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Pre-service Teachers' Experiences in Integrating Interdisciplinary Mathematical Modeling Activities into the 5E Instructional Model

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Abstract

This study aims to examine the experiences of pre-service science teachers in integrating interdisciplinary mathematical modeling (IMM) activities into the 5E instructional model. Conducted as a qualitative case study, the research involved 17 pre-service teachers who were asked to create lesson plans based on the 5E model using IMM activities they had prepared themselves, and their views on the process were collected. The findings of the study indicate that IMM activities were included in the introduction, exploration, and explanation phases of the 5E model. Most of the pre-service teachers stated that IMM activities were effective in understanding and solving real-life problems and emphasized that these activities strengthened the connection between mathematics and science. The results suggest that IMM activities, due to their shared characteristics and objectives with the 5E instructional model, can be effectively used as a learning tool within the 5E framework. This study provides important insights into the effectiveness of interdisciplinary teaching and highlights the importance and necessity of incorporating interdisciplinary education into teacher training programs. For more effective and generalizable results, it is recommended that experimental studies be conducted to investigate the in-class applications of interdisciplinary education.

Keywords: Interdisciplinary mathematical modeling, 5E instructional model, interdisciplinary instructional model, science-mathematics integration.

Introduction

The importance and necessity of integrating mathematics and science have been discussed for over a century (Frykholm & Glasson, 2005), and one of the most popular interdisciplinary educational approaches today is STEM (Science, Technology, Engineering, and Mathematics) education. STEM education involves the integration of at least two of the disciplines simultaneously. Although it is built upon four disciplines, the foundation of STEM is rooted in mathematics and science. Studies on the integration of mathematics and science within STEM education show that interdisciplinary approaches facilitate students' more comprehensive and in-depth learning (Hurley, 2001). While theoretically, a balanced integration of mathematics and science education is the goal in STEM education, teachers with expertise in different STEM disciplines may have different perceptions of STEM (e.g., Wang et al., 2011; Wong et al., 2016), which leads to variability in classroom practices based on the teacher's area of expertise (Wang et al., 2011). Moreover, the lack of a clear perspective on how to integrate these disciplines hinders the establishment of consistent development (Geiger et al., 2018; Doğan et al., 2018). A review of the literature shows that studies on the integration of mathematics and science due to STEM education are more prevalent in the field of science education, and in these studies, the mathematical dimension is often addressed superficially (English, 2015; Şahin et al., 2020; Every et al., 2025). Research on teachers' perceptions in STEM education has largely focused on the views of science teachers, with less research conducted on the views of mathematics teachers (Sevimli & Ünal, 2022; Every et al., 2025). In a study conducted with pre-service teachers in the fields of science and mathematics education, 47% of the participants stated that STEM activities were science-focused, while 23% believed they could be suitable for mathematics teaching (Cinar et al., 2016). Hurley (2001) conducted a meta-analysis of studies examining students' science and mathematics achievements in classrooms where the integration of science and mathematics was implemented, concluding that the interdisciplinary approach had a significant effect on science achievement, but a high effect value was not found for mathematics achievement. One possible reason for this outcome could be that practitioners were predominantly science teachers, with mathematics teaching being less emphasized. Some researchers agree on the necessity of teaching all relevant disciplines in interdisciplinary education models (Hom, 2014; English, 2015; Şahin et al., 2020).

Although the integration of mathematics and science has been a topic of discussion for years, the question of how to implement the joint teaching of these two disciplines remains a debated issue from the past to the present (e.g., Kren & Huntberger, 1977; Frykholm & Glasson, 2005; Şahin et al., 2020). Researchers (particularly science researchers) have developed theoretical models for practical applications by providing various definitions about how this integration should take place. For instance, Lonning and DeFranco (1997) proposed that the integration of mathematics and science could occur in five different ways: independent mathematics, mathematics-focused, balanced mathematics and science, science-focused, and independent science. Independent mathematics and independent science are defined as the integration of topics and concepts within each discipline, not between the two. In the mathematics or science-focused integration, the goal is to teach the central discipline, with the other discipline acting in a supportive role. In the balanced integration of mathematics and science, both disciplines are taught with equal importance. Kren and Huntberger (1977) presented a model where integration could occur in three ways: first, teaching mathematical concepts and then using them in science classes; second, teaching science concepts and then using them in mathematics classes; and third, teaching concepts from both disciplines simultaneously. Şahin and colleagues (2020) emphasize that having both mathematics and science teachers present in the learning environment and conducting teaching activities while assuming responsibility in their respective areas together is an effective solution. Researchers have experimentally demonstrated that such practices can be possible by implementing them in real classroom settings as part of a project. Frykholm and Glasson (2005) investigated the outcomes of the collaboration between mathematics and science pre-service teachers while creating interdisciplinary units and the effects of working together in schools during school internships (teaching practice). Their study focused on how pre-service teachers produced shared/supportive content and developed their pedagogical content knowledge in the context of the other discipline. Although each pre-service teacher carried out classroom practices individually, they used the other discipline in a supportive role. For example, science teacher candidates supported the teaching of scientific concepts with mathematical tools. This practice proposes a new model for teacher education programs and highlights the need for pedagogical content knowledge to be provided in an interdisciplinary context (Frykholm & Glasson, 2005). Considering the classifications mentioned above, it is seen that Şahin et al.'s (2020) emphasis on interdisciplinarity leans towards the balanced integration of mathematics and science, while Frykholm and Glasson's (2005) emphasis on interdisciplinarity is more aligned with mathematics-focused and science-focused integration.

