aktiviteler: **1.İlgi Uyandırma:** **Hedef:** Öğrencilerin akvaryum ekosistemine ilgi duymalarını sağlamak ve konunun önemini vurgulamak. “Bir akvaryum kurmanın ekosistem dengesine etkileri hakkında neler biliyorsunuz?” sorusuyla derse başlanır. Bir akvaryumun çalışma prensiplerini ve ekosistem içindeki farklı bileşenleri gösteren kısa bir video izletilecek. Video sonrası, öğrencilerin akvaryum ekosistemindeki temel bileşenler hakkında sorular sormalarını ve fikirlerini paylaşmalarını teşvik edilecek.	

Figure 4.
Lesson Plan Prepared by T5

Sınıf Düzeyi	**10**	
TEMA	**EKOLOJİ**	
Dersin Süresi	**160 dk- 4 ders saati**	
Beceriler	**Programda Yer alan Beceriler**	**Planınızda İşe Koşulacak Beceriler**
Kavramsal Beceriler	*FBAB9. Bilimsel Model Oluşturma* *FBAB10. Tümevarımsal Akıl Yürütme* *FBAB13. Bilimsel Sorgulama*	*FBAB9. Bilimsel Model Oluşturma* *FBAB13. Bilimsel Sorgulama*
Alan Becerileri	*KB2.4. Çözümleme* *KB2.6. Bilgi Toplama* *KB2.8. Sorgulama* *KB2.11. Gözleme Dayalı Tahmin Etme* *KB2.14. Yorumlama*	*KB2.4. Çözümleme* *KB2.6. Bilgi Toplama* *KB2.8. Sorgulama*
Eğitimler	**Programda Yer alan Eğilimler**	**Planınızda İşe Koşulacak Eğilimler**
	E1.1. Merak, *E1.4. Kendine İnanma (Öz Yeterlilik)* *E1.5. Kendine Güvenme (Öz Güven)* *E2.2. Sorumluluk* *E2.3. Girişkenlik* *E3.3. Yaratıcılık* *E3.4. Gerçeği Arama* *E3.5. Açık Fikirlilik* *E3.6. Analitik Düşünme* *E3.7. Sistematik Olma* *E3.11. Özgün Düşünme*	*E1.1. Merak,* *E1.4. Kendine İnanma (Öz Yeterlilik)* *E2.2. Sorumluluk* *E2.3. Girişkenlik* *E3.3. Yaratıcılık* *E3.5. Açık Fikirlilik* *E3.6. Analitik Düşünme* *E3.7. Sistematik Olma* *E3.11. Özgün Düşünme*
Sosyal-Duygusal Öğrenme Becerileri	**Programda Yer Alan Sosyal-Duygusal Öğrenme Becerileri**	**Planınızda İşe Koşulacak Sosyal-Duygusal Öğrenme Becerileri**
	SDB1.1. Kendini Tanıma (Öz Farkındalık) *SDB2.1. İletişim* *SDB3.1. Uyum* *SDB3.3. Sorumlu Karar Verme*	*SDB3.1. Uyum* *SDB3.3. Sorumlu Karar Verme*
Değerler	**Programda Yer Alan Değerler**	**Planınızda İşe Koşulacak Değerler**
	D3. Çalışkanlık *D5. Duyarlılık* *D8. Mahremiyet* *D9. Merhamet* *D13. Sağlıklı Yaşam,* *D14. Saygı* *D16. Sorumluluk* *D17. Tasarruf* *D18. Temizlik* *D19. Vatanseverlik*	*D3. Çalışkanlık* *D5. Duyarlılık* *D16. Sorumluluk* *D17. Tasarruf* *D18. Temizlik* *D19. Vatanseverlik*
Okuryazarlık Becerileri	**Programda Yer Alan Okuryazarlık Becerileri**	**Planınızda İşe Koşulacak Okuryazarlık Becerileri**
	OB1. Bilgi Okuryazarlığı *OB2. Dijital Okuryazarlık* *OB3. Finansal Okuryazarlık,* *Sanat okuryazarlığı* *Sağlık okuryazarlığı*	*OB2. Dijital Okuryazarlık* *OB8. Sürdürülebilirlik Okuryazarlığı* *Çevre ve iklim okuryazarlığı*
Disiplinler Arası İlişkiler	Coğrafya, Fizik, Kimya	
Beceriler Arası İlişkiler	Eleştirel Düşünme	
