

Gifted Students Designing Eco-Friendly STEM Projects*

Üstün Yetenekli Öğrencilerin Çevre Dostu STEM Projeleri Tasarımı

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Abstract. This study aims to investigate the experiences of gifted students while designing a STEM-based environmental project within a real-world context. The study employed a single case study with embedded units design in order to investigate the strategies that gifted students exploited in designing their STEM Projects, as well as their experiences in the actual design process. The data collected in the current study were in the form of video recordings, audio recordings, student artifacts, individual and group assessment forms with open-ended questions, and the teacher's journal. The participants of the current study involved 17 students from 3-4th and 5-6th grade science classes at a Science and Arts Center. The analysis of the data was achieved using content analysis. The findings indicated that when students were presented authentic STEM learning experiences that involve personally or contextually meaningful content, they adopt a critical thinking disposition that allowed them to investigate the criteria and constraints presented in the problem scenario, as well as the financial and environmental perspectives.

Keywords: STEM education, gifted students, engineering design, environmental education, case study

Öz. Bu çalışmanın amacı üstün yetenekli öğrencilerin gerçek dünya problemi bağlamında sunulan STEM odaklı projeler tasarlama sürecindeki deneyimlerini incelemektir. İç içe geçmiş tek durum deseninin kullanıldığı bu araştırmada Bilim ve Sanat Merkezinde öğrenim gören 3-4 ve 5-6. sınıf seviyesindeki üstün yetenekli öğrencilerin STEM odaklı çevre dostu projeler tasarlama sürecinde kullandıkları stratejiler ve deneyimleri ortaya konulmaktadır. Çalışmanın katılımcılarını Bilim ve Sanat Merkezindeki 3-4. ve 5-6. sınıf seviyesinde öğrenim gören 17 öğrenci oluşturmaktadır. Araştırma kapsamında toplanan verileri video ve ses kayıtları, öğrencilerin tasarım ürünleri, açık uçlu bireysel ve grup değerlendirmeleri ve öğretmen günlükleri oluşturmaktadır. Verilerin analizinde içerik analizi uygulanmıştır. Çalışmanın bulguları, öğrencilere kişisel ya da bağlamsal olarak anlamlı otantik STEM öğrenme deneyimleri sunulması durumunda, problem senaryosunda sunulan kriterleri ve kısıtlamaların yanı sıra finansal ve çevresel perspektifleri incelemelerini sağlayan eleştirel bir düşünme eğilimi benimseyebildiklerini göstermiştir.

Anahtar Kelimeler: STEM eğitimi, üstün yetenekliler, mühendislik tasarım, çevre eğitimi, durum çalışması

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Introduction

The term, gifted, has been widely-used in education over the past century. While there are various definitions for gifted education, the Marland Report prepared by the U.S. Commissioners of Education presented one of the most widely recognized definitions of giftedness as:

Gifted and talented children are those identified by professionally qualified persons who, by virtue of outstanding abilities, are capable of high performance. These are children who require differential educational programs and/or services beyond those provided by the regular school program in order to realize their contribution to self and the society. (Marland, 1972, p. 8)

In addition to the Marland Report's definition, Ross (1993) also defined gifted students as "students with outstanding talents who perform, or show the potential for performing, at remarkably high levels of accomplishment when compared with others of their age, experience, or environment" (p. 46). Those students give evidence of high achievement capability intellectually, creatively, and/or artistically, as well as specific academic fields and need services and activities that are not usually provided by ordinary schools (U.S. Department of Education, 2010). The reasons behind the fact that gifted students do not always reach their academic potential are numerous, but the most noticeable is usually based on deficiencies in teaching and learning environments (Rimm, 2003).

Gifted students learn differently from most students. They usually learn faster than their peers and perceive complex ideas and concepts, passionately interested in topics, and request more advanced work (Winebrenner, 2000). Gifted students do not benefit from instruction designed based on the needs and standards of their age-related grade level (Hockett, 2009; Reis, 2007). Therefore, it is necessary to provide them with specially designed instruction that provides them with opportunities to participate at a level based on their abilities and capabilities (Ross, 1993). The role of teachers in educational settings designed for gifted students is different from that of the traditional teaching role (Seeley, 1989; Tomlinson, 2001). Teachers of gifted students need to provide learning experiences based on their students' needs and interests, and to make the necessary curriculum adaptations in a flexibly way (Clark, 1997; Tomlinson, 2001).