Different teaching models proposed or implemented for interdisciplinary integration have made it necessary to revise existing teaching methods or develop new teaching techniques. The focus of this study is on an innovative approach: integrating Interdisciplinary Mathematical Modeling (IMM) activities into the inquiry-based 5E instructional model. Since the responsibility for interdisciplinary integration of teaching primarily falls on science teachers, and because pre-service science teachers are more familiar with the 5E instructional model than pre-service mathematics teachers, it was decided to work with these science teacher candidates. The research questions of this study, which examines the experiences of pre-service science teachers in integrating IMM activities into the 5E instructional model, are as follows:

- How do pre-service science teachers' skills in preparing a lesson plan suitable for the 5E instructional model using IMM activities compare?
- What are the pre-service science teachers' views on integrating IMM activities into the 5E instructional model?

Interdisciplinary Mathematical Modeling

Mathematical modeling is defined as the process of mathematizing real-life situations to propose solutions (Meier, 2009), and this definition contains two key features: real life and mathematization. The fact that the problem situation originates from real life and is mathematized in accordance with assumptions to reach a solution conveys the message that this cannot be achieved with mathematical knowledge and operations alone. Real life, by its nature, is complex, and consistent solutions must involve reasonable assumptions. This consistency not only includes mathematical coherence but also relevance to the real world. Therefore, effective assumptions are closely related to the correct use of knowledge from different disciplines. The conscious integration of this into mathematical modeling results in interdisciplinary mathematical modeling activities, which aim to teach at least two disciplines (Borromeo Ferri & Mousoulides, 2017).

Mathematical modeling is seen as an important tool in interdisciplinary education that involves mathematics (Kertil & Gürel, 2016; Zawojewski, 2016; Borromeo Ferri & Mousoulides, 2017; Doğan et al., 2018). In mathematical modeling, the problem situation must originate from real life, and this natural characteristic of modeling is more closely related to the sciences than mathematics (Borromeo Ferri & Mousoulides, 2017), while also ensuring the flexible, creative, and effective use of mathematics (Zawojewski, 2016). However, it must be clearly stated that mathematical modeling does not, on its own, carry an interdisciplinary feature. The relationship between mathematical modeling and different disciplines may exist implicitly, but when this is the case, the focus on mathematics teaching means that this feature only has a supportive effect in the modeling process. Interdisciplinary features can only emerge in connection with appropriate modeling problems (Borromeo Ferri & Mousoulides, 2017). Particularly, the Model Eliciting Activities (MEA) defined by Lesh and Doerr (2003) within the Model and Modeling Perspective provide an important foundation for adding an interdisciplinary dimension to mathematical modeling. The principles that MEAs must adhere to are defined as follows: (1) Model construction, (2) Reality, (3) Self-assessment, (4) Construct documentation, (5) Construct Shareability and Reusability, and (6) Effective prototype (for detailed information, see Lesh & Doerr, 2003). Based on these principles, Chamberlin and Moon (2005) divided the characteristics of MEAs into four sections (Figure 1).

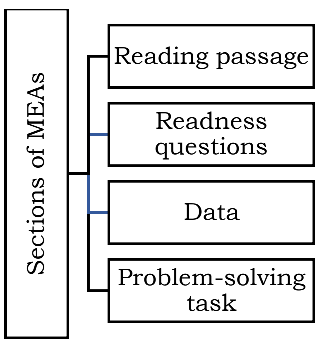


Figure 1. Sections of the MEAs (Chamberlin & Moon, 2005)

The reading passage and readness questions are used before the problem situation is given, in order to inform, draw attention, and stimulate curiosity within the real-life context of the problem. Then, students are provided with the necessary numerical and verbal data related to the problem situation (not all data necessary for solving the problem). In the final section of the MEA, the problem situation is presented, and students are asked to make assumptions based on the data provided in the third section and propose solutions (create models).

When an interdisciplinary dimension is added, mathematical modeling will help students develop their interdisciplinary integration skills and contribute to a clearer understanding of the applications of mathematics (Güder & Gürbüz, 2018; Doğan et al., 2018). As noted by Doğan and colleagues (2018), IMM activities possess the qualities necessary to facilitate the integration of science and mathematics teaching, especially in the transition to STEM education. The features that STEM activities must have—such as connection to real life, open-ended questions, and cyclical problem-solving processes—share similar characteristics with modeling activities, and the skills to be acquired are common (Maass et al., 2019; Gravemeijer et al., 2017). Therefore, mathematical modeling is considered to be a foundation for promoting STEM education and STEM literacy (Hallström & Schönborn, 2019). However, it remains unclear which teacher will carry out these activities in the classroom and how they will be implemented. More experimental studies are needed to examine the effects of the methods for implementing interdisciplinary activities on student success, motivation, and attitudes. While IMM activities aim for a balanced teaching of both disciplines (Gürbüz et al., 2018; Şahin et al., 2020), it is also possible to implement them in the classroom in a way that one teacher primarily focuses on their own field, with the other discipline supporting it. Indeed, many countries' education systems are not suitable for having two teachers in the classroom simultaneously (Kiray, 2012), and teacher training programs do not yet support this. Considering that the expertise of the educator plays a key role in interdisciplinary-focused models (especially STEM) (NAE & NRC, 2014, p.115), a science teacher who has not received mathematics education must receive the necessary training support to effectively integrate the disciplines (Baker et al., 2017; Stinson et al., 2009). Although not sufficiently emphasized in the literature, it is equally important for a prospective mathematics teacher to have knowledge in the field of science if they are to be the practitioner.

