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Pre-Service Mathematics Teachers' Experiences In Designing STEM Lessons

Büşragül Çelik Kaya[1], Didem Akyüz[2]

ABSTRACT

Research Article

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This study aims to investigate the views of pre-service mathematics teachers on STEM education and the challenges encountered during the lesson planning process. The qualitative research method was utilized for in-depth analysis. In the study, pre-service mathematics teachers were engaged in activities related to STEM that the researchers prepared. After this, they were asked to create and teach lesson plans focusing on STEM. In order to get more information about their experience, three interviews were conducted with them at the beginning, middle, and the end of the study. Analysis of the interviews revealed significant changes in the pre-service teachers' comprehension of STEM education. Furthermore, it was observed that the participants could integrate mathematics and science into their lessons more easily than engineering and technology disciplines. The participants who stated that the integration of mathematics and technology is important could not actually perform this integration effectively. Finally, the participants stated that STEM education is an essential educational approach within mathematics education, expressing their intentions to incorporate STEM activities into their future lesson plans.

Keywords: STEM Education, STEM Lessons, Interdisciplinary Approach, Lesson Planning, Pre-service Mathematics Teachers, Challenges

[1] MSc.Middle East Technical University, Department of Mathematics and Science Education, busragul.celik@metu.edu.tr, 0009-0006-1899-9555

[2]Prof. Dr. Middle East Technical University, Department of Mathematics and Science Education, dakyuz@metu.edu.tr 0000-0003-3892-8077

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INTRODUCTION

In this era, people are expected to keep up with the rapid advancement of technology (Chai et al., 2020). It is essential to stay current with change and be a part of it in all areas, including those of personal nature that impact daily lives. STEM education aims to propel economic progress and raise creative leaders who can catch up with the information and knowledge age (Wijaya et al., 2022). It is important in transforming theoretical knowledge into tangible products and fostering the acquisition of indispensable 21st-century skills such as creativity, strong communication skills, critical and analytical thinking, and the ability to cooperate. Countries that can produce, develop, and effectively utilize knowledge have distinct advantages in terms of economic indicators. McKay (2020) asserts that STEM education is a powerful method for teaching critical thinking processes, making judgments, and making decisions. It allows students to use theoretical knowledge about mathematics and science in daily life. Therefore, STEM education serves as a compass, effectively portraying the essential relevance of mathematics. STEM education helps students understand why they are learning these contents, and understanding the purpose behind the lessons positively affects students' motivation (Bybee, 2010).

STEM education offers pre-service teachers valuable knowledge concerning various learning approaches and effective methodologies (Wijaya et al., 2022). Nevertheless, research by Pimthong and Williams (2021) has shed light on a prevalent shortcoming: many pre-service teachers need an adequate grasp of STEM education's fundamental principles. The imperative for well-prepared educators in STEM education is emphasized by Çalış (2020). In order to provide an efficient STEM education environment for students and to facilitate the formulation of comprehensive lesson plans, it is crucial and necessary to train pre-service teachers in this domain. Given that teachers' proficiency and experiences in STEM fields significantly influence students' learning outcomes, the professional development of educators assumes a pivotal role in advancing STEM education (Margot & Kettler, 2019; Zhang & Zhu, 2023). Furthermore, Basu et al. (2021) contend that collaborative engagement with pre-service teachers holds substantial promise for propelling the development of STEM education. Considering the importance of STEM education and teacher education, this study thoroughly examines the lesson planning process for STEM education. By revealing the challenges encountered during the formulation and enactment of STEM lesson plans, this research suggests valuable implications for teacher educators and researchers.

Literature Review

STEM Education

Science, technology, engineering, and mathematics (STEM) education is a form of education that combines these subjects and shows learners how these fields are linked in real life scenarios (Fitzallen, 2015; Johnson, 2012; Marrero et al., 2014; Pimthong & Williams, 2018). When teachers use curriculum integration, the contexts can be given with all necessary details in other disciplines, establishing robust links to real-world applications (Corlu et al, 2014). The conventional approach of teaching disciplines as isolated entities often fails to mirror real-world practice, while STEM education actively seeks to fuse various disciplines together (Sian Hoon et al., 2022). It aims to raise new generations with awareness of innovation. Through STEM education, students can learn interdisciplinary skills that are essential for life (Corlu et al, 2014; National Research Council, 2011). Education offers a unique opportunity to harmonize and amalgamate all academic disciplines, fostering an environment where students can engage in holistic learning experiences. The implementation of an integrated STEM education approach has been shown to enhance student learning (Anderson et al., 2020; Bartels et al., 2019).

A substantial body of research highlights the advantages of STEM education. Researchers suggest that STEM education should be considered as an approach and be integrated into diverse subject matter. STEM education is directly related to life; therefore, according to Şahin and Yıldırım (2020), it helps to shape students' perceptions about professions. Suratno et al. (2020) states that there is a positive relationship between students' problem-solving skills and achievements with STEM education model. Moreover, Aydın (2020) posits that STEM education is an effective method to give students motivation and courage for creativity, problem solving and invention, especially in early grades. Similarly, both Anderson et al. (2020) and Zhang and Zhu (2023) affirm that STEM education equips students with the aptitude for innovative problem-solving when faced with challenging situations.

According to Bybee (2010), STEM education, an interdisciplinary approach, must support literacy in each STEM discipline. Science and mathematics are disciplines that are typically offered as distinct courses. This segregation is reflected in the provision of separate science and mathematics education programs. In light of technological advancements, the significance of integrating technology into all academic domains has gained prominence. Conversely, within the realm of STEM education, engineering stands out as one of the disciplines lacking a dedicated primary-level course. Consequently, the interpretation and implementation of engineering integration within STEM education assumes particular importance (Yata et al., 2020). The definition of engineering varies among sources. Some researchers define engineering as a profession. However, in STEM activities, Yata et al. (2020) defines engineering as a creative activity. On the other hand, Kelley and Knowles (2016) define engineering as a design process.

Pre-service Teachers' Views on STEM Education

Teachers who eagerly delve into STEM education experience a noticeable boost in their teaching confidence throughout their educational journey. STEM education practices support pre-service teachers' self-confidence (Sian Hoon et al., 2022). Moreover, this process heightens their understanding of real-world contexts and underscores the pivotal role of a comprehensive education (Berlin & White, 2010; Corlu et al., 2014; Darling-Hamond, 2006). Firstly, teachers must be familiar with the successful implementation of STEM activities. Understanding what teachers and pre-service teachers think about STEM education is essential. Hence, a substantial body of research is dedicated to STEM education, and investigations concerning perspectives on STEM education hold a significant position within this field. According to Pimthong and Williams (2021), the absence of a robust emphasis on STEM education in pre-service teacher education programs hinders the effectiveness of pre-service teachers, particularly those trained in single disciplines, in adopting interdisciplinary approaches.

Consequently, Pimthong and Williams (2021) advocate allowing pre-service teachers to craft lessons and engage in STEM teaching before completing their education. In alignment with this perspective, Wijaya et al. (2022) assert that the integration of STEM Post-workshop analysis revealed a noteworthy improvement in the participants' STEM knowledge, leading Berisha and Vula (2021) to conclude that the workshop had a positive impact on enhancing pre-service teachers' understanding of STEM concepts. Education in teacher training programs is imperative for nurturing 21st-century skills. Therefore, including STEM education practices within teacher education programs becomes essential (Anderson et al., 2020). However, Zhang and Zhu (2023) argue that the current STEM learning experience within teacher education programs needs improvement and enhancement. Berisha and Vula (2021) investigated the STEM knowledge and awareness of pre-service teachers. Despite limited prior experience with STEM activities, these pre-service teachers exhibited substantial dedication to advancing their own STEM proficiency (Sian Hoon et al., 2022).

