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Reverse Engineering Integration into Science Education at BİLSEMs: A Good Practice Application

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Abstract

This study aimed to examine reverse engineering as an instructional approach that promotes analytical thinking, problem-solving, and creativity among gifted students in Science and Art Centers (BİLSEM). The project[4] also sought to support science teachers' professional development within the TÜBİTAK 4005 Innovative Educational Technologies Program. The study was designed as a descriptive case study and application report. Reverse engineering-based training was provided to Science and Art Centers (BİLSEM) science teachers in accordance with the Ministry of National Education's 2024 Science Curriculum. Classroom implementations and teacher practices were evaluated throughout the process. The findings showed that participating teachers effectively integrated the reverse engineering cycle into their instructional practices. The applications also resulted in concrete student products, including 3D-printed prototypes, reflecting increased creativity, scientific inquiry, and interdisciplinary thinking. The study highlights the potential of reverse engineering applications in gifted education to enhance originality, productivity, and engineering-oriented learning. The findings suggest that integrating such practices into science education may contribute to innovative and sustainable teaching approaches.

Keywords: reverse engineering, gifted education, science and art centers, science education

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Introduction

The aim of the 21st-century understanding of education is to enable individuals to acquire scientific creativity skills, to structure and solve problems like experts, and to become individuals who question, experiment, research, and possess entrepreneurial skills. In our time, for better understanding of science subjects in schools, for students to be more successful, and for students' creativity skills to develop, educational methods need to be appropriate for the era. For this, instead of classical teacher-centered methods, student-centered methods should be applied, where students learn by doing,

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experiencing, and questioning, and engage with science subjects with the discipline and understanding of a scientist (Çavaş et al., 2013). According to the renewed understanding of science education, another expected behavior from students is the ability to explain technological developments using scientific methods, and to examine their different aspects within the context of the interaction between science, technology, and society. Including technology and engineering disciplines in science education, along with these different perspectives, is of great importance in achieving the desired goals. Including the concept of engineering in the science curriculum helps students establish relationships between mathematics, science, and design, and design purposeful products (Çavaş et al., 2013).

Today, student-centered, project-based, and interdisciplinary learning approaches are gaining increasing importance in education. Classical curriculum-based approaches are proving insufficient, especially for gifted and high-potential students; there is a need for richer, more flexible, and application-oriented methods that will develop students' cognitive potential, creativity, and problem-solving skills (Demircioğlu, Vural, 2016). In this context, Science and Art Centers (BİLSEM) are institutions that aim to provide project-based, enriched education tailored to the interests and abilities of gifted students (Vural, 2010).

One of the innovative approaches that has attracted attention in recent years is reverse engineering. Reverse engineering is the process of analyzing an existing product or system, understanding its components, and redesigning it. This process requires analytical thinking, creative problem-solving, engineering design, and systematic review skills; which makes it quite suitable for gifted students (Ercan, 2014). Due to the contributions of reverse engineering to the field, a project supported under the 4005 TÜBİTAK project was carried out in May 2025 with the aim of making the education process more effective and engaging for gifted students and contributing to the emergence of innovative and original products. Within the scope of this study, the aim was to present the applications made by science teachers in their own schools and the activities carried out during the project process as a result of the training given to BİLSEM (Science and Art Centers) teachers on integrating reverse engineering applications, an innovative approach, into their lessons, in order to enrich the learning processes in science education for gifted students studying in Science and Art Centers (BİLSEM), strengthen their scientific thinking skills, and train them as future leading scientists.

Gifted Education and Science and Art Centers (BİLSEM)

Gifted students are individuals who demonstrate significant superiority over their peers in intelligence, creativity, leadership, or academic/artistic fields. The education of these students requires individualized, talent-focused, and enriched environments (Ayaydın and Ün, 2018). BİLSEM (Science and Art Centers) are centers established in Turkey to support the education of gifted and talented students. These centers aim not only to improve students' academic achievement but also to help them discover and develop their individual talents. While traditional curricula in formal education generally focus on knowledge transfer, BİLSEM offer project-based activities, research studies, and applied training in art, science, and technology. This approach allows students to take an active role in learning and to connect what they learn with real life (Ayaydın and Ün, 2018).

The educational philosophy of BİLSEM (Science and Art Centers for Gifted Students) focuses on identifying students' strengths and developing them in these areas. For example, a student talented in mathematics or science can improve their problem-solving, analytical thinking, and creative approach skills through experimental projects and research conducted at BİLSEM. A student talented in the arts, on the other hand, has the opportunity to create their own unique style and bring their creative ideas to life in activities such as painting, music, or design. This process not only increases students' academic achievement but also strengthens their social skills such as critical thinking, collaboration, time management, and taking responsibility (Ayaydın and Ün, 2018).