Theoretical Framework: Integration of Interdisciplinary Mathematical Modeling and the 5E Instructional Model

The 5E instructional model, an inquiry-based teaching model, was initially designed in the late 1980s for use in teaching science (biology) (Bybee et al., 2006). The steps and contents of the 5E instructional model have been redefined by the same researchers with the support of experimental studies (Bybee et al., 2006). Since the 5E instructional model is considered an effective tool, particularly in STEM education, it has become a widely used model in science fields (Manunure & Leung, 2024). On the other hand, the literature includes studies discussing the suitability of Model Eliciting Activities (MEA) for STEM education, along with proposals and theoretical frameworks related to it (e.g., Baker et al., 2017; Tezer, 2019; Fry & English, 2023). In fact, in their study examining mathematics teachers' views on MOE, Tekin Dede and Bukova Güzel (2013) found that participants expressed the possibility of making interdisciplinary connections through MOE. This result is an important indicator that MOEs have a natural feature to enable interdisciplinary integration. In this study, IMM activities are considered as MOEs, and the theoretical framework of the study is based on the features of MOEs defined by Chamberlin and Moon (2005), forming a framework in which IMM activities are integrated into the steps of the 5E instructional model (Bybee et al., 2006).

In the **Engagement** phase, the goal is for students to mentally focus on an object, problem, or situation. Successful engagement occurs when students experience surprise in response to the learning activity and are motivated to take an active role in it. This creates cognitive dissonance, which encourages students to engage in learning. The teacher's role at this stage is to present the situation and set the rules. In order for a situation to be considered a problem, it must create a sense of helplessness in the individual and not be directly solvable (Kaiser et al., 2011). Such a problem situation, as defined by Piaget, creates cognitive dissonance and generates the desire to find a solution. In IMM activities, it is important to draw attention to the relevant real-life situation before presenting the problem situation, for example, through a newspaper article, video, or story (Chamberlin & Moon, 2005; Şahin et al., 2020). The second part of IMM activities is the preparation questions phase, which consists of warm-up activities. In this phase, questions are asked to ensure the understanding of the introductory article or video, along with open-ended questions that students may not be able to answer immediately. Thus, the introductory article or video section and warm-up activities of IMM activities can be applied in the engagement phase of the 5E instructional model.

The **Exploration** phase is the stage where students take action to resolve the cognitive dissonance they have experienced. The balancing process is where students use both their existing and newly acquired knowledge to explore their ideas. For this, an appropriate environment must be created, and sufficient time must be given. This phase is concrete and practical, and the learning process must be well-designed. In the third and fourth sections of IMM activities, data and the problem situation are shared with the students, and they are asked to propose solutions (create models). In this context, the exploration phase may be suitable for the implementation of IMM activities. The goal of exploration activities is to help students recognize concepts, processes, or skills and create experiences they can later use for discussion. The teacher takes on a guiding role, which aligns closely with the teacher role defined during the implementation of modeling activities.

The **Explanation** phase is the stage where scientific facts related to the lesson or topic are reached. In the exploration phase, students share the knowledge they discovered through their research and the conclusions they drew, and in the explanation phase, they discuss the alignment of this knowledge with scientific facts under the teacher's guidance. In this context, the main element of this phase is the presentation of the reports students are asked to prepare, or in other words, the models they have created. The discussion of the models emerging from the modeling activities is considered in terms of their applicability to real-life situations and their alignment with the relevant disciplines and the desired outcomes.

In the **Elaboration** phase, the focus is on transferring the discovery products presented by students in the explanation phase to new related situations. Elaboration is not just a phase for reinforcement. The learning process continues during this phase. In fact, in some cases, students may still have misunderstandings or may only understand a concept in terms of exploratory experience. Elaboration activities provide more time and experience, contributing further to learning in conjunction with new situations. While the model creation (report writing) and presentation phases of IMM activities are thoroughly discussed in the explanation phase, the adaptation of the models to new situations and the transformation of the model into a generalizable form, considering intergroup interaction, can be addressed in the elaboration phase. In model construction activities, Lesh and Doerr (2003) refer to this principle as effective prototype.

In the **Evaluation** phase, the informal assessments made throughout the process are replaced by formal feedback for both teachers and students regarding their competencies. This evaluation is twofold for teachers: assessing educational outcomes and determining students' level of understanding. The presentation and discussion of reports related to IMM activities, along with the evaluation of the modeling process, can be completed in the explanation and elaboration phases. In this context, there is no obligation for the IMM process to continue until the evaluation phase. However, during the evaluation phase, new ideas and assumptions can be considered, and follow-up questions can be used to inquire about the level of conceptual understanding achieved.

Considering the characteristics of IMM activities, they are thought to be a suitable tool for interdisciplinary integration, and the 5E instructional model is believed to be effective in transferring this tool to the teaching environment. Therefore, it is important to understand how IMM activities are integrated into the 5E instructional model before being implemented in the classroom, and the views of pre-service teachers on this process are of significant importance.

Method

Research Design

This study, which investigates pre-service teachers' competencies in preparing lesson plans aligned with IMM activities and the 5E instructional model, as well as their views on this process, is a qualitative case study. The main purpose of a case study is to collect in-depth information from an individual or group about a specific situation and to explain the situation in detail (Çepni, 2007). Based on the research's objectives, this design was deemed appropriate.

Participants

This study was conducted with 17 pre-service teachers -the whole class (14 female; 3 male)- in their final year of the Science Education program at a public university in Turkey. The participants were divided into 3 groups, each consisting of 4 members, and one group consisting of 2 members and 3 members. This study was conducted as part of a larger research project. Although the student groups were initially formed with an equal number of participants, 2 students did not participate in this phase. In the study, the pre-service teachers are coded as (Group no. Person no) (e.g., (2.3): the third member of the second group).