Öğrenme Çıktıları ve Süreç Bileşenleri	**BİY.10.2.5. Ekolojik sürdürülebilirliğin önemini yorumlayabilme** a)Ekolojik sürdürülebilirliğin önemini inceler. b) Ekolojik sürdürülebilirliğin önemini bağlamdan kopmadan dönüştürür. c) Ekolojik sürdürülebilirliğin önemini anlamı değiştirmeyecek şekilde yeniden ifade eder.	
Anahtar Kavramlar	iklim değişikliği, taşıma kapasitesi	
Ön Değerlendirme	**Ön Değerlendirme Sürecinde Neler Yapacaksınız? (Öğrencilerin mevcut bilgi düzeyleri, ilgi alanları ve öğrenme stilleri değerlendirilir)** "Sürdürülebilirlik nedir?", "Erozyon, iklim değişikliği vb. ile çevre ve sürdürülebilirlik arasında nasıl bir ilişki vardır?", "Su ve karbon ayak izi nedir?", "Biyolojik çeşitlilik neden korunmalıdır?", "Evsel atıklarınızı nasıl topluyor ve ayrıştırıyorsunuz?" gibi sorular sorularak öğrencilerin temel kabullere ilişkin öğrenme durumları değerlendirilecektir. Geri dönüşüm ve sürdürülebilirlik ile ilgili 5 soru içeren bir quiz yapılacak ve quiz sonunda sorula sınıfta tartışılacaktır.	
Öğrenme- Öğretme Uygulamaları	**STEAM (5 E, 6 E veya 7 E öğrenme modeli v proje tabanlı öğrenme modeli)**	
Uygulayacağınız Etkinlikleriniz	Bu ders kapsamında öğrencilerle Ankara Büyükşehir Belediyesi tarafından işletilen Mamak Çöplüğü'ne gezi düzenlenecektir. Gezi sırasında çöplükte geri dönüşümün nasıl yapıldığı incelenecek, elde edilen metan gazıyla kurulan sera ziyaret edilecektir. Gezi öncesinde hazırlanan çalışma yaprağı öğrencilere dağıtılacaktır. Burada tozlaşmada kullanılan bombus arılarıyla ilgili ve tozlaştırıcılarla ilgili bilgiler edinmesi sağlanacaktır. Gezi sonrası öğrencilerden yaşadıkları yerlerin yerel yönetimlerinde kurulabilecek "Modern Çöplük Modeli" oluşturmaları istenecektir. Bu uygulama 5 kişilik gruplar oluşturularak gerçekleştirilecektir.	
Öğrenme Kanıtları (Ölçme-Değerlendirme Teknikleri)	Gezi sırasında dağıtılan çalışma yaprağının doldurulması Modern Çöplük Modeli'nin dereceli puanlama anahtarı	

In addition to these examples, T18 also designed an activity involving the creation of an ecosystem model; however, the plan did not include details such as how the model should be constructed, or which materials should be used. Similarly, T2's aquarium activity and T8's poster preparation activity (Figure 2) did not reflect the STEAM approach in their instructional designs.

Overall, when examining teachers' development of instructional designs for teaching ecology through the STEAM approach, it was evident that only a few teachers achieved alignment between the learning outcomes and the activities they designed. Furthermore, some teachers wrote their own learning outcomes instead of selecting outcomes from the ecology component of the curriculum, which may indicate that they were not sufficiently familiar with the curriculum. Moreover, teachers were generally unable to integrate the STEAM approach into their instructional designs.