The objectives of the current reform documents at national and global scale are to improve K-12 science, mathematics, technology, and engineering (STEM) education in order to motivate more students to pursue STEM fields and to ultimately remain competitive in gradually global economy (National Academy of Engineering [NAE], 2014; National Research Council [NRC], 2011; Next Generation Science Standards Lead States [NGSS], 2013). Today's problems are complex and multidisciplinary, and their solutions often require the integration of science, technology, engineering and mathematics (STEM) knowledge and skills (National Research Council [NRC], 2011). However, STEM disciplines are generally taught as separate subjects in schools. The new interdisciplinary approach, known as STEM, was introduced in order to bring together the subject-specific content as well as the overarching ideas that integrate the STEM disciplines.

Even though STEM has been addressed by various educational reform and policy documents, it has yet to be adequately defined (Bybee, 2014). STEM may refer to a science course that incorporates other disciplines, a combination of one or more disciplines, or a transdisciplinary course or program (Bybee, 2014). "STEM integration is usually defined by merging the disciplines of science, technology, engineering, and mathematics in order to (1) deepen students'

understanding of these disciplines through fostering conceptual understanding, (2) broaden understanding of these disciplines within socially and culturally relevant STEM contexts, and (3) increase students' interest in STEM disciplines to aid their forthcoming career choices" (Roehrig, Moore, Wang, & Park, 2012, p. 2). Moore et al. (2014) argued that the integrated STEM framework includes the following aspects: 1) motivating and engaging context, 2) inclusion of mathematics and/or science content, 3) student-centered pedagogies, 4) engineering design or redesign challenges, 5) learning from failure, and 6) emphasis on teamwork and communication.

The National Science Board (2010) recommends that students of all grade levels should be provided with STEM-related experiences that involve open-ended real-world problems. Gifted students especially need such experiences in order to increase their engagement and interest in the STEM disciplines (Robbins, 2011). The literature reveals that traditional instructional methods can limit the potential of gifted students, resulting in gifted students losing interest and eventually causing a decrease in their academic achievement. Superficial experiences of a wide-range of topics were found to be ineffective in promoting gifted students' motivation, engagement, and achievement in the fields of science (Robinson, Shore, & Enersen, 2007). Gifted students require curriculum that emphasize overarching and interdisciplinary concepts (VanTassel-Baska, 1998), as well as flexible learning environments that can promote their interests, skills, and creativity (Koshy, 2002). Robinson, Dailey, Hughes, and Cotabish (2014) found that when gifted students were presented "with a real-world problem, make scientific connections using overarching concepts such as change and systems, they were better able to fully explore the content in an investigatory manner" (p. 17). Hence, STEM experiences in real-world contexts that require gifted students to draw from multiple disciplines in order to solve a given problem or design challenge have the potential to help them reach their true potential. To develop the STEM talent of young gifted learners, they need inquiry-based, problem-centered experiences (Robinson et al., 2014). Thus, gifted students need to be engaged in quality STEM learning within schools. While much of the research in gifted education is related to the characteristics of gifted students as learners, there is limited research relating to gifted students' STEM educational outcomes, as well as their STEM learning experiences (Morris et al., 2019). Therefore, the current study aims to investigate the experiences of gifted students while designing a STEM-based environmental project within a real-world context. The following research questions directed the study:

- How do gifted students experience designing a STEM-based environmental project within a real-world context?
- What strategies do gifted students use in designing a STEM-based environmental project within a real-world context?

Methods

Research Design

The study employed a case study design in order to investigate the strategies that gifted students exploited in designing their STEM Projects, as well as their experiences in the actual design process. A single case study with embedded units (Yin, 2014) was chosen to explore

the case, while considering the differences between the decisions made by each of the participants. “The ability to look at subunits that are situated within a larger case is powerful when considering that data can be analyzed within the subunits separately (within case analysis), between the different subunits (between case analysis), or across all of the subunits (cross-case analysis)” (Baxter & Jack, 2008, p. 550). The embedded units of analysis of the current study were 3rd and 4th graders as one unit of analysis, and 5th and 6th graders as a second unit of analysis. Using an exploratory type of case study (Yin, 2014), the study aimed to explore a phenomenon and the real-life context in which it occurred.

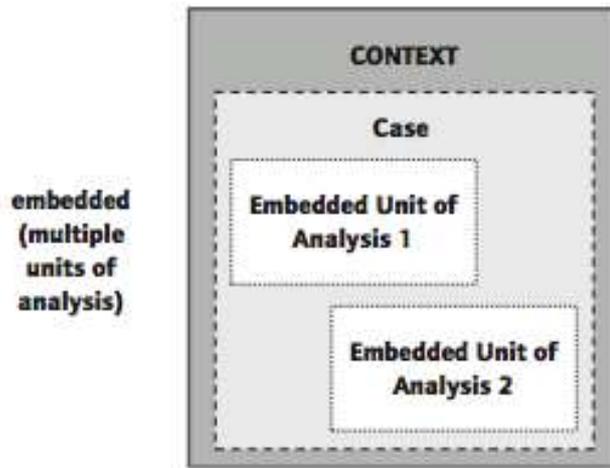


Figure 1. Single case study with embedded units (Yin, 2014)