Implementation Process

The implementation process of this study, which examines the pre-service science teachers' competencies in preparing lesson plans aligned with IMM activities and the 5E instructional model, as well as their views on this process, consists of 5 stages: (1) Determining pre-service teachers' views on the integration of Mathematics and Science courses, (2) Theoretical and practical training on mathematical modeling activities, (3) Classroom practices where interdisciplinary mathematical modeling activities are integrated into the 5E instructional model, (4) Pre-service teachers' preparation of IMM activities and lesson plans, (5) Collecting pre-service teachers' views. In planning the implementation process, researchers working in both mathematics education and science education designed an 11-week teaching program that utilized interdisciplinary mathematical modeling problems within the 5E instructional model. The details of the implementation process are presented in Table 1.

Table 1. Implementation Process

Phase	Week	Topic	Description
Phase 1	Week 1	Can mathematics and science be integrated? How?	Written feedback form (individual) – Classroom discussion (whole class)
Phase 2	Week 2	Introduction to Mathematical Modeling	Theoretical and practical training
Phase 3	Week 3	Interdisciplinary Mathematical Modeling	Insulation Problem (adapted to the 5E instructional model)
	Week 4	Interdisciplinary Mathematical Modeling	Global Warming Problem (adapted to the 5E instructional model)
	Week 5	Interdisciplinary Mathematical Modeling	Building a House from PET Bottles Activity (adapted to the 5E instructional model)
	Week 6	The 5E Instructional Model and the Use of IMM in this Model	Preparing a lesson plan suitable for the 5E instructional model
Phase 4	Week 7 Week 8	Preparing an IMM activity	Preparing an IMM activity to be used in the 5E instructional model
	Week 9	Editing and finalizing an IMM activity to be used in the 5E instructional model	Collecting the activities
	Week 10	Preparing a lesson plan using an IMM activity within the 5E instructional model	Collecting the lesson plans
Phase 5	Week 11	Evaluation of the process	Written feedback form (individual)

In this study, which was carried out with the joint participation of the researchers and the science education expert, the first week focused on gathering pre-service teachers' views on the creation of an interdisciplinary teaching model involving mathematics and science, and the potential effectiveness of such a model. It is known that the participants had prior knowledge of the 5E instructional model, as they had taken courses related to the 5E learning model in previous semesters of their undergraduate education. Therefore, no specific training content was created for the 5E instructional model. However, since the participants had not yet encountered mathematical modeling activities, a theoretical training covering the basic features of mathematical modeling was provided in the second week, and their learning was supported through activity applications. Over the next three weeks, IMM activities integrated into a lesson plan designed according to the 5E instructional model were implemented in the classroom. During this process, participants were divided into groups of four, and no changes were made to the group membership in the subsequent phases of the study. In the sixth week, a lesson plan in which the IMM activity was integrated into the 5E instructional model was examined and discussed according to the steps of the model. Later, each group was asked to prepare one IMM activity. Although the alignment of the activities with the IMM criteria was not examined in this study, the training program provided to the pre-service teachers allocated a three-week period to prepare IMM activities. During this period, each group's prepared activity was reviewed, and written feedback was given to ensure that the problems were aligned with the modeling criteria. After an average of four revisions, each activity met the IMM criteria. Thus, all activities in the lesson plans containing IMM activities suitable for the 5E instructional model adhere to the modeling criteria. In the next phase, pre-service teachers were asked to prepare a lesson plan using their IMM activities, which were suitable for the 5E instructional model. In the final week, pre-service teachers' views on this process were collected in writing. Table 1 reflects a detailed and long-term research process. Data were collected at each stage of of this broader process; however, this study specifically focuses on the last two stages of the implementation.

Since this research was conducted during the Covid-19 pandemic, the entire implementation and data collection process was carried out online. As the university's distance education platform provided the opportunity for individual and group work, sharing work online, and recording, no negative situations directly affecting the study occurred. However, the use of the distance education platform for monitoring and intervening in group activities simultaneously during the second and third phases of the teaching process can be considered a limitation.

Data Collection

The data for this study consist of lesson plans (5 plans) prepared by pre-service teachers as a group and written individual feedback forms regarding the integration of IMM activities into the 5E learning model. The questions in the written opinion form aim to elicit pre-service teachers' views on the process of preparing lesson plans in which they integrated IMM activities and, individually, on the alignment of these activities with the 5E instructional model, and some of these questions are: "Can you describe your process of preparing the IMM activity and integrating it into the 5E instructional model? (Please explain step-by-step what you did)", and "Do you think IMM activities are suitable for the 5E learning model? Why?"

Data Analysis

The lesson plans prepared by the participants were analyzed according to the steps of the 5E instructional model using the "5E Learning Cycle Lesson Plan Rubric" developed by Goldston et al. (2013) and adapted into Turkish by Güngören Çavuş et al. (2020). The written forms containing the views of pre-service teachers on the use of IMM activities in the 5E instructional model were analyzed using content analysis. The data analysis was conducted separately by the researcher and a science education expert and was examined systematically. Since the agreement rate for scoring the lesson plans and conducting the content analysis was above 94%, it can be said that the analyses have a high level of reliability (Huberman & Miles, 2002).

In this study, the lesson plans based on the 5E instructional model using IMM activities were prepared with the consideration of science education outcomes.

Findings

The findings of this study, which investigates the process of pre-service science teachers integrating IMM activities into the 5E instructional model and their views on this process, are presented under two main headings. The first part presents the findings related to the lesson plans in which pre-service teachers integrated IMM activities into the 5E instructional model, and the second part presents the findings related to their views on evaluating this process.