Çalisici and Sümen (2018) highlight that prospective mathematics teachers consider STEM a beneficial and indispensable approach that integrates complementary fields, garnering significant appreciation. According to Pearson (2017), pre-service teachers should be encouraged to understand the combination of different disciplines. Engaging in STEM education initiatives is valuable, but practical implementation goes beyond mere participation. To achieve a genuinely successful STEM education application, teachers need to possess a profound understanding of STEM principles. The depth of their familiarity with interdisciplinary education influences the efficacy of their growth and competence in this domain. The more they immerse themselves in and contemplate interdisciplinary approaches, the more powerful their progress and impact become. Teachers can observe the connections between science, technology, and engineering more clearly while preparing a lesson plan related to their field. This makes it easier for them and students to see mathematics clearly in all areas of life. Therefore, preparing a STEM-related lesson plan is critical for teachers to understand STEM education better.

As highlighted by Corlu (2014), educators often commence their careers without the essential integrated teaching knowledge required for effective STEM education delivery. This underscores the pressing need for enhancements in teacher education about STEM instruction. Maiorca and Mohr-Schroeder (2020) examined pre-service teachers' lesson plans. In the context of this study, pre-service teachers engaged in a STEM education activity and subsequently crafted STEM lesson plans upon completing their field experience. The study's findings indicated that almost all pre-service teachers incorporated problem situations necessitating engineering design and data collection into their lesson plans. Additionally, Bergsten and Frejd (2019) concluded that prospective mathematics teachers could produce integrated STEM course proposals by combining different disciplines. Cahyono et al. (2021) also investigated the potential for enhancing the 21st-century skills of prospective mathematics teachers by developing a STEM course model. They found that incorporating STEM education into teacher education programs is essential for prospective mathematics teachers. Consequently, providing pre-service teachers with opportunities to participate in integrated STEM activities likely enables them to observe the positive impacts of STEM education.

Furthermore, a substantial body of research has explored pre-service teachers' perceptions of STEM education, consistently revealing optimistic outcomes among teacher candidates. The prevailing consensus among researchers strongly advocates for including STEM education within undergraduate teacher training programs. However, it must be noted that most studies on this topic have primarily centered around science and technology (Bergsten & Frejd, 2019; English, 2016), indicating a potential need for a more comprehensive exploration across various teaching disciplines.

Despite a large body of research that indicate the importance of STEM education as mentioned above, there is a scarcity of studies that include lesson plans of pre-service mathematics teachers engaged in STEM based teaching activities. The present study aims to address this gap by conducting a detailed case study of three pre-service mathematics teachers as they engage in such a learning and teaching experience.

METHOD

Research Design

The qualitative research method, multiple case study, was used in the data collection process. Qualitative research design provides a detailed understanding of the participants and the process. It not only focuses on the outcome but also examines how participants understand the study and how it affects their behavior (Maxwell, 2008). The data obtained from the semi-structured interviews were analyzed according to the content analysis process (Fraenkel et al., 2019). Since the interview questions aimed to gather general knowledge about STEM education, we identified themes and patterns within the interview responses using content analysis. These categories included STEM components, advantages of STEM education, challenges in STEM education, and teaching strategies. This study examines pre-service elementary mathematics teachers' views on STEM education, their STEM lesson planning process, and the challenges they experience in the lesson planning process. The research titled "Investigation of Prospective Teachers' Views on STEM Education and the Difficulties Experience in the Lesson Planning Process" was approved by the Middle East Technical University Human Research Ethics Committee on 14 January 2022 with the number 28620816 and protocol number 0018-ODTUİAEK-2022.

Participants and Context of the Study

In this study, the convenience sampling method was utilized. In other words, the study was carried out with volunteer participants who met the desired conditions. The participants were final-year students of an elementary mathematics education program at a large public university in Ankara, Türkiye. During the data collection period, they took the Teaching Practice course in the spring semester of 2021-2022. After the aim and data collection process of the study were explained, among the 10 students that were enrolled in the course, 6 of them volunteered to participate in the study. Preparation of a STEM lesson plan was not compulsory as part of the course, and pre-service teachers who chose not to participate in the study had the option to prepare lesson plans based on their own preferences or desires. In this study, three of the six volunteer students were selected based on their lesson plans. Participants selected for the analysis were more excited and enthusiastic to participate in the study, and their lesson plans were more detailed. These participants are referred to as with the following pseudo names in this paper: Robert, Claire, and Sarah.

Sample Lesson Plans

During the course, pre-service teachers prepared two lesson plans. In this study, the participants were asked to prepare their lesson plans based on STEM education. Although this may seem difficult for pre-service teachers who have never participated in a STEM education activity before, most of the class was eager to gain experience in STEM education before graduation. After the participants prepared their first lesson plans, the researchers implemented STEM education activities during the course hours in April. Four STEM education lesson plans prepared by the researchers were implemented as sample lesson plans. These teaching sessions were conducted with the participant's consent and were recorded for analysis.

The first lesson plan is designed to explore linear equality through a bungee jumping activity. The participants were divided into three groups, each assigned to its station. There was a meter on the wall at these stations, and participants were asked to envision this location as a bungee jumping platform. Each group was provided with an activity sheet, a rubber band, and a bottle, which were prepared before the lesson. A bottle was used for this activity due to its easy accessibility and low cost. The groups, equipped with these materials, were then instructed to begin the activity. Their task was to calculate how many meters the bungee jumping station was above the ground by gradually extending the rubber band attached to the end of the bottle. Since the water in each bottle could vary, the heavier bottle would fall lower. As a result, participants concluded that one's weight needed to be considered when ensuring a safe landing for bungee jumping. They drew the graph and found the equation of the best-fit line. It was concluded that the person's height should have been added as a constant if the model jumped with its feet tied to the rope at the bungee jumping station.

Figure 1. Pre-service teachers conducting experiment at their designated bungee jumping station.

The second lesson plan was an activity aiming to develop table reading and comparing two data sets. Participants were asked to think about the characteristics of bridges and the factors that might be involved in the bridge collapse. Each group was told that they were the engineers who would rebuild this bridge. Four different types of bridges were presented, and they were expected to calculate the cost of each of these bridges. Each group chose a bridge according to their criteria. The participants were expected to present their bridge design at the end of the lesson. These criteria were the shortest time, lowest cost, and highest durability. After each group presented, the best possible bridge type was selected.

The third lesson plan was a ratio-related activity. The lesson began with the question of whether the participants could make paper airplanes and a website was shown with many types of paper airplanes. This website included information about paper airplane models' names, speed, flight time, distance, and ease of construction. The students discussed creating different variations of paper airplanes. Then, images from the furthest paper airplane competition were shared, and the video of the winning paper airplane was watched. The paper airplane's impressive flight distance was an intriguing introduction, prompting participants to contemplate the variables influencing its speed. In the main activity, the class was divided into three groups, and each group was given activity sheets. In addition, the groups were given papers of various sizes and weights and instructions on making an airplane with paper. Each group was asked to generate a hypothesis (i.e., a lighter paper airplane travels longer distances). Then, the groups were expected to test their hypotheses.

The last lesson plan aimed to collect and interpret data in daily life. It was aimed at discovering that the numbers given in statistics have a counterpart in daily life. The lesson began by talking about favorite snacks. Participants named their favorite dishes and snacks. Next, they inquired about their awareness of their daily calorie intake and how closely they paid attention to the nutritional values listed on the back of snacks. They were asked to open a website where they could find the nutritional value of foods. Using this website, they were expected to search their favorite foods' nutritional values (calories, fat, sodium, carbohydrates, protein) and write them in the table. After the groups finished collecting data and filling in the table, they found the mode, median, mean, and range and interpreted their collected data.