The daily activities of BİLSEM (Science and Art Centers for Gifted Students) are generally shaped according to the students' interests and abilities. For example, experiments can be conducted in science laboratories in the mornings, while in the afternoons, work can be done on robotics, software, or mathematics projects. Painting, sculpture, or music lessons are organized for students talented in art and music. Furthermore, through group projects, students learn to exchange ideas, solve problems together, and work in teams. These types of practices allow students to develop both their individual and social skills in a balanced way (Ayaydın and Ün, 2018).

Another important feature of BİLSEM centers is that they encourage students to produce projects that benefit society. For example, one student might conduct a project on recycling and environmental awareness, while another might design a solution in the field of robotics or software development. This process not only enables students to develop their own abilities but also helps them interact with society, grow into responsible individuals, and enhance their innovative thinking skills (Kadıoğlu Ateş and Mazı 2017). In conclusion, BİLSEM centers provide an educational environment that maximizes students' potential, nurturing them as creative, inquisitive, and socially beneficial individuals. Unlike classical education models, these centers encourage students to discover their talents, utilize their imaginations, and produce projects that contribute to society. BİLSEM centers not only offer students a unique learning experience but are also important educational institutions that cultivate future scientists, artists, and innovators (Kadıoğlu Ateş and Mazı 2017). According to Vural (2010), BİLSEM centers provide support to students in project-based activities, research, art, science, and technology fields outside of formal education. It is emphasized that the BİLSEM education model focuses on developing students' strengths, nurturing creativity, and producing projects that benefit society. Therefore, it is important for students studying at BİLSEM centers to implement engineering designs that will reveal their creativity by building upon existing products in their future productions.

What is Reverse Engineering?

Engineering science is divided into two branches: advanced engineering and reverse engineering. In advanced engineering, a product is conceived at the idea stage, designed abstractly, and then this idea is transformed into a tangible form through various modeling methods until it becomes a physical product. Advanced engineering is a scientific process that progresses from identifying the existing problem to generating and testing solutions, and making improvements based on the results, by applying the steps of scientific problem-solving (Türkücü and Börklü, 2018).

In reverse engineering, unlike advanced engineering, the process involves analyzing and thoroughly examining an existing product from a design and engineering perspective, and then redesigning, improving, and developing that product. Advanced engineering can sometimes lead to problems in process management and undesirable cost increases; to avoid such situations, using reverse engineering is more advantageous in such studies. Adapting reverse engineering applications to science education encourages students' interest in the field of engineering (Ercan, 2014).

Reverse engineering is a practice that greatly assists engineers in identifying and correcting deficiencies in ongoing production and design processes. It is applied to retrieve information that has been overlooked, is missing, or incomplete, or is otherwise inaccessible. In many industrial fields, reverse engineering involves examining a product in detail, as if under a microscope, disassembling it, and determining the purpose of each part (Bybee, 2013).

Reverse engineering is the process of analyzing an existing product or system to understand its components, operation, and design logic, and then redesigning it. It involves fundamental cognitive processes such as analytical thinking, systematic examination, abstraction, problem-solving, design, and creative re-engineering (West et al., 2015).

- Pedagogically speaking, reverse engineering:
- Encourages active learning among students.
- Integrates theory with practice.
- Develops critical thinking, creativity, and curiosity.
- Increases motivation because it works through real-life products and systems.

In these aspects, reverse engineering is an effective tool for unlocking the potential of gifted students (Dönmez et al., 2017).

STEM, Engineering and Design Approaches in BİLSEM

There are studies showing that engineering design processes can be applied in BİLSEM (Science and Art Centers for Gifted Students) environments. Studies have shown that activities based on STEM and engineering design processes have positive effects on the creativity and problem-solving skills of gifted students. Furthermore, modules that develop spatial thinking skills in BİLSEM students are also included in the literature (Taşçı and Şahin, 2020).

However, studies on reverse engineering-based applications in Turkey are limited. Therefore, the project titled "Integration of Reverse Engineering into Science Education in the Education of Gifted Students" within the scope of the TÜBİTAK 4005 program, conducted in 2025, is an important starting point. In this context, the aim of this study is to describe the reverse engineering-focused training process conducted for BİLSEM science teachers within the scope of the TÜBİTAK 4005 program and to present the tangible outputs of this process. Thereby, it aims to contribute good practice applications to the field that can be utilized in the education of gifted students.

Method (Proposal / Design)

This study is designed as a descriptive case study, which is one of the qualitative research approaches. The study serves as an application report presenting an educational process conducted within the scope of the TÜBİTAK 4005 program, along with its design and implementation stages.