The Process of Integrating IMM Activities into the 5E Instructional Model

To provide an overview of pre-service teachers' lesson plans showing the process of integrating IMM activities into the 5E instructional model, the lesson plans were evaluated using the 5E ILPv2 analysis framework and shared in Table 2. Following this, all lesson plan examples were descriptively examined according to each component of the 5E instructional model.

Table 2. Analysis of Lesson Plans

Activity name	General features of the lesseon plan	Engage	Explore	Explain	Elaborate	Evaluate	Additional lesson plan components
Pressure Problem	11	16	15	23	3	10	13
Biotechnological Afforestation Project	8	12	16	23	12	16	14
Electric Energy	11	16	12	22	9	14	14
Wheelchair Ramp	11	10	13	19	11	8	14
Solar Energy Instead of Fossil Fuels	11	13	15	11	4	15	13

The lesson plans in which pre-service teachers integrated IMM activities into the 5E instructional model show that the lesson plans differ particularly according to the components of the 5E model. All IMM activities were used in the exploration phase of the 5E instructional model, while the evaluation of the modeling process was addressed in the explanation phase of the 5E instructional model. Below, the detailed results of the lesson plans according to each phase are provided.

When examining the data for the engagement phase, it is observed that all groups included engaging activities aimed at stimulating students' curiosity, uncovering their existing knowledge, and preparing them for the relevant learning outcomes. Among these activities, videos available on various web-based platforms are the most frequently used. In four of the five lesson plans, showing videos related to the topic to students is considered. Additionally, visual materials consisting of various images, cartoons, and photos related to the topic were also used in the engagement phase. The activities in the engagement phase are shown in Table 3.

Table 3. Activities in the Engagement Phase

Activity Name	Content of the Engagement Phase
Pressure Problem	Video (Liquid Pressure Experiment in Composite Containers) Preparation Questions
Biotechnological Afforestation Project	Photo (Genetically Modified Corn) Newspaper Article (Light Emitting Plant Developed) Video (Biotechnology and its Applications) Preparation Questions
Electric Energy	Cartoon (Energy Conversion and Saving) Image (Conscious Use of Electrical Energy) Preparation Questions
Wheelchair Ramp	News Video (What Kind of Ramp is This?) Preparation Questions
Solar Energy Instead of Fossil Fuels	Documentary (Acid Rain) Newspaper Article (What is Chemical Rain? Is there a Risk of Chemical Rain in Istanbul?) Preparation Questions

All the materials and questions used in the engagement phase of the lesson plans are appropriate for the related learning outcomes and are designed to capture students' interest. For example, the cartoon used in the electric Energy activity is suitable for both of the targeted outcomes (Figure 1).

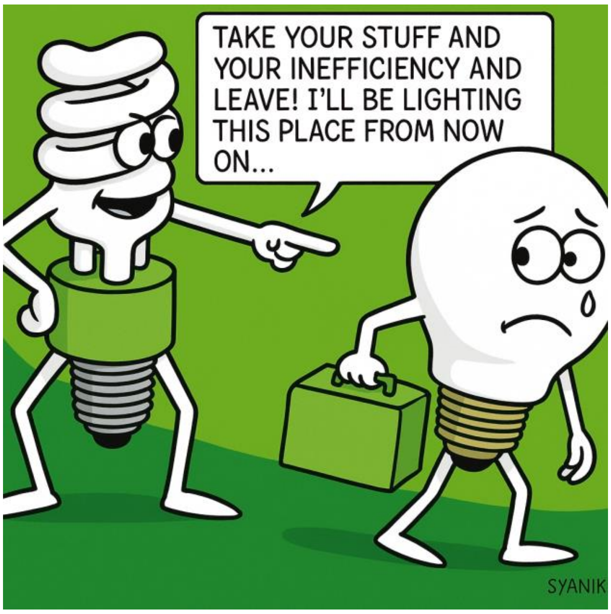


Figure 1. Energy Conversion and Energy Saving

However, it has been observed that some activities in the engagement phase are aimed solely at attracting attention (e.g., *What Kind of Ramp Is This?*), while others are intended to provide information related to the topic (e.g., *Biotechnology and its Applications*, *Acid Rain*). The content of the news report *What Kind of Ramp Is This?* is specifically about ramps that should be present at apartment entrances but have become unusable due to reasons such as walls being built in front of them or steps being made. Therefore, while it helps to draw students' attention to incorrect applications, it is not appropriate for linking with the learning outcomes.

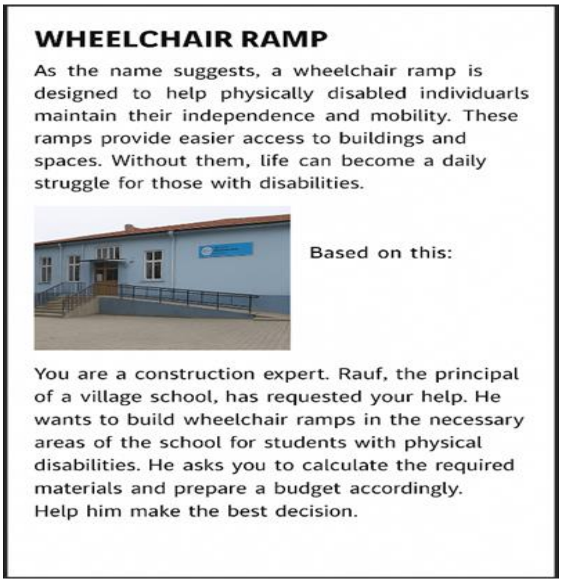
On the other hand, the *Acid Rain Documentary* and the *Biotechnology and its Applications* video are materials that contain all the details related to the topic. After watching these videos, the planned preparation questions (e.g., *What is acid rain? In which fields can we use biotechnology?*) are intended to focus on understanding what students have learned from the videos, rather than supporting their creative thinking skills.