Findings Regarding the Effects on Biology Teachers' Ecological Citizenship, STEM Awareness, and Attitudes Toward Art Education

In the research, the Ecological Citizenship Scale, the STEM Awareness Scale, and the Attitude Toward Art Education Scale were administered to the teachers as pre- and post-tests. A total of 26 teachers participated in the project; however, due to missing data in T11's post-test responses, quantitative analyses were conducted using the data obtained from 25 teachers. Table 3 presents the paired-samples t-test results for the difference scores.

Table 2.
Paired-Samples t-Test Results for Difference Scores

Measurement	n	Mean ($\bar{x}$)	SD (s)	df	t	p
Ecological Citizenship Pre-Test	25	3.56	.44	24	-3.52	.00
Ecological Citizenship Post-Test	25	3.87	.55			
STEM Awareness Pre-Test	25	3.85	.47	24	-3.90	.00
STEM Awareness Post-Test	25	4.27	.39			
Art Education Attitude Pre-Test	25	4.52	.40	24	-2.36	.03
Art Education Attitude Post-Test	25	4.71	.34			

As shown in Table 2, a paired-samples t-test was conducted to examine whether the scores of biology teachers' ecological citizenship differed before and after the implementation of the project activities. The analysis revealed a statistically significant difference between the pre-test mean scores ($M_{pre} = 3.56$) and post-test mean scores ($M_{post} = 3.87$), favoring the post-test scores [$t(24) = –3.52$, $p < .05$]. The effect size was calculated by dividing the obtained t-value by the square root of the sample size. Values around 0.50 are interpreted as medium, whereas values of 0.80 or higher indicate a significant effect (Green & Salkind, 2003). Accordingly, the computed effect size ($d = 0.70$) suggests that this difference represents an effect slightly above the medium level.

Similarly, teachers' STEM Awareness Scale pre-test scores ($M_{pre} = 3.85$) differed significantly from their post-test scores ($M_{post} = 4.27$) [$t(24) = –3.90$, $p < .05$]. This difference favored the post-test scores, and the calculated effect size ($d = 0.78$) indicates a large effect.

In addition, a statistically significant difference was found between teachers' pre-test ($M_{pre} = 4.52$) and post-test ($M_{post} = 4.71$) scores on the Attitude Toward Art Education Scale, again in favor of the post-test results [$t(24) = –2.36$, $p < .05$]. The effect size ($d = 0.47$) reflects a moderate level of impact.

Discussion and Conclusion

The findings of this study indicate that STEAM-based educational practices, implemented with biology teachers within the theme of ecology, significantly improved teachers' levels of ecological citizenship, their awareness of the STEM approach, and their attitudes toward art education. While teachers were observed to adopt a more holistic perspective on concepts such as environment, sustainability, and interdisciplinarity after the implementation, it was also identified that they did not demonstrate sufficient improvement in designing lesson plans aligned with the STEAM approach. The quantitative results revealed that teachers' STEM awareness increased significantly. Teachers' evaluations of the activities as "applicable," "interdisciplinary," and "creative" suggest that hands-on STEAM instruction contributed to the development of their pedagogical awareness. This finding aligns with previous research emphasizing that teachers gain professional confidence through active, practice-based learning experiences (Çorlu, et al., 2014; Herro & Quigley, 2016). Therefore, integrating STEAM activities into teacher education programs is critical, as it offers teachers meaningful opportunities for experiential learning related to innovative instructional models.

The results also demonstrate that STEAM education fosters not only academic gains but also social responsibility–oriented awareness among teachers. The significant increase in ecological citizenship scores from pre-test to post-test indicates that the STEAM approach serves as an effective tool in environmental education. This outcome is consistent with earlier studies suggesting that ecology and environmental concepts become more meaningful and enduring when taught through interdisciplinary methods (Green, et al., 2016; Gottfried, 2015; Kılınç, 2010).