Data Collection Tools

The researchers developed a semi-structured interview form as a data collection tool. The questions in the instrument were checked by taking expert opinions. The first interview included eight questions to gain insight into the participants' knowledge of STEM education and their thoughts on preparing a STEM lesson plan. The first interview consisted of questions about the definition of STEM education, the importance of STEM education, the aim of STEM education, and STEM lesson planning. The second interview was conducted during the lesson planning process after the STEM education application. It included nine questions related to the change in their views. In this interview, the lesson plan preparation experiences were questioned, and the challenges experienced and expectations about the lesson were questioned in detail. The last interview was conducted after participants presented their STEM lesson plans in the middle school where they were doing their internship. The purpose was to gather their experiences regarding whether the lesson met their expectations, any difficulties they encountered, and any changes they would like to make.

The interviews were conducted online via Zoom Meeting Application. With the permission of the participants, the interviews were recorded. Each interview lasted approximately 10-15 minutes, and each participant was interviewed for a total of approximately 30-40 minutes. After the individual interviews, pre-service teachers were asked to prepare a STEM lesson plan. Participants developed their STEM lesson plans through microteaching in the practice teaching course before presenting their lessons at their internship school. With the participants' permission, the lesson plans were recorded during microteaching.

Data Analysis

Each participant's STEM lesson plans and the microteaching videos were analyzed according to the conceptual framework of integrated STEM education (Kelley & Knowles, 2016; Roehrig et al., 2021). The common characteristics in the two articles on the conceptual framework of integrated STEM education were selected for analysis in this study. Seven characteristics of the framework used in this study are explained in detail below.

Focus on Real-World Problems

For a lesson plan to be STEM education, it must consist of a real-world problem (Kelley & Knowles, 2016; Roehrig et al., 2021). Choosing a real-world problem is challenging because numerous variables impact students' outcomes. Moreover, the problem statement should be inclusive and engaging for all students (Roehrig et al., 2021). If the data included themes related to real-world problems and the use of mathematics in daily life, it was coded as focusing on real-world problems.

Engagement in Engineering Design

Integrating engineering design into the lesson plan allows students to develop systematic problem-solving skills in situations they may encounter in STEM fields (Kelley & Knowles, 2016). Teachers must ensure students get the chance to assess their designs and redesign using the information gathered. Cost, materials, functionality, and social and political aspects should all be considered while making design decisions (Roehrig et al., 2021). According to Kelley and Knowles (2016), a STEM lesson plan includes a problem that requires an engineering solution to integrate engineering design. Furthermore, students should identify the criteria and constraints and collect, analyze, and interpret data. Moreover, the problem statement should be inclusive and engaging for all students (Roehrig et al., 2021). If the data included themes related to engineering, creativity, optimizing, and modeling, it was coded as focusing on engagement in engineering design.

Scientific Inquiry

Students learn how to ask questions, create hypotheses, and conduct studies using the accepted scientific methods through scientific inquiry, which trains them to think and act like scientists. When given the chance to create their questions about the science topic in the lesson, students start to research the connections between disciplines and take control of their own learning (Kelley & Knowles, 2016). If the data included themes related to sciences, conjectures, hypotheses, and inquiry, it was coded as focusing on scientific inquiry.

Technology Use in STEM Lessons

In the STEM lesson plan, technology should be conceived as a tool that positively impacts culture, society, politics, economy, and the environment. Teachers should allow students to consider technology critically, helping them become technologically literate. Also, problem-solving should be facilitated by using technology (Kelley & Knowles, 2016). If the data included themes related to technology, such as using GeoGebra, online materials, smart boards, and watching informative videos, it was coded as focusing on technology use.

Mathematical Thinking

STEM education provides students opportunity to understand how mathematics relates to their daily life, this way students' interest and success in mathematics may increase. Students should make sense of the mathematical problem and think about its solution. In a STEM lesson, students need to explain the meaning of a problem and look for entry points to a solution (Kelley & Knowles, 2016). If the data included themes related to understanding mathematical ideas, making sense of mathematics, and connecting with previous topics, it was coded as focusing on mathematical thinking.

Content Integration

Making connections between disciplines and between contexts is crucial to integration. Also, disciplines should be evident to students. To help students understand these linkages, teachers must use interdisciplinary models and representations and engage in deliberate facilitation and questioning (Roehrig et al., 2021). If the data included themes related to interdisciplinary connection, integration of four disciplines, and interdisciplinary transition, it was coded as focusing on content integration.

Twenty-First Century Skills and STEM Careers

Teachers should design small group activities to foster 21st-century skills like collaboration, critical thinking, analysis, and assessment. Teachers also need to carefully facilitate small group work to encourage equal engagement from all students. Students must be given clear instructions on working in small groups to develop 21st-century skills while problem-solving with design thinking (Roehrig et al., 2021). If the data included themes related to twenty-first-century skills such as collaboration and critical thinking, it was coded as focusing on twenty-first-century skills and STEM careers.

RESULTS

The findings of the three participants are presented independently of each other. The comparison of the findings obtained from the participants is presented in the discussion section.

The Case of Robert

Focus on Real World Problems

The lesson plan Robert prepared and implemented was for 6th-grade students. Robert's lesson aimed to integrate the shapes that students have learned to measure area into a real-world problem. In the introduction, Robert reminded the students of the types of thermal insulation that they had learned in the science lesson. Then, the aim was to attract students' attention by giving an example of an endangered bird. Before the main activity, Robert reminded the students how to find the area of a square, rectangle, triangle, and parallelogram because they would use the area of a square, rectangle, triangle, and parallelogram while building the birdhouse. Therefore, the properties and area relationships of these shapes were repeated. Robert showed a video about the birdhouse to move on to the main activity. In this problem, the students were expected to design a birdhouse using sticks and play dough brought by the teacher. For the birdhouse design, the students worked in groups and were expected to use at least two geometric shapes they had learned before. Then, they chose the materials for the birdhouses they had designed. They were expected to make this choice according to the criteria given on the activity sheet. At the end of the lesson, each group presented their birdhouse design and material selection.

Robert's lesson plan started by talking about birds. He asked the students if they kept birds and what they thought about the living conditions of birds outside. To increase students' attention to the lesson, Robert showed videos about birdhouses and started the lesson with an exciting story about keeping the birds that live outside warm.

Based on the story, the kid in the story shared his thoughts with his father and told him that he wanted to build a birdhouse. He also wanted to provide thermal insulation for the birdhouse and do it in the least cost and best way. The father suggested that his son build it thinking about the shapes he learned at school and asked him to calculate the cost. They also talked about endangered birds such as shearwater birds. As seen, Robert used the story about birds, and there was a real-world problem that needed an engineering design. In addition, before this problem, showing videos and talking about birds caught students' attention. Moreover, the problem had two criteria: 'the least cost' and 'the best way.' By looking at these criteria required in the problem, there was no single solution, so students were supported to find different solutions. There were multiple birdhouse designs. Robert's lesson plan consisted of a real-world problem that encouraged all students and had multiple solutions.

Engagement in Engineering Design

In the main activity, the students were expected to design a birdhouse. However, there were some criteria for this design process. The birdhouse skeleton must have contained at least two shapes they learned in the previous lesson: square, rectangle, triangle, and parallelogram. The birdhouse must be environmentally friendly, cost-effective, and aesthetic. The students were expected to consider these criteria when presenting their design. Thus, the students considered the cost, function, and aesthetics while designing their birdhouse, which was an engineering-level thinking process (see Figure 2). Also, the students could use sticks and playdough for the design model; they could create a design, analyze it, and redesign it. Thus, Robert’s lesson plan consisted of an engineering design.

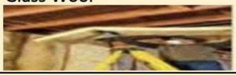
Insulation Material	Cost	Environmental Friendliness	Flammability	Cost
Plastic Foam 	low	harmful	burns easily	10 TL
Wood 	medium	harmless	burns easily	15 TL
Rock Wool 	low	harmless	fireproof	10 TL
Glass Wool 	low	harmless	hard to burn	10 TL
Silicone Wool 	very low	harmless	hard to burn	5 TL

Figure 2. Birdhouse Material Table in Robert's STEM lesson plan: insulation material, cost, environmental friendliness, combustion characteristics.