The exploration phase in all lesson plans includes IMM activity implementations. In this phase, all groups provided information, particularly emphasizing the student role in the activity's implementation. For example, phrases were used such as forming groups before starting the activity, asking students to read the problem situation individually before beginning, giving a specific amount of time for the activity, and asking students to create a report at the end of the activity. These important points to consider when implementing IMM activities were reflected in the lesson plans properly. When examining the lesson plans in terms of the targeted learning outcomes, the dimensions of the outcomes that the activities aim for are provided in Table 4.

Table 4. Dimensions of the Outcomes Targeted by IMM Activities

Activity Name	Targeted Dimension of the Outcome
Pressure Problem	Provides examples of the applications of liquid pressure characteristics in daily life and technology.
Biotechnological Afforestation Project	Makes predictions about future biotechnological applications.
Electric Energy	Discusses the importance of using electrical energy consciously and efficiently for family and national economy.
Wheelchair Ramp	Designs a mechanism that will make daily life easier by using simple machines.
Solar Energy Instead of Fossil Fuels	Proposes solutions for preventing acid rain.

When examining which dimensions of the related learning outcomes IMM activities aim for, it was found that the objectives of all activities, except for the Wheelchair Ramp (Figure 2), align with the intended outcomes.


WHEELCHAIR RAMP

As the name suggests, a wheelchair ramp is designed to help physically disabled individuarls maintain their independence and mobility. These ramps provide easier access to buildings and spaces. Without them, life can become a daily struggle for those with disabilities.

Based on this:

You are a construction expert. Rauf, the principal of a village school, has requested your help. He wants to build wheelchair ramps in the necessary areas of the school for students with physical disabilities. He asks you to calculate the required materials and prepare a budget accordingly. Help him make the best decision.

Figure 2. Wheelchair Ramp

The Wheelchair Ramp activity is an IMM problem, and as indicated in the learning outcome, it requires designing a mechanism that will make daily life easier by utilizing simple machines. However, in the problem situation, students are asked to determine the necessary materials for the ramp and create an appropriate budget. Therefore, the problem directs students to focus on determining the necessary materials and budgeting, rather than focusing on the inclined plane. Although the slope of the ramp should be considered to calculate the amount and cost of the required materials, this aspect is not central to the activity. Thus, it can be said that the activity is not fully aligned with the learning outcome, as it does not guide students to focus on calculating the slope of a ramp in a way that is suitable for real-life applications, where they could gain a mechanical advantage.

The Biotechnological Afforestation Project activity is designed in line with the lesson's learning outcomes and is a IMM problem that allows students to create models aimed at making predictions about future biotechnological applications (Figure 3).

BIOTECHNOLOGICAL AFFORESTATION PROJECT

The Gaziantep Metropolitan Municipality is planning to carry out afforestation activities in different areas of the city. However, unlike previous efforts, this new project is expected to be more innovative, eco-friendly, and cost-effective. For this reason, the municipality is seeking support from the city's youth. Young individuals who come up with promising ideas will be offered job opportunities.

Ece, a landscape architecture student, and Ayhan, a microbiology student, apply to participate in the project. Ayhan is aware that when the firefly gene is transferred to a tobacco plant, the plant can emit light. Inspired by this, Ece considers that instead of using tobacco plants, trees might be used for the same purpose. This way, they aim to contribute to the environment, provide natural lighting, and reduce energy costs—making the project both sustainable and economical.

Based on the table provided, Ece and Ayhan will select the tree species and the area to be afforested and calculate a reasonable cost estimate.

How would you assist them in this project?

Tree Species	 **Pine**	 **Weeping Willow**	 **Judas Tree**	 **Birch**	 **Blue Spruce**	 **Plane Tree**
Maximum Height	Up to 20 meters	Up to 15 meters	Up to 10 meters	Up to 25 meters	Up to 25 meters	Up to 50 meters
Cold Resistance	Resistant to -20°C	Resistant to -32°C	Resistant to -15°C	Resistant to -45°C	Resistant to -25°C	Resistant to -20°C
Flowering	No flowers	Yellow-green color	Purple-pink flowers	Yellow-green flowers	No flowers	No flowers
Price	53 TL	54 TL	32 TL	35 TL	123 TL	58 TL

Figure 3. Biotechnological Afforestation Project

In the Biotechnological Afforestation Project activity, students are presented with a problem situation related to a biotechnological innovation that exists but is not yet widely implemented, with the aim of using it more widely and effectively in the coming years.

The explanation phase in all lesson plans is planned as a continuation of the phase where students present the models (or reports) they produced at the end of the exploration phase of the IMM activity. In this phase, the discussion of the models produced by students is planned, along with guiding the students to reach accurate information under the teacher's guidance. In the lesson plan involving the Pressure Problem, the explanation phase is described as follows:

"Students are asked to express the inferences they made during the exploration phase. The correctness or incorrectness of the students' inferences is expressed by the teacher using scientific explanations related to the topic. Additionally, these inferences are evaluated in terms of their suitability for mathematics, science, and real-life applications. Then, the importance of pressure in daily life is explained with a few additional examples."

In the lesson plan for the Electricity Saving activity, the explanation phase is described as:

"At the end of the activity conducted in class, the teacher asks the students to express the inferences they made during the exploration phase to understand what conclusions they reached. The correctness or incorrectness of the students' inferences is expressed by the teacher using scientific explanations related to the topic. Information is provided to help with any missing parts. Additionally, these inferences are evaluated in terms of their suitability for mathematics, science, and real-life applications."