Teachers' reflections further revealed that they gained substantial knowledge related to ecological concepts through the activities. Their statements such as "factors affecting ecosystems, matter and energy flow, sustainability" (T3, Day 1), "environmental pollution, biodiversity, sustainability" (T20, Day 2), "the importance of diversity, environmental pollution, ecological balance" (T5, Day 3), and "plant systematics, how the environment transforms cities, use of technology in teaching ecology" (T19, Day 4) demonstrate this learning gain. Additionally, teachers expressed their intention to transfer these experiences to their students through statements such as "I can implement the ‘Collect the Sun for the Greenhouse’ activity and the plant–environment interaction study in my school,” and “I plan to conduct the aquarium activity as a performance task in the 9th-grade biology course.”

In this regard, STEAM education not only enhances teachers’ ecological literacy levels but also enables them to develop new pedagogical approaches (Videla, et al., 2021).

Another key finding of the present study is the significant quantitative increase in biology teachers’ awareness of the STEM instructional approach. Teachers' reflective statements show that they experienced hands-on STEAM practices more extensively than ever before and evaluated the adaptability of these activities to classroom instruction positively. This can be inferred from comments such as: “All activities contributed greatly. Although I have read many articles and attended seminars on STEAM, this is the first time I have felt this close to actual implementation” (T13, Day 1), “I believe they contributed to mathematics, engineering, art, and technology altogether” (T26, Day 1), and “There were contributions in interdisciplinary interaction, collaboration, art, and engineering” (Day 3). Like these findings, the literature also indicates that applied STEAM instruction enhances teachers’ lesson-design skills and their professional self-efficacy (Çorlu, et al.,2014; Herro & Quigley, 2016).

Another insight drawn from teachers’ views is the critical importance of active and practice-based experiences in helping teachers internalize new instructional models. This is evident in statements such as: “I once again observed that plans yield more meaningful outcomes when implemented rather than remaining on paper” (T26, Day 3), and “I can apply the tower activity in the Support and Movement Systems unit, and the floating house and terrarium activities in the ecology unit. The accessibility of materials and students’ imagination will lead to creative products” (T12, Day 1). In line with these results, prior research emphasizes the need for long-term STEAM training for teachers (Herro, et al., 2019), the importance of designing activities that foster creative thinking (Lin & Tsai, 2021), and the necessity of STREAM-oriented awareness and implementation projects (Ayverdi et al., 2024).

During the study, teachers were asked to prepare a lesson plan targeting a learning outcome of their choice from the ecology theme in the revised 10th-grade Biology curriculum. Eight participants completed their lesson plans, which were analyzed in terms of (a) alignment between learning outcomes and instructional design, and (b) conformity of the instructional design to the STEAM approach. The analysis revealed that some teachers did not consider the curriculum learning outcomes or designed activities that were not aligned with the stated outcomes. This finding may be explained by teachers’ curriculum literacy skills.

Curriculum literacy refers to teachers’ ability to analyze, comprehend, implement, and critically evaluate a curriculum a key domain of professional competence (Öztürk, 2019). This competence involves not only understanding curriculum objectives and content but also interpreting the philosophical, pedagogical, and sociocultural foundations of the curriculum (Yüksel, 2021). Bozdoğan and Yıldırım (2020) found that pre-service teachers often fail to establish the relationship among objectives, learning outcomes, and assessment. International research similarly argues that curriculum literacy requires a critical pedagogical lens that goes beyond simply reading the document and includes interpreting its cultural and ideological underpinnings (Connelly, et al., 2020). These findings highlight the need to systematically develop curriculum literacy within teacher education programs.