With this real-world problem and engineering design, students were expected to develop STEM skills. Robert stated that he had difficulty choosing the materials for engineering design. In the microteaching, he asked for feedback on whether spaghetti pasta was the right decision as a material. Robert thought of play dough for the spaghetti pasta's connection points. Styrofoam was suggested as a material, but as it might be a complex material to obtain, it was eliminated. At the end of the discussion about materials used in the activity, it was decided that wooden sticks and play dough were appropriate as wooden sticks were more solid. During the discussion of the problem, one group explained their model as follows:

"We thought of the birdhouse as a pyramid. Since the area of the triangle would be less than the square, we wanted to reduce the cost by cutting the area. So, we made the side parts triangular and the base square."

Many groups used two or three geometric shapes during the birdhouse construction. Therefore, it was decided in the class discussion that using all the geometric shapes students had learned would be challenging. Therefore, it was decided to limit the engineering design criteria to using at least two geometric shapes.

Another group presented their design and defended their material choose.

'When choosing materials, we first looked at whether they harmed the environment and eliminated plastic. We also eliminated wood for the exterior because of the risk of burning. We were undecided between silicone wool and rock wool, but we decided silicone wool was better since it costed the least. If we were going to choose thermal insulation material for the exterior, we thought that by making the inside wooden and outside silicone, we could provide two-sided insulation and eliminate the risk of burning.'

In summary, although Robert successfully integrated engineering design into his lesson plan, he stated that he had the most difficulties in this discipline while preparing his lesson plan. However, looking at the lesson plan, we can say that Robert applied the engineering design criterion in the lesson plan.

Scientific Inquiry

In a STEM lesson, students need to think like a real-life scientist. They should ask questions, create a hypothesis, and test this hypothesis. The students designed a model in Robert's lesson plan; however, it was questionable whether they used scientific inquiry since students did not create a hypothesis and collect data. On the other hand, thermal isolation was the main reason for designing the birdhouse. Robert initiated the lesson by introducing a topic that students had previously covered in their science class: thermal insulation. By incorporating a subject from science into the mathematics class, he encouraged students to consider the interconnections between different disciplines. In microteaching, Robert informed his classmates about thermal insulation. He asked where we use thermal insulation in daily life, the importance of thermal insulation, and the benefits of thermal insulation. Next, he explained that in a house with thermal insulation, there would be no extra costs for heating by stating that: 'Thermal insulation prevents energy loss when we consider the heating in houses, the prices paid to reduce thanks to thermal insulation.'

In addition, for the choice of bird, Robert suggested that it would be nice to choose an endangered bird species and, at the same time, gave information about endangered animals, which was another topic in science education. In summary, Robert thought it was easy to establish the relationship between science and mathematics and successfully integrated science into his STEM lesson plan. However, the lesson plan needed to generate hypotheses by collecting and analyzing data.

Technology Use in STEM Lessons

In Robert's lesson plan, technology was used as a tool. For example, he used a smart board to show PowerPoint slides and videos about birds to catch students' attention. He started the lesson by showing two exciting videos related to birdhouses. He used the smart board only to show the videos. In addition, Robert continued the lesson with a PowerPoint presentation on the smart board. Robert's use of a pre-prepared presentation rather than a traditional whiteboard demonstrates the ease of incorporating technology into teaching mathematics. However, it is worth noting that while technology was used as a teaching tool, it did not necessarily engage students in active learning or encourage them to use technology in their learning processes. Since the students did not use technological tools themselves and saw that Robert needed to make more use of technological materials during the lesson, it can be concluded that the lesson plan needed to be revised to develop technological literacy. He did not use any interactive tools in his lesson plan. Thus, more technology integration was needed in Robert's lesson plan, although he said that technology integration was essential.

Mathematical Thinking

Based on the story given in the lesson, the birdhouse needed to have a low cost. To calculate the cost, the students needed to find the area of the birdhouse they designed. Students used the rulers to calculate the area of the exterior of the skeleton they designed (i.e. the surface area of the birdhouse). After calculating the surface area, students needed to calculate the cost of the insulation material they had chosen, using the prices given per.

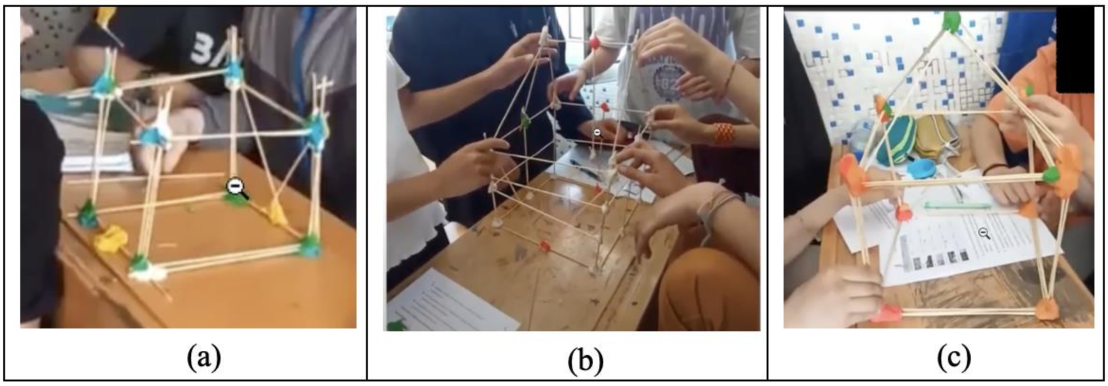


Figure 3. Birdhouses designed by 6th grade students.

The students were expected to calculate the area of the exterior of the skeleton designed using a ruler. They measured the side lengths of the exterior of the birdhouse they designed with a ruler and calculated the area of the shapes they used with the values they found. After calculating their areas, they were expected to calculate the cost of the insulation material they had chosen, using the prices given per $1cm^2$. Cost of silicone: $1cm^2$=5 TL, Glass wool, Rock wool, and Plastic cost: $1cm^2$=10 TL, Wood cost: $1cm^2$= 15 TL. The students made mathematical area calculations with the measurements of their designs and calculated the cost. Since the answers varied based on students' unique designs, they encountered multiple instances of area calculation. The complexity of this problem necessitated a precise application of mathematics. In alignment with the lesson's objectives, students engaged in problem-solving that specifically involved finding areas. Robert's approach illustrated his commitment to concretely integrating mathematics into his lessons, fostering an environment where students start questioning the presence of mathematics in other disciplines. According to Robert, as he did not teach a new mathematical objective from scratch, integrating mathematics was easy, and he satisfactorily integrated mathematics into the lesson plan.

Content Integration, 21st Century Skills and STEM Careers

When we examined the four disciplines individually in Robert's lesson plan, although technology integration was weak, science, mathematics, and engineering were presented to students. Also, the connection between these three disciplines was handled smoothly. Furthermore, STEM lesson plans must be prepared to develop students' 21st-century skills. To achieve this improvement, the STEM lesson plan should include small group work. Robert preferred group work in the lesson plan. In Robert's lesson plan, group work was written as follows:

"The teacher will divide the students into four groups and distribute sticks and play dough. Then, the students will be asked to create a skeleton of a birdhouse, considering the criteria. The students will be given five minutes to think about the birdhouse skeleton, and if they wish, they can take out paper and draw their design. They will be given twenty minutes to make their designs and calculate the areas of the shapes they use and their costs. While the students make their designs, the teacher can walk around, answer the students' questions, and give them the missing materials if the groups still need them. NOTE: The design of the birdhouse is left to the students, and the teacher should not direct the students' designs."