Project Participants

The research was conducted in the spring semester of 2025. The study group consisted of 30 science teachers working in the education of gifted students in the Aegean region and neighboring regions. Criterion sampling, a type of purposeful sampling, was used in sample selection. Science teachers working in the education of gifted students in the Aegean region and neighboring regions were selected as the criterion. Thirty science teachers (14 women, 16 men) participated in the study.

Implementation Process and Activities

The project, "Integration of Reverse Engineering Applications into Science Education in the Education of Gifted Students," was designed as a comprehensive training program for science teachers working at Science and Art Centers (BİLSEM). The primary objective of the program was to equip teachers with the pedagogical and practical skills necessary to design and conduct reverse engineering-based workshops within their own institutions.

The implementation phase consisted of a four-day intensive training module. To ensure active participation and conceptual understanding, the training incorporated diverse pedagogical methods, including open-ended experiments, augmented reality, scientific field trips, gamification, STEAM activities, predict-observe-explain (POE/TGA), and creative drama.

The Training Schedule

The training program was structured progressively to guide participants from theoretical foundations to practical synthesis:

- Day 1 (Theoretical Foundation): The training commenced with creative drama exercises to foster group dynamics, followed by theoretical sessions introducing the core concepts and application areas of reverse engineering. Preliminary exercises, such as "recreating with colors," were conducted to establish the fundamental logic of reverse engineering.
- Day 2 (Multidisciplinary Applications): The focus shifted to real-world and sectoral applications. Activities covered diverse topics including additive manufacturing, efficient solar energy use in vehicles, biomimetics, urban planning, product health analysis, and healthcare applications.
- Day 3 (Advanced Integration): Participants engaged in advanced design applications, utilizing augmented reality for historical examples in a museum setting, exploring reverse engineering in music, and conducting mathematical analyses for structural engineering (e.g., bridge design).

- Day 4 (Original Design and Synthesis): The final day was dedicated to synthesis and production. Guided by historical examples, participants created structural and musical designs. The training culminated with the participating teachers developing and presenting their own original reverse engineering lesson plans and prototypes.

Key Activity Examples from the Implementation To solidify the reverse engineering cycle, several hands-on activities and field experiences were integrated into the training process. Notable examples include:

Structural Analysis ("Which Bridge Design is the Best?"): This activity aimed to teach the reverse engineering cycle by analyzing the structural integrity of a system using mathematical calculations. Participants created various bridge designs, which were then subjected to weight tests to determine the most robust structure. Subsequently, participants examined the winning design and compared its structural features to their own.

Figure 1. "Which bridge design is the best?" activity teacher preparations

Figure 2. Designs created by teachers in the "Which bridge design is the best?" activity.

Energy Efficiency ("Using Solar Energy Efficiently in My Car"): In this activity, participants designed functional solar-powered cars. Each group's prototype was examined, and the technical differences between the car that operated the longest and the others were critically discussed.

Figure 3. "Using Solar Energy Efficiently in My Car" activity teacher preparations

Optics and Disassembly ("Reverse Engineering and Colors"): Focusing on the properties of light, participants examined the colors produced by shining different colored filters into a light source, successfully revealing the connection between color formation and the reverse engineering concept.

Figure 4. Reverse Engineering and Colors activity application

Industrial Field Visits: To transcend the classroom environment and demonstrate the real-world impact of reverse engineering, participants visited industrial sites. These visits allowed teachers to experience industrial reverse engineering processes firsthand, thereby fostering potential collaboration opportunities between the industry and educational institutions.

Figure 5. Reverse Engineering and Application Areas

Data Collection and Analysis of Outputs

A descriptive analysis approach was adopted to analyze the obtained data. Accordingly, process photographs and observation notes were utilized to describe how the implementation was carried out. The prototypes and designs developed by the teachers, along with the activities conducted by the students, are presented visually in the findings section as evidence that the training achieved its targeted outcomes.

Ethical Statement: This study was approved by the Educational Research Ethics Committee of Aydın Adnan Menderes University with the decision dated March 26, 2025, and numbered 2025/5-XX. During the research process, the participants (teachers) were informed about the purpose and procedure of the study. The principles of data confidentiality and voluntary participation were explained, and 'Informed Voluntary Consent Forms' were obtained from each participant. Furthermore, all necessary permissions for classroom applications and shared student visuals were meticulously followed.

Findings

The outputs of the implementation process are presented in two main categories: the reverse engineering-based lesson plans developed by the participating teachers and the tangible classroom applications reflecting the multiplier effect of the project on BİLSEM students.