In this context, it can be inferred that biology teachers need to develop a deeper understanding of the revised curriculum and receive practical training in implementing new instructional methods. Moreover, several teachers did not sufficiently integrate the STEAM components—particularly mathematics and technology—into their lesson designs. These findings parallel with previous studies showing that teachers often struggle with interdisciplinary integration (Margot & Kettler, 2019). Engineering and mathematics components tend to be addressed superficially or overlooked in instructional designs (Stohlmann, et al., 2012). Similar patterns were observed in the current study, where some teachers identified connections to mathematics, art, and technology but did not elaborate on how these would be incorporated into the activities. For example, T4 proposed designing a solid-waste recycling center and T5 proposed designing a modern landfill; however, the instructional steps and disciplinary integrations of these activities were not articulated.

Such challenges, commonly reported among pre-service and early-career teachers (Alanazi, 2019; Şahin-Taşkın, 2017), were also observed in this study despite the participants being experienced teachers. This may be attributed to limited familiarity with STEAM, insufficient design-thinking experience, reliance on ready-made activities, or limited creativity in lesson planning. These findings further underscore the need to strengthen teachers' instructional design skills and highlight the importance of mentoring or coaching in bridging the gap between planning and implementation (Wilson, 2016).

Finally, the significant improvement in teachers' attitudes toward art education indicates that the STEAM approach enhanced their awareness of the educational value of art. This finding aligns with research suggesting that integrating art with STEM supports aesthetic sensitivity, imagination, and creativity (Henriksen, 2014; Land, 2013). Most participants expressed that creative thinking and interdisciplinary integration make instruction more engaging and meaningful for both teachers and students.

Limitations and Recommendations

The present study is limited to 26 biology teachers (5 male, 21 female) who participated in a total of 26 activities conducted over six consecutive days. In line with the data obtained from the study and the researchers' observations, the following recommendations are offered for future research:

1. Strengthening the emphasis on STEAM in teacher education programs. Pre-service teachers should be introduced to interdisciplinary instructional approaches early in their training. Faculties of education should integrate more STEAM-oriented course content, and teacher candidates should be provided with opportunities to engage in hands-on STEAM activities.
2. Implement practice-oriented in-service training programs. Like the current study, in-service training initiatives should include activities that allow teachers to engage directly in implementation, combining planning and practice. Such programs should also incorporate contemporary themes such as ecological issues, environmental literacy, and sustainability.
3. Enhance the interdisciplinary nature of STEAM activities. Teachers should be provided with guiding materials and sample activity sets that illustrate how to integrate engineering, mathematics, and technology components more holistically. Strengthening these elements will support the creation of instructional environments aligned with the core aims of STEAM education (Aydın, 2020, Margot & Kettler, 2019).
4. Emphasize the educational role of art. To prevent the art component from being used superficially, teachers should receive foundational training in art pedagogy.

This will help support the development of aesthetic awareness and creative thinking skills among students (Henriksen, 2014).

5. Strengthen mentoring and feedback mechanisms. Teachers should receive expert support during instructional design processes. Lesson plans should be reviewed and enriched in terms of interdisciplinary alignment, material selection, and assessment criteria (Wilson, 2016).
6. Conduct long-term follow-up studies on classroom implementation. Future projects should monitor teachers' classroom practices over extended periods and examine the impact of STEAM education on student learning outcomes.

References

Aydın, G (2020). Prerequisites for elementary school teachers before practicing STEM education with students: A case study. Eurasian Journal of Educational Research, 20(88), 1-40. DOI: 10.14689/ejer.2020.88.1

Alanazi, HM (2019). A study of the pre-service trainee teachers' problems in designing lesson plans. AWEJ, 10(1). https://doi.org/10.2139/ssrn.3367545

Ali, MI, Ismail, A, & Nurfadila, MY (2025). The effect of STEAM-based environmental learning on students' ecoliteracy level at SDI Hartaco Indah Makassar. Journal of Innovative and Creativity, 5(2), 11280–11288.