The STEM lesson plan should include a specific occupational group for students to learn about STEM careers. However, Robert did not include a specific STEM occupation in his lesson plan. A specific occupational group could have been mentioned during the problem-solving process, and the students could have been informed about that occupation as one of the STEM careers.

The Case of Claire

Focus on Real-World Problems

Claire prepared a lesson plan for 7th-grade students. Claire's lesson plan was about the maximum cargo to be loaded on a ship. Claire's main activity started by giving students a real-life problem with a news article about a ship accident. After reading the news article, the students were informed of the main activity. They were asked to imagine themselves as ship captains at the port where the news article accident occurred. They were asked to take the necessary precautions to prevent accidents like this.

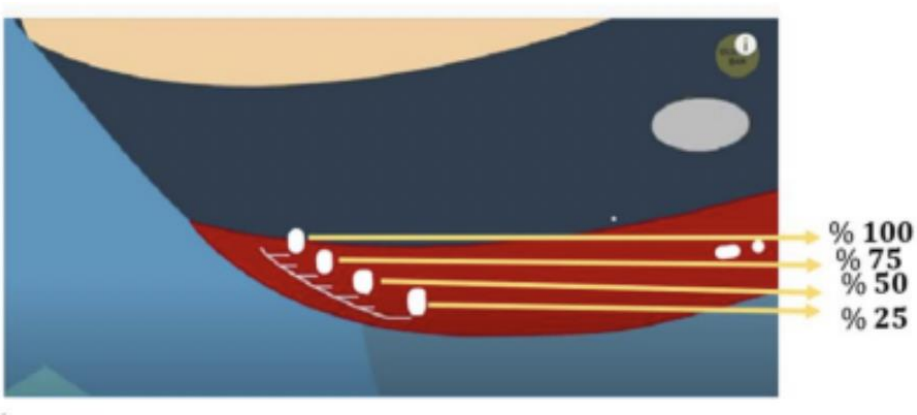


Figure 4. Sinking value of the ship according to the limit line and tons loaded.

Thus, Claire used a mathematics problem that required calculations to address a real-life issue. Her STEM lesson plan involved a real-world problem that encouraged all students and had multiple entry points.

Engagement in Engineering Design

In Claire's lesson plan, no problem situation required students to create a design. Students were expected to fill in the table according to the data and determine the environmental sensitivity of the ship according to the table in Figure 5.

800-900 Barrels	700-800 Barrels	600-700 Barrels
Low environmental sensitivity	**Medium** environmental sensitivity	**High** environmental sensitivity

Figure 5. Environmental sensitivity based on the ship's total fuel consumption.

The problem situation in the main activity did not require students to create a model. Students did not need to test the design and redesign it. Thus, Claire's lesson plan did not meet this criterion. According to Claire, engineering was the most challenging discipline to integrate into a STEM lesson plan. Claire stated that she was more familiar with the science discipline because it had many daily life connections. However, it was challenging for her to integrate engineering because she did not know about it. Claire stated that the engineering terms were high for her, and she had no interest in engineering.

Scientific Inquiry

Students were required to calculate density by applying the ratio of mass to volume, which is a mathematical operation. This illustrates how mathematics is integrated into their science curriculum, where they learn about topics like density. Consequently, introducing a science topic in a mathematics class encouraged students to explore the interconnections between these two disciplines. Claire had the idea of doing the orange experiment (see Figure 6). After showing the experiment and asking students to provide explanations, Claire went on to clarify the experiment and reinforced the concept of density they learned in their science class. She explained: "Due to air pockets within the orange peel, its overall density is lower. This lower density allows the unpeeled orange to float because its volume is larger than its mass." Density is the mass of a substance per unit volume. In calculations, density is obtained by dividing the mass of the substance by its volume. If the density of an object is greater than the density of the liquid in which it is placed, the object sinks into the liquid and displaces the liquid by its volume (MoNE, 2023). This approach connected the experiment to the scientific concept of density and helped students understand the relationship between science and mathematics in real-world scenarios.

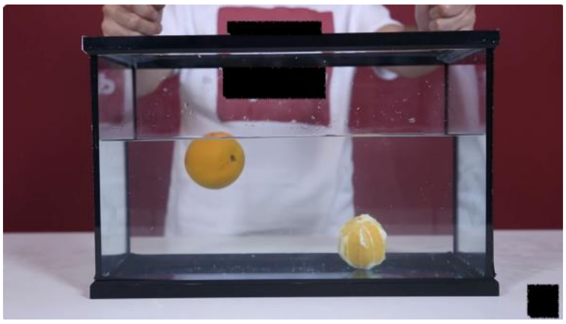


Figure 6. Video of an experiment showing that oranges do not sink with the peel.

After this experiment, Claire discussed why ships did not sink and created a discussion environment in the class. To transition into the main activity, Claire introduced the concept of the red line under the ships and explained how it relates to density. This approach encouraged students to consider the factors that affect density and set the stage for the upcoming activity: "When the weight of ships is light compared to their volume, their density is below one. In this way, they do not sink. A line under the ships shows the maximum amount that can be loaded. Even after this limit, some ships are painted in different colors".

After calculating the total fuel oil requirement of four types of ships, the students were expected to classify their environmental sensitivity. Claire stated that she had a hard time preparing the lesson plan. For example, she had to learn the difference between mass and weight for science integration. She emphasized that teachers should have sufficient knowledge about other disciplines to avoid giving students incorrect information about other disciplines.

Technology Use in STEM Lessons

In Claire's lesson plan, technology was used as a tool. She used a smart board to show PowerPoint slides and videos about an experiment on density and a news article about a sinking ship to catch students' attention. Claire started the lesson by showing an interesting video and news article. She used the smart board to support students with visuals.

Only video was used in the lesson plan for technology integration. Therefore, a simulation of ships sinking as they are loaded was suggested during microteaching. However, Claire did not include such a simulation and questions that support mathematical reasoning in her lesson plan. Even though she did not mention the discipline of technology among the difficulties she experienced while preparing a STEM lesson plan, she used technology superficially. Therefore, the students were not given the chance to develop technological literacy.

Mathematical Thinking

Claire's lesson plan aimed to express the relationship between two multiplicities by examining real-life situations, calculate the quantity corresponding to a given percentage of a given multiplicity, and calculate the whole multiplicity of given quantity. Figure 4 shows that if the ship sinks up to 100% below the limit line, it is carrying the maximum weight it can handle and will sink if loaded any further. Conversely, if the ship is submerged below the limit line of up to 50%, it carries only half of its maximum weight capacity. When the ship's submersion reaches 100%, it indicates that the ship has reached its maximum carrying capacity, and any additional weight will cause it to sink according to the limit line.

SHIP SELECTION CRITERIA	SHIP 1	SHIP 2	SHIP 3	SHIP 4
The Maximum Carrying Capacity of The Ship	....	....	....	....
The Amount of Sinking Depending on Tons	For every 9000 tons, 25% of the ship sinks	There are 36000 tons of cargo on board while 40% of the ship is unsinkable	With 39000 tons of cargo on board, 75% of the ship sank.	When loaded at two-fifths of the carrying capacity, the ship has 16000 tons of cargo and 60% of the ship is unsinkable

Figure 7. Table of the maximum carrying capacity of the ship and the amount of sinking depending on tons

The students were expected to find the total carrying capacity of the ship according to the sinking percentage of the ship (see Figure 7). For example, in the second ship scenario, if 40% of the ship is still above water and it carries 36,000 tons of cargo, it means that 60% of the ship has already sunk with that cargo load. Here, the students needed to find the relationship between the sinking percentage and the amount of cargo on board and find the total carrying capacity of the ship. In the first ship scenario, with every 9,000 tons of cargo, if 25% of the ship sinks, the maximum carrying capacity of the first ship is 36,000 tons. This part of the table focuses on finding the total capacity of the ship when a specific percentage of it sinks, which is the main mathematical objective of the lesson plan.