Teachers' Design-Based Lesson Plans and Reflections

To evaluate the pedagogical integration of the training, teachers were asked to reflect on how they would implement the reverse engineering approach in their own BİLSEM classrooms. The responses indicated a strong internalization of the reverse engineering cycle: disassembly, analysis, and redesign.

For instance, one participant proposed an activity focused on electrical circuits:

"When teaching electrical circuits, I could plan a reverse engineering-based activity. At the beginning of the lesson, students could disassemble small electronic devices and examine their circuit structures. We would discuss how these circuits work and what each component does. Then, we would brainstorm about how these circuits could be redesigned in different ways... In the final stage, the most suitable circuit design for a specific purpose would be created... This process allows students to understand electrical circuits more deeply and improves their problem-solving skills."

This reflection demonstrates that the teacher successfully adopted the core methodology. Another notable output was a detailed activity plan titled "In Pursuit of Light: Analyze and Redesign the Flashlight." This plan was designed to introduce students to reverse engineering within the "Electrical Circuits and Energy Transformations" unit. In this scenario, students systematically disassemble a simple flashlight to identify basic components (battery holder, LED, switch). After evaluating the system, students are guided to propose more ergonomic, environmentally friendly, or efficient models. The teacher highlighted specific innovative redesign ideas, such as:

- A flashlight model charged by integrated solar panels,
- A motion-sensor version that automatically activates in the dark,
- A prototype with a body designed entirely from recycled materials.

The teacher noted that by testing these circuit designs with low-cost materials like breadboards and LEDs, students would connect scientific knowledge with engineering applications, fostering higher-level cognitive skills and a STEM-oriented approach.

Classroom Applications and Student Prototypes

The ultimate goal of the TÜBİTAK 4005 project is to transfer these skills to gifted students. Following the training, participating teachers successfully implemented reverse engineering activities in their classrooms, resulting in tangible student products.

Figure 6. 3D printed prototypes designed

Figure 7. 3D dinosaur designs by BİLSEM students

As shown in Figure 6 ve Figure 7, students actively participated in the production phase of the reverse engineering cycle. By utilizing 3D printers, students transformed their conceptual and digital designs into tangible three-dimensional objects. This application not only demonstrates the students' ability to model complex structures (such as dinosaurs) but also highlights the successful translation of the teacher training program into practical, student-centered engineering activities.

Conclusion

The primary aim of this application report was to describe the reverse engineering-based training process for BİLSEM science teachers and present its tangible outputs. The findings clearly demonstrate that the participating teachers successfully internalized the reverse engineering cycle, effectively translating theoretical training into practical, design-based lesson plans. Furthermore, the classroom applications-evidenced by the students' 3D-printed prototypes-indicate a strong multiplier effect, showing that the professional development of teachers directly and positively impacted the creative production processes of gifted students.

Since gifted individuals possess a natural inclination towards analytical thinking and resolving complex structures, the reverse engineering process provides these students with an optimal mental challenge. In these applications, students discover how systems work by disassembling technological tools they encounter in daily life, developing alternative functional solutions, and actively participating in the knowledge production process. As Ülger (2025) emphasizes, reverse engineering-based science activities contribute significantly to students' understanding of the engineering design cycle through practical application and interdisciplinary thinking.

Consequently, the reverse engineering-based teaching approach holds strong potential for developing the scientific reasoning, creativity, problem-solving, and engineering design skills of gifted students. This approach aligns perfectly with the flexible and talent-oriented environments of Science and Art Centers (BİLSEM). However, as Akkaş and Tortop (2015) suggest, its widespread adoption requires sustained teacher training, adequate infrastructure, and appropriate evaluation systems. Ultimately, reverse engineering stands as a forward-looking and innovative pedagogical model in gifted education.

Recommendations

Based on the implementation process and the tangible outcomes of this study, the following recommendations are presented for policymakers, educators, and future researchers:

The Ministry of National Education (MoNE) should incorporate reverse engineering and STEM applications into the science curriculum in a more structured and concrete manner. Providing a formal framework will encourage teachers to implement such innovative activities systematically.

While the four-day training program yielded positive results, planning longer-term and continuous professional development programs would enable the production of even more original and complex design activities. These programs should heavily feature applied methods.

Since reverse engineering inherently requires the integration of science, technology, engineering, and mathematics disciplines, school administrations should encourage teachers from different branches to collaborate and conduct joint reverse engineering projects.

While this study focused on the teacher training process and its immediate classroom reflections, future experimental research should be conducted by providing reverse engineering training directly to students. Measuring the direct effects of these applications on students' critical and creative thinking skills using quantitative or mixed-methods approaches will significantly contribute to the literature.

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