Context

The current study was conducted within a Science and Art Center in Turkey that primarily serves to gifted students outside of normal school hours. The learning activities at the center are designed based on the enrolled students' needs and interests. Although the teachers use a variety of different educational resources within their instruction, they do not follow any particular curriculum. The learning goals in these environments involve promoting high-order thinking, problem-solving skills, and student creativity. Therefore, the teachers, and especially the science teachers, at the center are highly motivated to apply STEM-focused learning activities within their classes.

The class where the current study took place was taught by a science teacher with more than 10 years of teaching experience. In addition to her teaching assignments, the teacher was working on her doctoral degree at the time the study was conducted.

The STEM-focused curriculum used in the current study was designed based on VanTassel-Baska's (1986) "Integrated Curriculum Model" (ICM) that was developed to meet the needs of gifted learners. The ICM involves the following dimensions: (1) concepts, issues, themes; (2) process and product; and, (3) advanced content. The STEM module applied in this study focused on a design challenge that was based on a real-world scenario. Students were expected to design a living complex by considering criteria such as living units designed to maximize

profits but with environmental friendly solutions. The activity commenced with a client letter requesting the students to design a pictorial drawing of a living site that involved natural land as well as urbanized areas. Whilst designing their projects, the students were expected to incorporate pro-environmental ideas as well as basic design skills. The activity took place with the classroom environment and the length of the activity was approximately five hours. There were two applications: one for 3rd and 4th grade students, and one for 5th and 6th grade students.

Participants

The participants of the current study involved 17 students from two different science classes at a Science and Arts Center. The students in the first classroom were in their 3rd or 4th grade at school, while the students from the other classroom were in their 5th or 6th grade. The participant students were selected based on parent consent and student assent. These students were asked if they were willing to be audio-recorded and their interactions closely monitored. As the Center is not required to follow a curriculum, the same STEM activity module was implemented to both classes. Information about the participants from the 3rd and 4th grade classroom is provided in Table 1, and the participants from the 5th and 6th grade classroom in Table 2.

Table 1.

Participant Information: 3rd and 4th Grades

	<i>Name</i>	<i>Age</i>	<i>Grade</i>	<i>School Type</i>
Group I	Amy	9	3	Public
	Beth	9	3	Public
	John	10	4	Public
Group II	Gwen	10	4	Public
	Christina	9	4	Public
Group III	Dolores	9	4	Public
	Freddie	10	4	Private
	Roger	10	4	Public

Table 2.

Participant Information: 5th and 6th Grades

	<i>Name</i>	<i>Age</i>	<i>Grade</i>	<i>School Type</i>
Group IV	Kelly	10	5	Public
	Miley	10	5	Public
	Nick	11	5	Public
Group V	David	11	6	Public
	Alicia	11	5	Private
Group VI	Richard	10	5	Public
	John	11	5	Public
	Paul	12	6	Public

Group I

The first design group involved one male and two female students. John is a fourth-grade student at a public (state) school. He likes Science and Math classes. He often uses technology for playing computer games and undertaking research on the Internet. He is also good at working in groups. Amy is a third-grade student who attends a public school. She describes herself as a music talent. She demonstrates high-level teamwork skills and works with her friends congenially and responsively. Beth is also a third-grade student attending a public school. She likes Science class, but does not like Math, especially the solving of math-related problems. She reads books frequently. Possessing high-level self-expression and communication skills, she is good at working in groups.

Group II

The second design group also involved one male and two female students. Brian is a third-grade student attending a private school. While being successful in Math and Science classes, he spends most of his time reading. Gwen is a fourth-grade student at a public school. She enjoys Science and Math classes. She likes designing projects and undertaking research about new technologies. She describes herself as a good team member. Christina is also a fourth-grade student in a public school. She likes Science classes, especially doing laboratory experiments. She uses technology for learning. She likes designing and team-working.

Group III

The third design group involved one female and two male students. Dolores was a fourth-grade student of a public school. She likes Science classes and wants to be a biologist. While she actively participates in class discussions, she sometimes significantly criticizes her friends. Since she usually wants to lead the group discussions, Dolores sometimes causes conflicts in the groups she works in. Freddie is also a fourth grader, but attends a private school. He likes Math classes in which he actively participates. He describes himself as being a good problem solver in math. He uses technology to design simple animations. He expresses himself very well, and works in groups actively. Roger is in the fourth grade at a public school. He likes Science and Technology classes. He uses technology to play games. He wants to be a professional swimmer. Because of his hyperactive personality, he struggles to work in groups.