Claire preferred to use the concept of percentages in Figure 4 since percentages are the subject matter. That is, when the ship is loaded, if the limit line of 25% is sunk, the ship carries a weight of 25% of the maximum amount of cargo that can be loaded. The ship can still be loaded up to 75% of its maximum capacity. However, Claire was concerned that the term 100% sinking used in the activity could be confused with the sinking of the entire ship. She defined 100% as when the ship reaches the top of the limit lines at the bottom of the ship. In order to avoid this confusion for the students, she explained the term 100% used in the activity at the beginning of the activity and during group work.

Although Claire had a hard time making mathematics connections in her lesson plan, she included mathematics problems that align with the objectives. The main activity of the lesson was all about percentage problems. Therefore, Claire successfully integrated mathematics into the STEM lesson plan.

Content Integration, Twenty-first Century Skills, and STEM Careers

When we examined the four disciplines one by one in Claire's lesson plan, although technology integration was weak, science and mathematics were clearly presented to students. On the other hand, there was no engineering design in Claire's STEM lesson plan. Considering only mathematics and science disciplines, the connection between these two disciplines was handled smoothly. In the lesson, the students tried to solve a problem involving science using mathematics. This enabled students to see these two disciplines separately and, at the same time, to use them all together. To conclude, Claire successfully integrated two disciplines other than technology and engineering.

STEM lesson plans must be prepared to develop students' 21st-century skills, including collaboration, critical thinking, creativity, analysis, and assessment. She supported students by having each group work as a team, encouraging students who had found the solution to explain it to their peers who were still struggling. In this way, the importance of teamwork was emphasized.

Moreover, Claire asked the students to imagine themselves as ship captains to solve the problem. As a ship captain, the students needed to make appropriate calculations to avoid sinking accidents. There were also issues of fuel consumption and environmental awareness that they needed to think about as captains. In this way, students had a chance to learn about a professional group and solve problems they may encounter in this profession utilizing their STEM skills. Claire's STEM lesson plan cultivated problem-solving and decision-making skills, exemplified by the role of the ship captain. Therefore, it can be said that her lesson plan supported this criterion.

The Case of Sarah

Focus on Real-World Problems

Sarah created a lesson plan for 6th grade students. Sarah's lesson plan began by explaining the working principle of the bicycle. Students needed to understand the gear system of the bicycle in order to find the distance traveled by the bicycle and make the gear selection.

‘When bicycles were first produced, they worked directly on human power. In other words, when we pedaled once, we could only travel as far as the perimeter of the wheel. Simple machines (pulley, gear, etc.) that we use to reduce human effort and make our lives easier appear as gears in the working mechanism of bicycles. With this gear system, we are now able to travel more for perimeter the wheel when pedaling once. The diameter ratios of the cogwheel in the gear system and the ratio of the number teeth on the cogwheel of on them are equal. The ratio of pedaling speed and number of gears directly affects the speed of the bicycle, the energy expended, and the distance traveled. Depending on the slope of the road, the effort spent by the person while pedaling may increase or decrease. The driver can reduce the gear ratio to reduce the effort. The large gear ratio makes it challenging for the driver when going uphill.’

After explaining the working principle of the bicycle and the formula to be used in the problem, Sarah moved on to the real-life problem situation in the activity.

‘A famous bicycle company brings young engineers together with a competition for a new bicycle model to be produced. The company asks engineers to design a bicycle’s gear system and wheel structure in accordance with their criteria. The new bicycles they produce must be low in cost and can travel long distances with little effort. It is expected that the bicycle, which has only one gear for an easy use by everyone, will be a product for teenagers and adults. Using the given information in Figure 8, you are expected to answer the following questions. By answering these questions, you will calculate and decide on the wheel diameter and gear ratio of the bicycle. Please consider the criteria the company asks of you and show your work clearly. You must defend your choice.’

Wheel Diameter (cm)	Estimated Production Cost
61 cm	2.140 TL
66 cm	2.560 TL
70 cm	4.370 TL
71 cm	5.130 TL
74 cm	6.260 TL

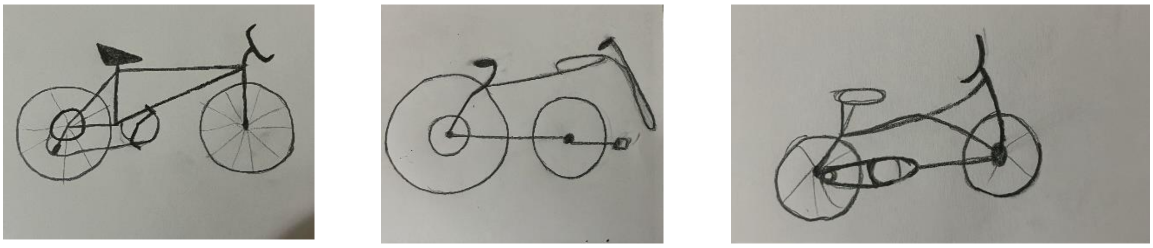
Gear Ratio (Front/Back)
4,82
4,08
3,79
2,65
2,30
1,71
1,47

Figure 8. Wheel diameter of bicycles produced, the estimated production cost and the Gear Ratio table Sarah used in the activity sheet.

As it might be seen, Sarah's lesson plan included a mathematics problem about bicycle design and the working principle of the bicycle. Sarah’s STEM lesson plan consisted of a real-world problem that encouraged students with entry points.

Engagement in Engineering Design

Sarah’s STEM lesson plan required the students to design a new bicycle. The students were given tables shown in Figure 8. They were expected to consider these tables in their decision-making process. Also, the problem required some criteria. The new bicycle must be low in cost and travel long distances with little effort. The students were expected to take these criteria into account when presenting their design. They had to consider the cost and the gear ratio while choosing their bicycle design, which is an engineering level of thinking process. Sarah’s lesson plan consisted of an engineering design. With this real-world problem and engineering design, the students were expected to develop STEM skills.



(a) (b) (c)

Figure 9. Bicycle designs of the groups of pre-service teachers during microteaching.

In Sarah's STEM lesson plan for microteaching, she expected from her fellow pre-service teachers to design and draw bicycles for the wheel diameter of their choice. The bicycle drawing allowed the students to show their designs concretely and add art discipline to the lesson plan. However, in light of the feedback received, Sarah decided to remove the bicycle design component from the lesson plan as it would be too time-consuming to make 6th graders draw bicycles and would not leave time for the targeted math objectives.

In the microteaching, a pre-service teacher presented the bicycle design of the first group. They chose the wheel diameter of 61 cm, which was the most appropriate when considering the economic conditions. Also, he mentioned that the price increased a lot when the wheel diameter increased. For example, when the wheel diameter increased by 10 cm, the price tripled. For this reason, 61 cm was the cheapest. In addition, he stated that they chose the middle one in the gear ratio (2.65). He stated that as the gear ratio increased, the force that the rider consumed increased. Therefore, they did not choose the one with the largest gear ratio. A bicycle with the 4.82 gear ratio would be difficult to use. That is why, his group chose 2.65 to be an average value. Their bicycle design was shown in Figure 9 (a).

Another pre-service teacher presented the bicycle design of the second group. They chose a wheel diameter of 66 cm because there was a 5 cm increase from 61 cm to 66 cm and the price only increased by 420 TL. On the other hand, when the wheel diameter was 70 cm, the price almost doubled. According to him, when they considered the ratio, they thought that 66 cm was the most suitable. He stated that they chose the wheel ratio of 2.65 in order not to have difficulty when climbing. He also stated that the ratio of 4.82 would be better for long distance, but they wanted to choose a model for daily use. Their bicycle design is shown in Figure 9 (b). They also designed a windbreak in front of the bicycle.

