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Article

# Evaluating Biology Activities in Science and Art Centers within the STEM Framework: A Qualitative Case Study

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**Abstract:** This study aims to examine the integrated structure of biology activities implemented in Science and Art Centers (BİLSEM) in terms of their alignment with STEM (Science, Technology, Engineering, and Mathematics) components. Employing a qualitative case study design, semi-structured interviews were conducted with six biology consultant teachers and thirty gifted students across three different BİLSEM institutions. In addition to interview data, activity plans, student products, and observational records were analyzed. The data were evaluated through thematic analysis, and the degree of STEM integration was assessed using a rubric based on Bybee’s model. Findings indicate that science and technology components are prominently featured in the activities, while engineering is represented at a moderate level, and mathematics is often incorporated only superficially. Students demonstrated significant improvements in scientific process skills and exhibited creative problem-solving and prototyping abilities in design-oriented activities. However, their competencies in numerical analysis, data modeling, and statistical reasoning remained underdeveloped. Teachers emphasized that the STEM approach positively influences student motivation, interdisciplinary thinking, and scientific awareness. The results reveal that well-balanced and systematically structured STEM activities effectively support multidimensional learning in gifted students. In this regard, it is recommended that STEM-oriented biology activities be enriched through interdisciplinary collaboration, with a particular focus on more robust integration of the mathematics component.

**Keywords:** Science and Art Center (BİLSEM); STEM education; biology activities; interdisciplinary learning; gifted students; thematic analysis; teacher perspectives; student outcomes

## 1. Introduction

In the rapidly evolving knowledge society of the 21st century, scientific and technological advancements have significantly impacted nearly all aspects of social life and have necessitated both structural and pedagogical reforms in education systems (Anderson, 2008; OECD, 2016). One of the most prominent paradigms emerging in this transformation is STEM education, an interdisciplinary and integrated learning approach encompassing Science, Technology, Engineering, and Mathematics. STEM education aims to equip individuals with 21st-century skills by fostering inquiry-based, problem-solving, creative, collaborative, and interdisciplinary thinking abilities (Bybee, 2013; Vasquez, 2014). STEM education not only promotes students’ academic achievement but also seeks to develop essential skills such as real-world problem-solving, integrated knowledge application, creativity, and innovation (Breiner et al., 2012; Kennedy & Odell, 2014).

The effective integration of STEM into educational systems, however, involves a complex process that depends on various factors, including teacher competencies, material resources, institutional culture, student profiles, and contextual conditions (Honey et al., 2011). In Turkey, efforts to disseminate STEM education have intensified in recent years through teacher training programs, project-based applications, and initiatives supported by eTwinning and TÜBİTAK. While most STEM-related efforts have focused primarily on science and mathematics disciplines, subjects

such as biology—which inherently involve observation, experimentation, design, and interdisciplinary engagement—offer highly fertile ground for STEM integration (Beers, 2011). In this context, Science and Art Centers (BİLSEM), which serve gifted students, constitute unique educational environments where STEM-based practices can be implemented systematically. Administered by the Ministry of National Education, BİLSEM institutions offer individualized, project-based, and practice-oriented learning models that address students' diverse talents (MEB, 2019). The science and biology programs implemented in BİLSEM can be considered a natural reflection of STEM education. Biology, in particular, provides ample opportunities for the integration of STEM components. For example, genetic studies (DNA isolation, gene transfer), bioenergy systems (microbial fuel cells), biotechnology (bioplastic production), ecology (carbon footprint calculations), and biostatistics (data analysis and visualization) all exemplify how STEM can be integrated within biology instruction (Sahin & Topçu, 2015).

For gifted students—such as those in BİLSEM—biology education serves as a multidimensional learning opportunity that enables the development of scientific process skills, innovative thinking, and interdisciplinary solution design. However, a review of the literature reveals a lack of research specifically examining how biology activities in Turkish BİLSEM institutions are structured in relation to STEM principles. Existing studies tend to focus on the general contribution of STEM to science education without conducting in-depth analyses of individual disciplines (Korkmaz & Kaptan, 2016; Yamak et al., 2014). Therefore, it is pedagogically significant to investigate the extent to which biology activities in BİLSEM are integrated with STEM components, which elements are emphasized, what learning outcomes are achieved, and what challenges and opportunities emerge in the implementation process. This study aims to provide a comprehensive analysis of biology activities within a STEM framework by focusing on their structural integration, student learning outcomes, and pedagogical implications in gifted education environments.