Group IV

The fourth design group involved one male and two female students, who were all in the fifth grade. Kelly goes to a public school. Although she likes Science and Math classes, she is also interested in Language Arts because of her favorite teacher. She likes making scientific experiments, painting, and designing. She wants to be a costume designer. She usually wants to work individually because she thinks her groupmates do not fulfill their responsibilities. Miley also goes to a public school. She likes Music class and Gymnastics. She does not like Science and Math classes, unless there is a design aspect in it. She wants to be a pharmacist. She uses technology for her research and likes group work. Nick, goes to a public school. He likes Math and Science classes and wants to be a Math teacher. Like Miley, he does research via technology and likes working in groups.

Group V

The fifth design group involved one female and two male students. Alicia is a fifth-grade student who attends private school. She also likes designing, but in a more artistic way. Her favorite activities are drawing and playing piano. She is good at both individual and group work. David goes to a public school and is in the sixth grade. His favorite subject is Science and he wants to be a computer engineer. He takes part in other student project groups as he likes designing, and enjoys designing new and interesting materials through tinkering. Although David likes working alone, he is able to work in groups responsibly. Richard is a fifth grader, but goes to a public school. He is interested in science, and he uses technology to play video games and communicate. He usually wants to work alone. He struggles to work in groups, and is therefore unable to contribute to group works.

Group VI

The sixth design group involved just two male students. John is a fifth grader going to a private school. Despite having two parents who are both Math teachers, he is more interested in Geography and History. However, he wants to be an engineer. He likes working on projects that involve technology aspects. He prefers both individual and group work. Paul is a sixth grader going to a public school. He likes Science and Math classes. He is really into technology. Although he prefers working alone, he is able to work in groups effectively.

Data Collection

Using a case study design, a variety of different data was collected in order to provide a better understanding of the strategies that the students employed in designing their STEM Project, as well as their reflections about the learning process. The data collected in the current study were in the form of video recordings, audio recordings, student artifacts, individual and group assessment forms with open-ended questions, and the teacher's journal. The classroom was video-recorded throughout the project design process, while the individual design group discussions were audio-recorded in order to reveal their design considerations. In addition to the video and audio recordings, the students' design artifacts were also collected. Open-ended forms were also completed and collected from both the individual groups and design groups at the end of the design process. Lastly, the classroom teacher completed a journal in order to provide a reflective balance.

Data Analysis

The analysis of the data was achieved using content analysis, examining the raw data deeply in order to classify codes into a number of categories representing similar meanings (Weber, 1990). The purpose of content analysis in the current study was to "provide knowledge and understanding of the phenomenon under study" (Downe-Wamboldt, 1992, p. 314). Data analysis in the current study occurred in three stages: (1) open coding; (2) identification of patterns and categories; and, (3) building themes. Categorical aggregation was employed by collecting instances from the data to look for issue-relevant meanings. Then, cross-case analysis was conducted, studying two or more cases to look for similarities between them. The data derived from multiple perspectives (teacher and students) allowed for triangulation. The code

against multiple data sources were triangulated by considering the codes emerged within one data source with other data sources; hence, supporting the credibility of the naturalistic code.

Findings

In this section, each design group is presented in order to describe the experiences and considerations of the students during the design process. Then, the findings that emerged through cross-case analysis are presented.

Embedded Unit I: 3rd-4th Grade Class

Design group I

While designing their prototypes, the main conflict that the group members experienced concerned the balance between income/runoff values (the management of excess rainwater on a surface) and design concerns. While one of the group members (John) insisted on balancing the income and runoff values, another member (Amy) focused more on the esthetic and user-friendly side of the design. To illustrate this; in deciding what types of units that they would use in their projects, John strongly advocated considering the criteria about income and runoff, whilst Amy considered the anticipated residents in order to design the most user-friendly site (see the following sample conversation). Hence, it was clear that there was no agreement among the group members.

Amy: Consider buying a house in a housing estate. Wouldn't you want a playground?

John: Playgrounds have a high runoff. Kids can play on grassland.

Amy: We can have one playground at least.

John: Ok, let's balance the income and runoff values first. Then, we can use one unit for a playground if we have any vacancies. (After a while) Do you still want a playground? It has runoff but no income. It makes no sense.

Amy: We should sympathize with the residents, then design the units. If you live in a housing estate, don't you think you would need a playground for the kids? We need to understand the users' perspectives. Esthetic and user-friendly environment are also criteria, not just income.

In another instance, John advocated the idea that they should not use units that do not create any value. John's other group members sometimes criticized his attitude during the design process.