Ariza, JÁ, & Olatunde-Aiyedun, TG (2024). A systematic literature review on STEAM pre-and in-service teacher education for sustainability: Are teachers ready? Eurasia Journal of Mathematics, Science and Technology Education, 20(9), em2498. https://doi.org/10.29333/ejmste/14155

Arpaci, I, …, & Bahari, M (2023). An experimental study on the implementation of a STEAM-based learning module in science education. Sustainability, 15(8), 6807. https://doi.org/10.3390/su15086807

Ay, F, & Erik, NY (2020). Üniversite öğrencilerinin küresel ısınma ve iklim değişikliğine yönelik bilgi ve algı düzeyleri. Cumhuriyet Üniversitesi Sosyal Bilimler Dergisi, 44(2).

Aykanat, E (2018). Okul öncesi öğretmenlerinin sanat eğitimine yönelik tutumlarını belirlemek üzere ölçek geliştirme çalışması (Yayınlanmamış yüksek lisans tezi). Başkent Üniversitesi, Eğitim Bilimleri Enstitüsü, Ankara.

Ayverdi, L, …, & Önder, EY (2024). Sürdürülebilir Kalkınma Amaçları Bağlamında STREAM Yaklaşımına Yönelik Öğretim Tasarımlarının Geliştirilmesinde Fen Bilimleri Öğretmenlerinin Görüşleri. Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi, (62), 3005-3033. https://doi.org/10.53444/deubefd.1482764

Baek, S (2023). Fostering students' environmental competencies through a plant STEAM education program in Korean elementary schools. Asia-Pacific Science Education, 9(2), 488-520. https://doi.org/10.1163/23641177-bja10069

Baş, T, & Akturan, U (2017). Sosyal bilimlerde bilgisayar destekli nitel araştırma yöntemleri. Seçkin Yayıncılık.

Bildiren, Ş, & Sargıncı, M (2022). İklim değişikliğine bağlı olarak gelişen su sıkıntısına alternatif bir çözüm önerisi: Atmosferik su hasadı. Düzce Üniversitesi Süs ve Tıbbi Bitkiler Botanik Bahçesi Dergisi, 1(1), 21–29.

Bozdoğan, AE, & Yıldırım, A (2020). Öğretmen adaylarının öğretim programı okuryazarlığı düzeylerinin değerlendirilmesi. Eğitimde Kuram ve Uygulama, 16(1), 23–41. https://doi.org/10.17244/eku.654789

Bulut, G (2024). Çevre eğitimi konulu STEM etkinliklerinin ortaokul öğrencilerinin çevre sorunlarına yönelik tutumları, STEM algıları ve öğrenme sorumluluklarına etkisi ile bilişsel yapıları ve görüşlerinin incelenmesi (Yüksek lisans tezi). Balıkesir University, Institute of Educational Sciences.

Bush, SB, & Cook, KL (2019). Structuring STEAM Inquiries: Lessons Learned from Practice. In MS Khine, & S Areepattamannil (eds). STEAM Education. Springer, Cham. https://doi.org/10.1007/978-3-030-04003-1_2

Colucci-Gray, L, ..., & Gray, DS (2017). Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: How can school curricula be broadened towards a more. British Educational Research Association. https://doi.org/10.13140/RG.2.2.22452.76161

Connelly, FM, Fang, H, & He, MF (2020). Curriculum literacy in global contexts. In F. M. Connelly (Ed.), The Sage handbook of curriculum and instruction (pp. 103–119). SAGE Publications.

Creswell, JW, & Creswell, JD (2018). Research design: Qualitative, quantitative, and mixed methods approach (5th ed). SAGE Publications.

Çapar, G (2019). İklim değişikliği eğitim modülleri serisi 8: Su kaynakları yönetimi ve iklim değişikliği.

Çilek, E (2019). Atmosferdeki sıcaklık değişiminde rol oynayan gazların etkisi: Bir STEM etkinliği. Araştırma Temelli Etkinlik Dergisi, 9(2), 109–131.