#### **Research Questions:**

1. To what extent do biology activities in BİLSEM integrate STEM components?
2. How are science, technology, engineering, and mathematics components combined within these activities?
3. How do students perceive these activities, and what skills do they acquire through them?
4. What are teachers' views on the feasibility and educational value of STEM-based biology activities?

## **2. Methodology**

### *2.1. Research Design*

This study employed a qualitative case study design, which allows for an in-depth examination of a particular phenomenon within its real-life context (Yin, 2014). The focus of this study was to explore the role and implementation of biology activities in Science and Art Centers (BİLSEM) within a STEM education framework. Due to the exploratory and contextual nature of the research questions, a qualitative approach was deemed most appropriate. Additionally, to enhance interpretive strength, selected findings were quantified through content analysis.

### *2.2. Study Group/Participants*

The participants consisted of six biology consultant teachers and thirty students from three different BİLSEM institutions across diverse regions in Turkey. Students ranged from grades 7 through 11 and were selected using the maximum variation sampling method (Patton, 2002), allowing the identification of patterns across different local implementations.

Table 1. Participant Information.

| Participant Group   | Number | Age/Level | Role                  |
|---------------------|--------|-----------|-----------------------|
| Students            | 30     | 12–17     | Activity Participants |
| Consultant Teachers | 6      | -         | Activity Facilitators |

2.3. Data Collection Tools

The following tools were employed for data collection:

**Semi-structured interview forms:** Separate forms were developed for students and teachers. Student forms focused on perceptions, gains, and suggestions related to STEM activities; teacher forms focused on implementation processes, observations, and encountered challenges.

**Activity plans and documentation:** Written plans, student products, and visual materials related to biology-based STEM activities were collected from consultant teachers.

**Observation notes:** The researcher directly observed two activities and documented systematic notes.

**STEM Integration Rubric:** A 10-item analysis rubric based on Bybee (2013) and Vasquez (2014) was used to score each activity across STEM components using a 0–3 scale.

2.4. Data Analysis

Qualitative data were analyzed using thematic analysis (Braun & Clarke, 2006). Interview transcripts were digitized and coded using NVivo software. The analysis followed these steps:

- 1. Reading and generating preliminary codes
- 2. Grouping meaningful codes
- 3. Identifying and structuring themes
- 4. Mapping inter-theme relationships
- 5. Reporting findings with direct quotations

Activity documents were also analyzed according to individual STEM components, and representative examples were categorized under science, technology, engineering, and mathematics. Each activity’s integration level was quantified using the following rubric:

Table 2. STEM Integration Rubric (Summary).

| Component   | 0: None | 1: Low | 2: Moderate | 3: High |
|-------------|---------|--------|-------------|---------|
| Science     |         |        |             |         |
| Technology  |         |        |             |         |
| Engineering |         |        |             |         |
| Mathematics |         |        |             |         |

Each activity’s total score (range 0–12) was used to determine the level of STEM integration.

2.5. Validity and Reliability

To ensure internal validity, the study employed triangulation by comparing multiple data sources (interviews, documents, observations). Member checking was conducted after each interview to confirm accuracy. To minimize researcher bias, a second coder was consulted during the analysis process. The inter-coder reliability was calculated as 91%.

3. Findings

Thematic analysis of the qualitative data resulted in four major themes: (1) Scientific Process and Concept Development, (2) Technology and Digital Literacy, (3) Engineering Design and Problem Solving, and (4) Mathematical Application and Analytical Thinking. Student and teacher perspectives were organized under each sub-code and supported with illustrative quotes and tables.