In all lesson plans, the explanation phase is structured using similar expressions to align with the 5E instructional model.

The elaboration phase is the stage where students generalize the knowledge they have gained to new situations. In the lesson plans where IMM activities are integrated into the 5E instructional model, the elaboration phase has been planned to ensure that the results obtained through the models created at the end of the IMM process are generalizable. Additionally, applications related to other dimensions of the targeted learning outcomes have also been addressed in this phase (Table 5).

Table 5. Elaboration Phase Applications of the 5E Instructional Model by Activity

Activity Name	Elaboration Phase
Pressure Problem	In this phase, students are asked to research the daily life and technological applications of pressure in solids, liquids, and gases, examine the working principles, and prepare a poster related to these investigations.
Biotechnological Afforestation Project	In this phase, students are asked what the beneficial or harmful aspects of biotechnological applications could be for humanity. Using the 6 Thinking Hats technique, students are asked to express their opinions on this topic. Finally, they are asked to create a poster about this topic and present it to the class.

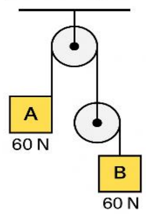
Activity Name	Elaboration Phase
Electric Energy	Videos showing how electrical energy is converted into heat, light, and motion are shown. After the videos, students' thoughts and comments on the videos are collected. Students are asked to give examples from daily life based on the energy transformations in the videos. The topic of electrical energy conversion to light energy is discussed, and the importance of electricity saving in daily life is elaborated. Students are asked to write a poem about electricity saving and present it to their classmates.
Wheelchair Ramp	Each group is asked to design an original simple machine project that can be used in daily life and make life easier. If conditions allow, the designed mechanism is built in 3D.
Solar Energy Instead of Fossil Fuels	To understand how acid rain forms and the damage it causes to the environment, Activity 1 is conducted. Students are asked to note and share the information they have learned from the experiment. To reinforce and raise awareness about acid rain.

As seen in Table 5, the elaboration phase of the 5E instructional model integrated with the Pressure Problem activity involves a plan that focuses on researching the real-life applications of pressure in solids and gases. In the Biotechnological Afforestation Project activity, students are asked to design an innovative project with an environmentally friendly approach that ensures energy savings. In the elaboration phase, it is emphasized that biotechnological applications not only have positive uses but can also have harmful ones. In the Electric Energy activity, which involves the conversion of electrical energy into light energy, the conscious and efficient use of electrical energy is highlighted. The elaboration phase of the lesson plan integrated with this activity plans for videos to be shown and discussed regarding the conversion of electrical energy into heat, light, and motion. The lesson plan, particularly focusing on the conversion to light energy, also emphasizes energy saving. In the Wheelchair Ramp activity, the elaboration phase of the lesson plan asks students to work on simple machine designs that can ease real life, different from the models they created during the activity. In this phase, students, who focused on inclined planes in the Wheelchair Ramp activity, are expected to become aware of other types of simple machines that can be encountered or are already used in real life. In the Solar Energy Instead of Fossil Fuels activity, the use of environmentally friendly solar panels instead of thermic power plants, which have harmful environmental effects, is highlighted. The Elaboration phase involves activities regarding the formation and damages of acid rain. As noted in the findings of the exploration phase, the experiment planned for this phase might have been more appropriately placed as part of the IMM activity in terms of the flow of the topic.

Considering the activities planned for the elaboration phase, it is evident that various teaching methods and techniques are also utilized in this phase. The main activities used in this phase include poster preparation, poster design, writing poems/stories, drawing, creating 3D designs, experiments, stations, and the Six Thinking Hats technique.

The evaluation phase consists of unit-end assessment questions in all lesson plans except for the Biotechnological Afforestation Project lesson plan. The types of questions used in the evaluation phase and the corresponding outcome dimensions to be assessed are provided in Table 6.

Table 6. Evaluation Phase Applications of the 5E Instructional Model by Activity

<table>
<tr><th>Activity Name</th><th>Question Types</th><th>Sample Questions</th></tr>
<tr><td>Pressure Problem</td><td>Multiple Choice</td><td>I. Fire truck ladder
II. Dentist chair
III. Dynamometer
Which of the devices listed above operate based on the principle of liquid (hydraulic) pressure?
A) I and II
B) I and III
C) II and III
D) I, II, and III</td></tr>
<tr><td>Biotechnological Afforestation Project</td><td>Open-Ended</td><td>• What new things have you learned about biotechnology, which we have often heard about?
• Why is it important to use products produced by biotechnology?
• What changes could be made to improve our country's development in terms of biotechnology usage?</td></tr>
<tr><td>Electric Energy</td><td>Fill-in-the-Blanks
Open-Ended
Matching</td><td>• Provide examples of tools and devices made by utilizing the conversion of electrical energy into light energy.
• Match the appliances below with the appropriate fuse ratings required to protect them.
<table><tr><td></td><td>Fuse ratings</td></tr><tr><td>Hair dryer (2A)</td><td>5A</td></tr><tr><td>Iron (4A)</td><td>3A</td></tr><tr><td>Refrigerator (0.7A)</td><td>1A</td></tr><tr><td>Washing machine (5A)</td><td>6A</td></tr></table></td></tr>
<tr><td>Wheelchair Ramp</td><td>Multiple Choice
True-False</td><td>In the pulley system shown below, two frictionless and massless pulleys are used. Object A is hanging from one end of to rope, while object B is connected to a movable pulley. The system is in equilibrium.