Beth: He does not let us do anything because the units we want to use causes runoff.

Another important discussion occurred in this group was the objectivity of some of the design criteria. The group members never questioned the criteria about money and runoff, while they often asked who would evaluate their design based on esthetic and extra Low Impact Development (LID) criteria. In addition, while brainstorming about the possible LID options, Amy and Beth often asked their teacher whether or not their ideas could be considered as LID. Some of their ideas were designing buildings in a way that each apartment achieved maximum sunlight and used domestic wastewater for the watering of grassland. The members of the group

also discussed other potential ways to reduce the level of runoff. One of the ideas they strongly advocated for was as follows:

Amy: We plan to design roads with tiny holes that has plastic layers on them. These plastic layers will be semipermeable like cell membranes. We will make tiny holes in them so that the cars passing through will not be affected. However, those plastic layers will let the storm water transfer through to the soil.

Following the activity, the students completed a short self-evaluation form in order to reflect their experiences throughout the process. While all of the students in this group mentioned that they enjoyed designing their prototypes, they also addressed certain points that were challenging to them. One challenge that the students mentioned in their self-evaluations was meeting criteria about the esthetics of their designed prototypes. Also, while completing their group evaluation form, the only option they responded negatively to was their encouragement of each other.

Design group II

Whenever they started designing their projects, the members of this group critically examined the criteria. They also often tried to stretch the criteria based on the ideas they created. For instance, one of the group members argued that if they found an original idea, they should have been able to use it within their design, regardless of its conformity to the original criteria. After they were convinced, the students constantly rechecked the criteria to see whether or not they were on the right track.

Christina: We need more lawn and trees around the ponds. It would be aesthetic and organized for the residents.

An important point noticed in the data collection were the debates that occurred happened about the decision-making processes of the group. To illustrate; whilst making a design decision, one group member protested at one of the actions, stating disapproval of the others' decisions. After that, the group members discussed that design actions should be decided unanimously, not just by a majority.

Designing their prototype, one of the challenges the group members faced was deciding whether or not to use grassland or woodland in their site design. Because these areas did not have represent any income value, one of the students argued there being no point in considering such areas.

Gwen: We have no natural land on our site yet. Let's decide where to locate some.

Brian: But it has zero income. There is no point putting in any grassland. We can use other options.

Another important discussion was about locating the different units. At first, the group members only focused on meeting the income and runoff criteria in their design, which is why they only expressed interest in the numbers and their calculations. Following Gwen's suggestion, the group decided to reconsider the organization of the units.

Gwen: Don't organize the units randomly. The arrangement is also important. You only focus on the numbers. Having an esthetic and user-friendly environment is also an important criteria, I think.

Christina also criticized the way they designed their prototype, based merely on financial concerns.

Christina: If you put only one housing unit and nine industrial and commercial units in the design, it cannot be called a 'living space for people.' It would be an industrial area, and no one would want to live there.

While designing their prototypes, the members of the group competed with the other groups. They often discussed whether or not there would be a first place awarded. It was a strong motivation in finishing their design successfully.

Brian: I want to be in first place.

Christina: Even if we don't get first place, we should not be disqualified.

Gwen: Disqualified?

Christina: If you don't meet the criteria in your design, you are disqualified, I think.

The group members also highlighted certain important points on their individual and group forms. Gwen stated that they learned how to work as a team during the design process. She also noted that they experienced difficulty in finding different and original environment-friendly ideas. Christina stated that the hardest part was meeting the esthetic expectations in their design.

Design group III

Prior to starting the design of their prototype, the students in the group listened carefully to the instructions from their teacher, as well as discussing the key points. Then, they started their design without any planning or sharing out of responsibilities. Hence, they struggled to work effectively at the beginning. One of the most significant issues they faced was to decide who would lead the group work. Freddie and Roger competed with each other in order to lead the group, whereas Dolores decided to take a backseat and accept her responsibility. The rivalry between Freddie and Roger ensued throughout the design process. To illustrate; when Freddie walked through their design with his groupmates, in order to determine if there was any mistake made, Roger criticized him by stating that it was a waste of time. In another instance, Freddie stated that the calculations he was making was the hardest part of their design, therefore he considered the responsibilities of the others to be relatively easier by comparison. In general, Roger criticized the works of his groupmates and complained about them. Moreover, he often interacted with the students from other groups, which disconcerted the teamwork.

Roger: You don't listen to me, so we are having constant problems. We are behind where the other groups are up to.

Due to all these issues, there were constant crises in the group, which resulted in group members not being informed about all of the design decisions.

While designing their prototype, the students in this group agreed to use T-Charts that involved the pros and cons of their design decisions. Therefore, they brainstormed using this chart in order to decide the best actions. Dolores insisted on using environmentally-friendly units in their design, stating that it was a must because of the nature of the class.