Çevik, M (2017). A study of STEM Awareness Scale development for high school teachers Ortaöğretim öğretmenlerine yönelik FeTeMM Farkındalık Ölçeği (FFÖ) geliştirme çalışması. Journal of Human Sciences, 14(3), 2436-2452. DC: World Bank. https://doi.org/10.1596/978-1-4648-0342-0.

Çorlu, MS, Capraro, RM, & Capraro, MM (2014). Introducing STEM education: Implications for educating our teachers in the age of innovation. Education and Science, 39(171), 74–85.

Dallı, A (2019). Madde döngüleri ve çevre sorunları konusunda STEM yaklaşımına dayalı öğretim tasarımı (Master's thesis, Bursa Uludag University (Turkey).

Doğal Hayatı Koruma Vakfı (WWF-Türkiye). (2020). Korumazsak kaybederiz: Sürdürülebilir bir Türkiye için korunan alanlar hedef: 2030'a kadar.

Erdoğan, S (2020). STEAM ve sanat eğitimi. Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, (44), 303–316.

Gottfried, MA (2015). Chronic absenteeism in the classroom context: Effects on achievement. Urban Education, 54(1), 3–34. https://doi.org/10.1177/0042085915618709

Green, C, Medina-Jerez, W, & Bryant, C (2016). Cultivating environmental citizenship in teacher education. Teaching Education, 27(2), 117-135. https://doi.org/10.1080/10476210.2015.1043121

Green, SB, & Salkind, NJ (2003). Using SPSS for windows and macintosh: analyzing and understanding data (3rd ed). Upper Saddle River, NJ: Prentice Hall.

Gülhan, F (2023). Environmental sustainability in science education in the Anthropocene: A view from STEAM education. Science Insights Education Frontiers, 14(2), 2129–2143. https://doi.org/10.15354/sief.23.re088

Hales, T (2001). The Honeycomb Conjecture. Discrete Comput Geom, 25, 1–22. https://doi.org/10.1007/s004540010071

Hamarat, E (2019). 21 yüzyıl becerileri odağında Türkiye'nin eğitim politikaları.

Hasanah, SS, Riandi, AP, & Kaniawati, I (2022). STEM training for lesson plan on bioplastic and environment: Does it affect the teachers? Moroccan Journal of Chemistry, 10(3), 10–3. https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.33144

Henriksen, D (2014). Full STEAM ahead: Creativity in excellent STEM teaching practices. The STEAM Journal, 1(2), Article 15. https://doi.org/10.5642/steam.20140102.15

Herro, D, Quigley, C, & Cian, H (2019). The challenges of STEAM instruction: Lessons from the field. Action in Teacher Education, 41(2), 172-190. https://doi.org/10.1080/01626620.2018.1551159

Hetland, L, & Winner, E (2004). Cognitive transfer from arts education to nonarts outcomes: Research evidence and policy implications. In Handbook of research and policy in art education (pp. 135-161). Routledge.

Karatekin, K, & Uysal, C (2018). Ekolojik vatandaşlık ölçeği geliştirme çalışması. International Electronic Journal of Environmental Education, 8(2), 82–104.

Kelley, TR, & Knowles, JG (2016). A conceptual framework for integrated STEM education. International Journal of STEM education, 3(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Keum, JH, & Baek, S (2025). Enhancing environmental competence through a STEAM climate change education program in lower elementary grades. Asia-Pacific Science Education, 11(1), 203–228. https://doi.org/10.1163/23641177-bja10095

Kilinç, S (2018). Exploring of STEM readiness of a faculty of education in turkey (Doctoral dissertation, Middle East Technical University).

Land, MH (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. Procedia Computer Science, 20, 547–552. https://doi.org/10.1016/j.procs.2013.09.317

Liao, TT (2016). Editorial overview. Journal of Educational Technology Systems, 45(1), 3-4. https://doi.org/10.1177/0047239516654806

Lin, CL, & Tsai, CY (2021). The effect of a pedagogical STEAM model on students' project competence and learning motivation. Journal of Science Education and Technology, 30(1), 112-124. https://doi.org/10.1007/s10956-020-09885-x

Livingston, SA (2014). Equating test scores (without IRT). Educational testing service.