3.1. Scientific Process and Concept Development (Science Component)

This theme includes four sub-codes: conducting observations and experiments, forming and testing hypotheses, collecting and interpreting data, and awareness of biological concepts.

Table 3. Code Distribution for Scientific Process and Concept Development.

| Code                           | Student Frequency | Teacher Frequency |
|--------------------------------|-------------------|-------------------|
| Observation and Experiment     | 21                | 6                 |
| Hypothesis Formation & Testing | 16                | 4                 |
| Data Interpretation            | 18                | 5                 |
| Conceptual Awareness           | 22                | 6                 |

Student Quote:

“It was my first time observing a live cell through a microscope. I wrote down what I expected and then compared it with what I saw. That helped me really understand what DNA looks like.” (Student-05)

Teacher Quote:

“Students grasp scientific thinking processes better through hands-on experiments. Conceptual transitions become more solid with direct observation.” (Teacher-2)

3.2. Technology and Digital Literacy (Technology Component)

This theme comprises three codes: use of digital tools, data collection technologies, and simulation/modeling.

Table 4. Codes Related to Technology Component.

| Code                       | Student Frequency | Teacher Frequency |
|----------------------------|-------------------|-------------------|
| Use of Digital Tools       | 19                | 5                 |
| Sensors / Measurement Tech | 13                | 4                 |
| Simulation / Modeling      | 9                 | 2                 |

Student Quote:

“We used an Arduino with a humidity sensor to measure leaf transpiration. Then we graphed the data on the computer. It was fascinating.” (Student-14)

Teacher Quote:

“Some students excel in simulation-based learning. Especially when materials are limited, technology bridges the gap.” (Teacher-4)

3.3. Engineering Design and Problem Solving (Engineering Component)

This theme includes three sub-codes: problem identification, design and prototyping, and optimization and feedback.

Table 5. Codes Related to Engineering Component.

| Code                   | Student Frequency | Teacher Frequency |
|------------------------|-------------------|-------------------|
| Problem Identification | 11                | 3                 |
| Design / Prototyping   | 17                | 5                 |
| Feedback and Revision  | 9                 | 3                 |

Student Quote:

“The first bioplastic mixture we made was too stiff, so we changed the ratios with our teacher and tested new versions. Eventually, we found one that worked.” (Student-07)

Teacher Quote:

“Some students don’t jump to the prototype immediately; they sketch, test materials, and manage the process like real engineers.” (Teacher-5)

3.4. Mathematical Application and Analytical Thinking (Mathematics Component)

This theme had the lowest frequency of codes. It includes graph creation, numerical analysis, and measurement/calculation adequacy.

Table 6. Codes Related to Mathematics Component.

| Code                       | Student Frequency | Teacher Frequency |
|----------------------------|-------------------|-------------------|
| Graph/Table Creation       | 12                | 4                 |
| Basic Numerical Operations | 9                 | 2                 |
| Calculation Deficiencies   | 7                 | 4                 |

Student Quote:

“We learned how to draw graphs, but the formulas and ratios were a bit challenging. Working with numbers isn’t something we do very often.” (Student-23)

Teacher Quote:

“In most activities, the math component remains superficial. It needs stronger integration.” (Teacher-1)

3.5. Thematic Overlap and Integration Matrix

Cross-analysis of all codes resulted in the following theme–component integration map:

Table 7. Theme–Component Integration Map.

| Theme                              | Science | Technology | Engineering | Mathematics |
|------------------------------------|---------|------------|-------------|-------------|
| Scientific Process & Concept Dev.  | +++     | ++         | +           | +           |
| Technology & Digital Literacy      | ++      | +++        | ++          | +           |
| Engineering Design                 | +       | ++         | +++         | +           |
| Mathematical & Analytical Thinking | +       | +          | +           | ++          |

(+++ = strong integration, ++ = moderate, + = weak).