Dolores: Hey! It's a science class. We need to consider the environment, because it is the objective of our class. Money is good, but you know, we have to care about the environment too.

On the other hand, Roger offered to use the units that had either the highest income or the lowest runoff values. Freddie criticized that decision because it would rule out the user-friendly aspects of their design, hence not being able to address the preferences of the target audience.

At one point, Freddie figured out an approach that was not used by any other group. He calculated the ratio between the income and runoff values and tried to keep that as high as possible. In addition, Dolores asked whether or not their environmentally-friendly ideas could be an excuse to use different units with high runoff values. Therefore, they could use the units with greater income values.

In their individual evaluation forms, the students in this group reflected their experiences during the design process. Freddie stated that he enjoyed the mathematical operations the most; whereas, Dolores addressed making physical models as her most favorite. Roger believed that the brainstorming processes while making design decisions were the most valuable part. On the other hand, their group evaluation form indicated that communication among the group members were unsatisfactory. They stated that the group members were unable to encourage and appreciate each other enough, which was consistent with the observations.

Embedded Unit II: 5th-6th Grade Class

Design group IV

During the design process, the students in this group started by assigning responsibilities for each member. At the beginning, the group had long discussions to come up with some original ideas. Hence, they sometimes became demotivated for short periods of time. After struggling to find their ideas, Nick offered to search for good and innovative examples, as well as for environmentally-friendly ideas. Instead, they decided to consider the areas that they lived in and to observe around them.

Miley: Let's think about our hometown. What are the examples of environmentally-friendly living areas. We can talk about them to get some inspiration.

Kelly: Ok. Do you know any?

Miley: I am sure there are some good examples, right? A simple example are the solar panels we see around us. We can incorporate similar ideas in our design.

Another important task that the students in this group worked on was finding a balance between income-generating and environmentally-friendly aspects of their designs. At different points, the students tried to increase their income and reduce the negative impacts on the environment. However, they were not quite sure about the standards for income and runoff values. Therefore, they often struggled to strike a balance between the two. They sometimes questioned the necessity of environmentally-friendly projects due to their lack of economic value. Eventually, the members of this group concluded that they needed a comprehensive perspective for their project in order to address such conflicts.

Nick: We need to have a comprehensive consideration for our project. If we struggle with only one dimension, we won't be able to design a valid living complex. A strong design requires us to employ multiple perspectives.

The students also discussed whether or not the residents of their designed area would accept environmentally-friendly projects. To illustrate; Kelly argued that their design should aim to change the habits of those who usually opted for their own comfort instead of protecting the environment. Hence, she offered to introduce radical improvements in place of traditional pro-environmental ideas. Notwithstanding, they came up with some pro-environmental ideas to use within their design. For instance, they suggested leaving a gap between the soil and the roads laid upon it, thus enabling transference of rainwater through to the soil. Another suggestion was to produce biodiesel for sustainability.

The group members reflected their experiences on their individual and group forms. To illustrate; Miley indicated that she had become more aware of the environmental impact of their housing site. They also stated that the design process taught them different aspects, such as mathematical calculations and trade-off skills. One of the skills that all three students claimed to gain was with regards to team-working. They stated that they learned about the sharing of responsibilities and working as a team in order to complete a task.

Design group V

In their design, the most frequently addressed concern was the target audience for whom the students designed their site. They often discussed the preferences, expectations, and behaviors of their target recipients in order to better design their prototype. As soon as the prototype was finished, they asked each other if they would prefer to live in that kind of place. Then, they critically examined who was their target, and whether they were customers who preferred the environment or money.

David: Let's figure out our audience. Who are we supposed to convince? Environment-friendly people or money-minded customers. Then, we can design our area based on their preferences.

This particular group's main concern while designing their prototype was the environment. They frequently used terms like environmentally-friendly and environmental ethics. They also held discussions about human impact on the environment and also about urban sprawl. In order to minimize the negative human impact on the environment, they considered various environmentally-friendly projects to use in their designed land. Some of those projects involved utilizing the tops of buildings as green lands, and the effective use of waste water and sewerage systems. Hence, while designing their prototype, their primary focus was the environment.

David: Our main focus is the environment. Everybody in the construction business cares about money. Our concern should be to take care of the environment. That would make us different from the rest.

On the other hand, designing an environmentally-friendly project posed a challenge for them. After a while, they figured out that their design was not going to be able to meet the income criteria. Then, they discussed how to meet the optimum values from both environmental and economic perspectives. During those discussions, they repeatedly consulted the criteria in order to be sure. Having spent too much time on that part, the group requested additional time in order to complete their design.