Margot, KC, & Kettler, T (2019). Teachers' perception of STEM integration and education: A systematic literature review. International Journal of STEM Education, 6(1), 2. https://doi.org/10.1186/s40594-018-0151-2

Mochizuki, Y, & Bryan, A (2015). Climate change education in the context of education for sustainable development: Rationale and principles. Journal of Education for Sustainable Development, 9(1), 4-26. https://doi.org/10.1177/0973408215569109

MEB (2024). Türkiye Yüzyılı Maarif Modeli Öğretim Programları.

OECD (2024). Education at a glance 2024: OECD indicators. OECD Publishing.

ÖSYM (2023). 2023-YKS sınav sonuçlarına ilişkin sayısal bilgiler.

Öztürk, C (2019). Öğretim programı okuryazarlığı: Kavramsal bir çözümleme. Eğitim ve Gelecek Dergisi, 15(4), 54–67. https://doi.org/10.30786/jeg.513479

Runco, MA, & Charles, RE (1997). Developmental trends in creative potential and creative performance. In The creativity research handbook (Vol. 1, pp. 115–152).

Stohlmann, M, Moore, T J, & Roehrig, GH (2012). Considerations for teaching integrated STEM education. Journal of Pre-College Engineering Education Research (J-PEER), 2(1), Article 4. https://doi.org/10.5703/1288284314653

Şahin-Taşkın, C (2017). Exploring pre-service teachers' perceptions of lesson planning difficulties. Journal of Education and Practice, 8(12), 59–67.

Suri, H (2011). Purposeful sampling in qualitative research synthesis. Qualitative research journal, 11(2), 63-75. https://doi.org/10.3316/QRJ1102063

TEDMEM (2023). Bir bakışta eğitim 2023 (TEDMEM Eğitim Raporu).

TÜBİTAK (2023). Biyoloji Öğretmenleriyle EKO-STEAM.

United Nations Framework Convention on Climate Change (1992). United Nations Treaty Series, vol. 1771, pp. 107–. Entered into force March 21, 1994.

Un World Water Development Report (2020).

Videla, R, Aguayo, C, & Veloz, T (2021, September). From STEM to STEAM: An enactive and ecological continuum. In Frontiers in

Education, 6, 709560. Frontiers Media SA. https://doi.org/10.3389/feduc.2021.709560

World Health Organization [WHO] (2018). 9 out of 10 people worldwide breathe polluted air, but more countries are taking action.

Wilson, SM (2016). Measuring instructional practice: Looking back and looking ahead. Educational Researcher, 45(1), 26–31. https://doi.org/10.3102/0013189X16665619

World Economic Forum (2019). What are the 21st-century skills every student needs? Erişim.

Worl Economic Form (2025). The Future of Jobs Report.

WWF-Türkiye (2021). Korumazsak Kaybederiz: Sürdürülebilir bir Türkiye için korunan alanlar — Hedef: 2030'a kadar]. WWF-Türkiye.

Yıldırım, A, & Şimşek, H (2013). Sosyal bilimlerde nitel araştırma yöntemleri (9. baskı). Seçkin.

Yıldırım, A, & Şimşek, H (2016). Sosyal bilimlerde nitel araştırma yöntemleri. Seçkin.

Yıldırım, B (2019). Fen bilgisi öğretmen adaylarının STEM eğitiminde biyomimikri uygulamalarına yönelik görüşleri. Gazi Üniversitesi Gazi Eğitim Fakültesi Dergisi, 39(1), 63-90.

Yüksel, Ş (2021). Program okuryazarlığı bağlamında öğretmen yeterlikleri: Derinlemesine bir inceleme. Kuram ve Uygulamada Eğitim Yönetimi, 27(4), 651–672. https://doi.org/10.14527/kuey.2021.024