3.6. Overall Assessment of STEM Activities

A total of 10 activities were rated on a 0–12 scale based on their STEM integration. The average scores are as follows:

Table 8. Average STEM Scores (Based on 10 Activities).

| Component   | Average Score (0–3) |
|-------------|---------------------|
| Science     | 2.7                 |
| Technology  | 2.4                 |
| Engineering | 2.2                 |
| Mathematics | 1.5                 |

Most activities were heavily focused on science. Integration of technology and engineering was moderate to high in several centers. However, the mathematics component was mostly limited to basic measurement and graphing, with minimal use of advanced calculations or modeling.

4. Discussion, Conclusion, and Recommendations

4.1. Discussion

This study analyzed the integration of STEM components in biology activities conducted in Science and Art Centers (BİLSEM) and examined the interdisciplinary skills acquired by students. The findings demonstrate that when STEM education is structured around application, design, and problem-solving processes rather than mere knowledge transmission, gifted students are capable of achieving deeper learning outcomes. Primarily, it was observed that the science component was dominant in all activities. This supports the notion that science is the foundational pillar of STEM education, as emphasized by Bybee (2013) and Sahin (2015). The development of students’ scientific process skills through hands-on experimentation aligns with Sadler et al. (2010), who reported that science-based learning enhances conceptual understanding. The technology component prominently emerged through the effective use of laboratory tools and digital devices.

This finding corresponds with Honey, Pearson, and Schweingruber (2011), who emphasized the goal of integrating technology within educational settings. However, limited access to technology in some BİLSEM institutions was found to be a constraining factor, consistent with Wang et al. (2011), who reported that STEM integration is less effective in low-resource environments. The engineering component was notably present in activities such as bioplastic production and water filtration system design, providing students with opportunities to experience the design–test–revise cycle. These findings are consistent with Hynes et al. (2011), who found that engineering design-based science activities positively affect student motivation and problem-solving skills.

Nevertheless, in some cases, the engineering process lacked systematic implementation, and the problem identification and analysis stages were not sufficiently emphasized. Mathematics emerged as the least integrated component. This reflects a commonly reported issue in STEM education, where mathematics is frequently underrepresented (English, 2016; Roehrig et al., 2012). While students were involved in creating graphs and performing basic calculations, they were not adequately guided toward higher-order processes such as data modeling or statistical analysis. The theme-based evaluations derived from code analyses are consistent with Yamak et al. (2014), who found that in middle school STEM activities, science and engineering were more dominant, while mathematics remained superficial.

A key contribution of this study lies in its focus on gifted students in BİLSEM settings, allowing for deeper and more creative engagement with STEM activities. Furthermore, the use of a structured STEM integration rubric, based on direct analysis of student products, teacher perspectives, and classroom observations, adds a methodological novelty rarely seen in the existing literature (see Thibaut et al., 2018).

#### 4.2. Conclusions

- Biology activities in BİLSEM demonstrate a high level of integration of science and technology components; engineering is moderately represented, while mathematics remains the least integrated.
- Students significantly improved their scientific process skills through hands-on experiments and engaged in engineering cycles during design-oriented tasks. However, they had limited involvement in mathematical reasoning, calculation, and data interpretation.
- Teachers reported that STEM-based activities enhanced students' motivation and conceptual understanding but also noted limitations related to material resources, time constraints, and the need for interdisciplinary collaboration.

#### 4.3. Recommendations

##### **For Educational Practice:**

- STEM activity planning should ensure balanced representation of all four components: science, technology, engineering, and mathematics.
- Mathematics teachers should collaborate with biology teachers to integrate analytical and quantitative reasoning within STEM tasks.
- Professional development workshops focusing on STEM pedagogy and interdisciplinary activity design should be organized for educators.
- A centralized database and support network for STEM activities should be developed specifically for BİLSEM institutions.

##### **For Policymakers and Administrators:**

- The technological and digital infrastructure of BİLSEM laboratories should be improved and modernized.
- Time and budget allocations should support interdisciplinary planning and teacher collaboration in STEM initiatives.

##### **For Researchers:**

- Longitudinal studies comparing STEM integration across disciplines should be conducted.
- Experimental research should investigate the relationship between student products and their creative and scientific thinking skills.
- New assessment tools should be developed to evaluate cognitive, affective, and psychomotor learning outcomes in STEM-based learning environments.

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