In general, the group members worked well with each other. However, Richard proposed different ideas from the group members, which caused problems with the others. To illustrate, when other group members did not accept his solution to increase the income, he raised his

voice against his groupmates. Even though this caused some problems at first, the group resolved this issue without the teacher's interference.

Despite the crises faced during their design process, in their individual evaluation forms, the group members stated that they learned how to work as a team. In addition to teamwork, the students also mentioned that the design process taught them about time management. Lastly, one of the group members indicated that they needed to consider the balance between environment and money in order to successfully design a living site.

Design group VI

As soon as they took the directions about the design task, John and Paul started working together. In general, their communication with each other was very good, and they worked very effectively as a team. John was the one who put forward the ideas, but also sought his teammate's approval. Because there were only two of them in the group, they struggled with sharing responsibilities in order to complete the design task. For instance, they questioned if they could compete with the other groups in terms of the esthetic criteria. Thus, they constantly interacted with other teams' students working next to their table.

Different from the other groups, when these two students started working on their design, they immediately focused on the esthetics and user-friendly aspects. They argued that if they designed their prototype well enough, they would eventually meet the criteria. Mathematical operations were not performed whilst designing their prototype, which resulted in their not meeting the income and environment-friendly criteria. Therefore, they had to change their initial design so as to meet the criteria. Before this, they had tried to negotiate with their teacher to bend the rules, stating that they designed the best prototype, albeit independent of the criteria. They argued that their target audience would not care about the criteria as much as its esthetic design.

One of the reasons why they did not focus on the income or environment criteria was probably due to the requirements for mathematical operations to be performed. They were more inclined to focus on the esthetic and artistic aspects. When they realized that they had to work on the other criteria, they struggled a great deal and lost motivation. At one point, they asked the teacher if they could use a calculator, although their academic competency was more than adequate to complete the math. Without receiving a calculator, the group members decided to work together in order to complete the task. However, they struggled to meet the minimum income criteria.

This particular group's design preferences were inclined more towards natural land rather than urbanization. Considering their target audience, they proposed a discussion about their choices, and whether it was a more urbanized or natural area. Consequently, they decided that it was not the wisest decision to design a project that was either the most valuable or environment-friendly project. Hence, they argued that a standard project with medium values would be more convincing for their target audience. Last but not least, the students provided some original environmentally-friendly ideas, such as transferring rainwater to the ground effectively and stabilizing the environment via natural areas.

In their individual forms, the students indicated that they learned how to be both thrifty and temperate. In addition, they believed that the learning process provided them with some important skills such as understanding the expectations of a target audience. Moreover, according to the students, time management was another skill that they portrayed during the design process. Their group self-evaluation form indicated that they worked satisfactorily throughout the activity.

Cross-Case Analysis

The cross-case analysis was employed in this study in order to accumulate the information from each case, compare and contrast the cases, and thus producing new knowledge. After the cross-case analysis, the following themes emerged: (1) target audience; (2) ways to approach criteria and constraints; (3) group dynamics; and, (4) money vs. environment. Each theme is described as follows.

Target audience

While designing their projects, students from different groups frequently took their target audience into consideration. Their design decisions were strongly influenced by the target audience for whom they were designing their projects for. For instance, Group I and Group V started their discussions off by deciding who their audience was. They strongly believed that their target audiences' preferences, expectations, behaviors, and habits should impact their design. Hence, they tried to note observations about the behaviors of residents in their local area.

In addition, they sometimes criticized their design decisions about whether or not their audience cared. Group IV proposed an environmentally-friendly project, but then they questioned if the future residents of their projected land would accept living with such a project. One member of the group argued that their environmentally-friendly project could affect the quality of their lives. Group VI also had similar concerns, with the students in this group believing that their target audience would care more about the esthetics of their design project than other criteria. Therefore, they should focus on esthetics, instead of trying to balance income and/or environmentally-friendly ideas.

Ways to approach criteria and constraints

Considering the importance of criteria and constraint aspects for critical design skills, the experiences of the groups in dealing with those aspects were crucial. As soon as they started their design task, students in different groups critically evaluated the criteria and constraints. To illustrate; Group I critically examined the objectivity of the criteria, as well as the logic behind them. Additionally, in order to carry out their design ideas, the students in Group II and Group VI tried to bend the rules for criteria and constraints of the design task. They argued that designing the best project was the main objective of the activity, that they should be able to play around with the criteria and constraints for the sake of esthetics and for the user-friendliness of the project. In order to meet the criteria, the design groups sometimes employed different strategies, such as using T-Charts to decide pros and cons for each design decision. Lastly, the groups often realized that when they only paid attention to financial or environmental concerns,

they were unable to meet the given criteria. Therefore, they understood that they needed to take the criteria and constraints into consideration throughout the design process.