Finally another student presented the bicycle design of the third group. She stated that her group chose wheel diameter of 66 cm, similar to the second group, because there was not much difference between 66 cm and 61 cm in terms of cost. They thought it was more appropriate to choose 66 cm. Moreover, they chose a gear ratio of 2.30. She stated that since they increased the wheel diameter by 5 cm, they could choose the gear ratio smaller. Their bicycle design is shown in Figure 9 (c).

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Sarah stated that she enjoyed thinking about different disciplines together, however it was challenging for her to reduce the activity to the students' level. Sarah prepared an activity to develop critical thinking skills at engineering level. The students were expected to prepare a bicycle model according to the given criteria. This shows that Sarah applied the engineering design criterion in her STEM lesson plan.

Scientific Inquiry

In a STEM lesson, students should think like a real-life scientist. They should ask questions, create a hypothesis, and test this hypothesis. In Sarah's lesson plan, it is questionable whether they made a scientific inquiry since students did not create any hypotheses and collect data. On the other hand, Sarah's lesson plan began with a clear science connection. Sarah started the lesson with the working principle of a bicycle and showed a video about it (see Figure 10). This video was actually about gear wheels, and it explained gear wheels with a bicycle example. Cogwheels are the subject of 8th grade science lesson. Sarah showed the bicycle mechanism that is relevant to her lesson instead of watching the whole cogwheels as students learn simple machines and cogwheels in detail in 8th grade science course.

Sarah thought that this content was appropriate for 6th graders because students encounter simple machines in daily life. In her reflection in the lesson plan, she noted that almost all the students used bicycles and that this topic was of interest to them.

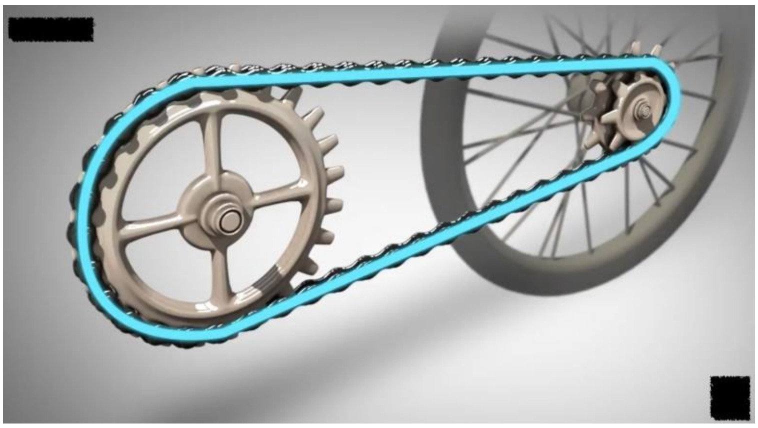

Figure 10. An image from the gear wheels video.

To find the traveled distance a bicycle takes, students needed to use the circumference of the circle they learned in mathematics lesson. In the lesson, students could observe the relationship between mathematics and science discipline. In addition, students discovered mathematical formulas through the guiding questions which were explained in detail in the mathematical thinking section.

Technology Use in STEM Lessons

By using technology as a tool in the STEM lesson plan, students should be taught that technology is a facilitating tool in real life. Also, the teacher should give students the chance to develop technological literacy. In Sarah’s lesson plan, technology was used as a tool. She used smart board to show PowerPoint slides and the video about the working principle of a bicycle to catch students’ attention and give information about the activity.

There was no video component in Sarah’s draft lesson plan. She planned to explain the working principle of the bicycle verbally. However, during the microteaching, she received feedback that the working principle of the bicycle should be understood by the student because it forms the basis of the activity. Therefore, it was thought that the visual effect of this presentation could be enhanced. During the microteaching, Sarah’s fellow pre-service teachers searched for an appropriate video. It was decided that the video was necessary and sufficient to understand the subject.

Except for the video Sarah used at the beginning of the lesson, she did not integrate technology into the STEM lesson plan. She did not use technology sufficiently during the lesson. As the students themselves did not use technology, they did not witness teacher's use of technology adequately. In other words, technology was not used to support students’ mathematical understanding. Thus, integration of technology was limited.

Mathematical Thinking

Sarah started the lesson with the working principle of bicycle. In this part of the lesson, students needed to understand the effect of the gear diameter ratio and the number of pedaling cycles on the rotation of the wheel because they were expected to design a bicycle based on these variables. Sarah also aimed to help students to discover that the distance traveled on a bicycle is related to the perimeter of a circle. She explained this in the activity sheet as follows: ‘At this point, we can discuss the distance traveled as the number of rotations of the wheel times the perimeter of the wheel.’

Sarah's activity sheet included the number of rotations of the wheel:

‘The number of rotations of the wheel depends on the number of pedal turns and the ratio of the diameter of the front and rear gears. This means that when we turn the pedal one time, the rear gear and therefore our rear wheel will rotate by this ratio…Depending on the slope of the road, the effort spent by the person while pedaling may increase or decrease. The driver can change the gear ratio by downshifting to reduce the effort. A large gear ratio makes it difficult for the driver when going uphill.’

The students were expected to solve the question given in activity sheet with this information. The number of rotations of the wheel was an equation and the students needed to think about how changes to the variables might affect the equation. This part was important for understanding the variables and the equation. By giving these formulas, Sarah encouraged students to think critically.

The first question in the activity sheet was as follows: 'What does an increase in wheel diameter mean?'. The expected answer to this question was that as the wheel diameter increased, the traveled distance by the wheel increases depended on the diameter. Based on the circumference formula, the distance traveled depended on the diameter of the bicycle. This question aimed to help students to understand the perimeter of circle and establish the relationship between diameter and circumference. Therefore, Sarah reinforced the target objective with this question.

The second question in the activity sheet was as follows: 'What does an increase in the gear ratio mean?'. The expected answer to this question was the greater the gear ratio, the greater the distance the bicycle traveled in one pedal rotation. In the following of the lesson, the students were asked: 'How many pedaling cycles it takes for your bicycle to cover a distance of 500 meter?' With this question, the students were expected to apply the circumference relation they had discovered. Also, each student solved this question for the bicycle of his/her own design. This allowed the students to see more than one solution to a single question and see the features of the bicycle they designed. Sarah established the integration of mathematics in the STEM lesson plan with the questions she added after the bicycle design. Therefore, she supported mathematical thinking in her STEM lesson plan.

Content Integration, Twenty-first Century Skills, and STEM Careers

All disciplines should be clearly visible in the STEM lesson plan and the link between disciplines should be clear. When we examine the four disciplines one by one in Sarah' STEM lesson plan, it can be stated that although technology integration was weak; science, mathematics and engineering were included in the lesson. Also, the connection between these three disciplines was handled. Moreover, in the first version of Sarah's STEM lesson plan, there was a drawing of a bicycle, which Sarah also thought of as an art integration.

In a STEM lesson plan, it's important for the problem to have multiple entry points and solutions so that students can approach it freely. While the teacher can provide guidance, they should refrain from simply telling students how to solve the problem. This encourages students to think critically and problem-solve independently. In Sarah's STEM lesson plan, there was a part for designing a bicycle. The students were expected to design a bicycle. The students could choose one of the options in the table considering their reasoning. In microteaching, three group chose three different designs. Therefore, this part of the activity had more than one solution. At the end of the lesson, the students were required to present their designs with the reasons for their choices. During this presentation, they were required to defend their solutions, which would enable them to develop their multidimensional thinking in the face of problems in their future professions.