Group dynamics

Working cooperatively as a group was an important part of the design process. The design groups approached this process differently. Some groups worked on each task together in a cooperative manner, whereas others shared out responsibilities at the beginning and then worked on them individually. In Group IV, each member was assigned with certain responsibilities at the beginning. Then, they came together at the end to complete their design project. On the other hand, Group II worked together cooperatively on each design task and made design decisions via brainstorming. The groups sometimes experienced problems in working as a team. For example, a dominant student who tried to lead the design work caused conflicts in both Group III and Group V. However, in Group VI, the dominant character did not cause a problem, as he constantly sought his groupmate's approval for each task.

Money vs. environment

Due to the nature of the design activity, the students from all groups alternated between prioritizing money and the environment. Thus, the most heated discussions were about whether or not to design projects having the highest value or the most pro-environmental aspects. Most groups worked hard to strike a balance between money and the environment. Students in Group III even found a special formula to determine the perfect balance between the two. However, that was not the case for all groups. For instance, students in Group I and Group II decided not to use land units that did not generate any money, even though the units would cause less damage to the environment compared to others. On the contrary, students in Group III and Group V chose the environment over money by making pro-environmental decisions in their projects, as well as using terms such as environmental ethics in their discussions.

Discussion and Conclusion

This case study aimed to investigate the experiences of gifted students designing a STEM-based environmental project within a real-world context, as well as the strategies they used throughout this process. The cross-case analysis provided four main themes: Target audience; ways to approach criteria and constraints; group dynamics; money vs. environment.

Curriculum and activities designed for gifted students should differ from standard learning materials in order to meet the specific needs of the gifted learners, as well as providing complex multi-faceted open-ended challenging problems (Purcell, Burns, Tomlinson, Imbeau, & Martin, 2002). VanTassel-Baska (2012) highlighted that the use of such kinds of problems helps the gifted student to benefit from learning experiences by creating new understandings based on content. The current study showed that providing students with engineering design activities with open-ended real-world problems helped them present higher-order thinking skills such as evaluating pros and cons of decisions and designing based on the expectations of a fictional target audience. In addition, they developed problem-solving skills by considering criteria and constraints of a design task in order to find the best solution. Like Van Tassel-Baska (2003),

who argued that high-level open-ended problems were a crucial aspect of instruction for gifted students, the current study indicated that when gifted students receive learning experiences via real-world open-ended problems, they are able to build higher levels of knowledge and thinking. Wang (2012) similarly emphasized the role of open-ended engineering problems/challenges that simulate a real-life situation in order to build students' knowledge and skills.

Gifted students favor authentic STEM learning experiences that involve personally or contextually meaningful content (Morris et al., 2019; Siegle et al., 2014). Those experiences allow the students autonomy over their decision-making processes, application of creativity, and ways to approach the content (Morris et al., 2019). This study also approved that when students provided personally meaningful content and context, they were more willing to critically analyze the content and the problem scenario. The findings of the study indicated that the participants constantly evaluated the criteria and constraints presented in the problem scenario. Their evaluation of these aspects was strongly influenced by their personal opinions, perspectives, and vested interests due to the personally meaningful context. Thus, they adopted a critical thinking disposition that allowed them to investigate the criteria and constraints presented in the problem scenario, as well as the financial and environmental perspectives which were taken by the actors in the scenario.

The literature calls for a need to encourage connections to real-world issues and to include advanced science-related activities in the science classroom (Lang, Drake, & Olson, 2006). Hence, engineering design problems within a real-world context enhances students' active learning, their high-level engagement, and their team-working skills (Pendergraft, Daugherty, & Rossetti, 2009). The design groups in the current study approached teamwork differently, based on the characteristics of the group members in order to complete their design projects. Regardless of their team-working approach, the students encouraged each other to participate in the design process. Hence, the students were highly engaged in the design process.

Vedder-Weiss and Fortus (2012) argued that science education that is limited to science content knowledge is unable to increase the motivation and engagement of students towards science. Thus, a new pedagogical approach is needed (Osborne & Dillon, 2008; Vedder-Weiss & Fortus, 2012). The current study showed that STEM-focused design processes enhanced not only the students' motivation and engagement, but that it also provided the students with knowledge and skills crucial to their development. One of the important skills that the students commonly presented during the design process was problem solving. The students frequently used problem-solving strategies in order to find their design solutions. The literature indicates that there have only been a limited number of studies that investigate the problem-solving processes of gifted students (Kaplan, Doruk, & Ozturk, 2017). Hence, this study aimed to fill a gap in the literature.

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