Furthermore, STEM lesson plan must be prepared to develop students' 21st century skills such as collaboration, critical thinking, creativity, analysis, and assessment. To achieve this improvement, Sarah included group work in her STEM lesson plan. In the main activity, the students worked in groups of four. Sarah mentioned that she encouraged teamwork among her students by assigning them to work in groups. In this collaborative setting, she also encouraged students who had successfully reached a solution to explain it to their peers who were still working on it. The STEM lesson plan needs to include a specific occupational group for students to learn about STEM careers. In her STEM lesson plan, Sarah asked the students to imagine that they were an engineer and to solve the problem by thinking like an engineer. As an engineer, students needed to make appropriate calculations.

DISCUSSION and CONCLUSION

The development of participants' comprehension and competencies in STEM education was evident throughout the study. Robert initially had an idea about STEM education but acknowledged a lack of sufficient knowledge. Subsequently, after participating in the intervention and preparing a lesson plan, he expressed satisfaction with his participation, highlighting improvements in his STEM knowledge and the ability to design a successful STEM lesson plan. While Claire did not have any knowledge about STEM education at the beginning, at the end of the study she prepared a successful STEM lesson plan and expressed the importance of STEM education for her field. She expressed her intention to incorporate STEM activities into her future lesson plans. In contrast to other participants, Sarah possessed knowledge about STEM education and its significance at the beginning of the study. In the last interview, Sarah not only acquired a general understanding of STEM education but also delved into its origins and underlying purpose.

All three participants in this study added real-world problems to their STEM lesson plans. In addition, all three participants stated that STEM education is a good way to integrate real-life problems into the mathematics lesson so that there is a direct answer to the question of where mathematics is encountered in daily life. Supporting the study of Çorlu et al. (2014), the current study also concluded that STEM education offers opportunities for daily life applications. Furthermore, as Ceylan and Karahan (2021) point out, the real-world problems used by the participants in their STEM lesson plans involve more than one discipline.

Two of the participants (Robert and Sarah) successfully integrated engineering design into their lesson plans. Robert included a model design activity with the use of materials in his lesson plan. Students had the opportunity to test the robustness of their designs. They were also expected to design according to the given criteria. Robert's lesson plan supported that the letter E in STEM education also stands for designing. Similarly, Sarah expected the students to design according to the criteria. Unlike Robert, Sarah did not have a concrete design in her lesson plan. Claire, on the other hand, did not include engineering design in her lesson plan. When the three participants were compared, Robert seemed be the most successful in engineering design. He could integrate engineering successfully into the lesson plan (Maiorca & Mohr-Schroeder, 2020).

In terms of the challenges experienced, all three participants indicated that engineering was the most difficult discipline to integrate into STEM education. As argued by Chai et al. (2020), pre-service teachers in this study also found the integration of engineering into STEM lesson plans the most challenging. Especially, Claire stated that she could not integrate engineering to her

STEM lesson plan due to her lack of knowledge in the field of engineering which supports the statement of Chai et al. (2020).

All three participants in the study started their STEM lesson plans with science integration. They integrated the topics the students had learned or would learn in the science course. When the challenges experienced were evaluated, two of the participants stated that the integration of science was the easiest. They stated that it was easy to connect science and mathematics because the science course uses mathematics. On the other hand, Claire stated that she had difficulty in science integration. According to Claire, her lack of expertise in the field of science could lead to misconceptions, and she felt the need to have a solid understanding of science before attempting integration. The challenges experienced by Claire support the statement of Nadelson et al. (2012). In addition, as Lawson et al.'s (2021) emphasized Claire also stated that different disciplines need to plan STEM education together.

At the beginning of the study, the participants argued that technology integration was very important for mathematics education and that the use of technology was necessary in our age. However, it was observed that technology integration was weak in all three lesson plans. As for the use of technology, the participants only included videos and presentations on the smart board to their lessons. However, according to McCulloch et al. (2018) the use of smart boards is not sufficient for technology integration in mathematics courses and teachers need to have knowledge about integrating technology into their lessons. This might stem from the fact that, participants did their internship in a public school, they prepared their lesson plans in accordance with the school conditions. For example, Robert wanted to have the students design in a digital environment instead of using sticks and play dough. However, he could not do it because of the conditions at school. Claire and Sarah stated that the students did not used to use technology in lessons. Thus, these situations might have also affected their use of technology (Tondeur et al., 2013).

Before preparing the STEM lesson plan, the participants stated that GeoGebra could be used in the STEM lesson plan. They mentioned the benefits of concretizing abstract concepts, visualizing them and increasing student interest by giving GeoGebra as an example of technology integration similar to Şahin and Kabasakal (2018). On the other hand, none of the participants used GeoGebra in their STEM lesson plans and their technology integration was weak. Although the participants identified GeoGebra as a STEM material, they did not use it in the lesson plans. As Jocius et al. (2021) noted, the participants used the Internet sources as technology integration in their STEM lesson plans. As Chai et al. (2020) stated, it can be concluded that pre-service teachers might be inadequate in integrating technology into their lesson plans due to their insufficient knowledge of technology. Furthermore, the participants' weakness in technology integration supports Jocius et al., (2021)'s argument that pre-service teachers need to master technology skills. Although the participants had positive opinions about the use of GeoGebra in mathematics lessons, they did not use it in their lesson plans. They argued that it would be difficult to apply GeoGebra due to the conditions of public schools. On the other hand, while the participants focused only on technology in designing STEM lesson plans in the first interview, they realized the importance of science and engineering disciplines after the intervention. Therefore, science and engineering integration may have overshadowed technology integration. Thus, the reasons for the lack of technology use in the STEM lesson plans might stem from lack of technology knowledge or focusing more on other disciplines in STEM.

In the current study, the participants successfully integrated mathematics into their STEM lesson plans. They stated that they had difficulties in making mathematics visible in other disciplines during the preparation process. In Sarah's draft STEM lesson plan, mathematics integration was weak. She strengthened the mathematics integration in her lesson plan according to the feedback she received in microteaching. Robert and Claire stated that the transition from other disciplines to mathematics should be set clearly and explicitly. Claire said that she was afraid of getting a reaction from the students that the lesson did not include mathematics. However, similar to Sian Hoon et al. (2022); all participants made a lot of effort to improve themselves in the field of STEM education.

According to the participants in this study, thanks to STEM education, students went beyond the usual mathematics education and thus their thinking about mathematics was positively affected. This result can be considered an example of making mathematics enjoyable, as noted by Tatar et al. (2013), and Sümen and Çalisici (2016). Also, as Anderson et al. (2020) and Bartels et al. (2019) stated, participants argued that STEM education is effective in learning.

All of the participants emphasized the importance of students developing new skills while preparing STEM lesson plans and included group work in their STEM lesson plans. In addition, Sarah and Robert expected the groups to present their designs and defend their answers at the end of the lesson which aimed to develop 21st century skills. This result supports the studies by Wijaya et al. (2022), and Zhang and Zhu (2023). Moreover, two participants included a professional group in their STEM lesson plans. Claire asked the students to imagine that they were a ship captain and Sarah asked the students to imagine that they were engineers. Sahin (2020) also argues that STEM education should offer students the opportunity to recognize professional groups.

An important point of consideration for future research is the need for more in-depth exploration of the specific challenges pre-service teachers face in each discipline when preparing STEM lesson plans. While participants in this study mentioned the disciplines they found most and least challenging, a more comprehensive analysis could yield richer insights. To address this, future studies could employ more detailed questioning or provide specific examples to gather more nuanced data regarding the difficulties encountered in each discipline. Moreover, data collection tools can be developed in future studies. Qualitative research was conducted in this study. Quantitative or mixed studies can be conducted to investigate the challenges pre-service teachers face during the preparation of STEM lesson plans.

DECLARATIONS

Ethical Approval: The research titled "Investigation of Prospective Teachers' Views on STEM Education and the Difficulties Experience in the Lesson Planning Process" was approved by the Middle East Technical University Human Research Ethics Committee on 14 January 2022 with the number 28620816 and protocol number 0018-ODTUİAEK-2022.

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Competing interests: The authors declare that they have no competing interests.

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