If the weight of object A is 60 N, what must be the weight of object B for the system to remain in balance?
A) 30 N B) 60 N
C) 90 N D) 120 N
<table><tr><td>Gears are not used to increase speed.</td><td>T</td><td>F</td></tr><tr><td>Gear wheels with the same centers and different sizes that are connected to each other rotate in the same direction and with the same number of turns.</td><td>T</td><td>F</td></tr></table></td></tr>
<tr><td>Solar Energy Instead of Fossil Fuels</td><td>Open-Ended
Multiple Choice</td><td>• What are some solutions for preventing acid rain?
Regarding acid rain:
I. Reduces productivity in agricultural products and natural vegetation.
II. Causes pH levels in aquatic habitats that organisms cannot tolerate.
III. Occurs only when carbon dioxide changes in the atmosphere exceed normal levels.
Which of the statements are correct?
A) Only I B) Only II C) I and II
D) I and II</td></tr>
</table>

In the evaluation phase of the lesson plans where IMM activities are integrated with the 5E instructional model, the majority of the activities consist of multiple-choice questions. In the lesson plan involving the Biotechnological Afforestation Project, the evaluation questions are open-ended, designed to cover the other four phases of the 5E instructional model. In the Pressure and Solar Energy Instead of Fossil Fuels lesson plans, some of the evaluation questions are aligned with the 5E instructional model, while others consist of unit-end questions used for assessment purposes.

Opinions on the Process of Integrating IMM Activities into the 5E Instructional Model

The opinions of the pre-service teachers about the process of preparing IMM activities in groups and integrating them into the 5E instructional model are discussed under two main headings: whether IMM activities are an effective learning tool for the 5E instructional model and the difficulties they faced during the process of integrating IMM activities into the 5E instructional model.

Are IMM Activities an Effective Learning Tool for the 5E Instructional Model?

When examining the pre-service teachers' opinions on the compatibility of IMM activities with the objectives and structure of the 5E instructional model, it was found that all but one participant expressed positive views. Pre-service teacher 1.2 stated: "(IMM activities) will waste too much time because they do not cover the entire topic." This view indicates that the participant sees the time allocated for the IMM activity as a waste of time. The opinions of the pre-service teachers on this topic and the frequencies of these views are presented in Table 7.

Table 7. Opinions on Whether IMM Activities Are an Effective Learning Tool

Category	Codes	Sample Opinion	Frequency
Mathematical and Logical Thinking	Logical Thinking	"The integration of the two disciplines promotes logical thinking." (2.1)	6
	Cause-Effect Relationship	"While solving mathematical modeling problems, students base their ideas on a cause-effect relationship." (3.3)	2
	Problem Solving	"It aims to improve the student's problem-solving skills in terms of mathematics." (4.3)	3
Creative Thinking	Making Assumptions	"The IMM approach presents problem situations that are open to different assumptions." (3.3)	2
	Offering Different Solutions	"It enables students to propose solutions in different ways and forms." (2.2)	2
	Gaining a Different Perspective	"In terms of science teaching, it helps students approach problems from a different perspective. In this way, students will relate the topic more to their daily lives." (4.2)	2
Understanding and Solvin	Relating Real-Life Situations to Mathematics and Science	"In science teaching, it allows students to create real-life problems, and they can better understand that mathematics can be used in every field." (5.2)	5

Category	Codes	Sample Opinion	Frequency
	Relating Mathematics and Science	"Since the paths of science education and mathematics intersect, addressing both together makes it more understandable and more enjoyable." (1.1)	6
	Seeing the Applicability of Scientific Knowledge in Real Life	"I think the knowledge learned here can be used more in daily life." (3.2)	7
Effective Learning	Meaningful Learning	"It helps students think about the topic more deeply with a problem situation, enhancing their understanding." (4.1)	5
	Lasting Learning	"When disciplines are taught together, it becomes more enjoyable and the learning lasts longer." (2.2)	3
Affective Contributions	Valuing Mathematics	"It will create positive changes in students' perspectives on mathematics." (4.2)	6
	Being Attention-Grabbing/Enjoyable	"Providing examples of how a topic might appear in daily life helps increase interest in the topic and aids in better understanding." (1.2)	5

The written opinions shared by pre-service teachers about their experiences integrating IMM activities into the 5E instructional model revealed that one pre-service teacher had a negative opinion solely based on the argument that IMM activities would take too much time. Table 7 contains other (positive) opinions. Pre-service teachers stated that IMM activities align with the objectives and characteristics of the 5E instructional model by highlighting the contributions they make to learning. Initially, the opinions about whether IMM activities are effective tools were examined under five categories: mathematical and logical thinking, creative thinking, understanding and solving real-life problems, effective learning, and affective contributions. Pre-service teachers (n=18) believe that IMM activities would contribute the most to helping students understand and solve real-life problems. The opinion that scientific knowledge can be applied in real life was the most frequently occurring view (n=7) under this category. Additionally, the data show that participants see IMM activities as an important tool for integrating mathematics and science (n=6) and believe it supports mathematical and logical thinking skills (n=6). Pre-service teachers also believe that IMM activities can lead to meaningful (n=5) and lasting (n=3) learning. Most pre-service teachers (n=11) expressed opinions not only about cognitive contributions but also about the affective effects of IMM activities. Opinions related to how IMM activities could contribute to developing a positive attitude towards mathematics had the second-highest frequency (n=6).

It is observed that pre-service teachers have a strong consensus that IMM activities are an effective tool for teaching mathematics and science. The findings related to their opinions about the appropriateness of integrating IMM activities into the 5E instructional model are presented in Table 8.

Table 8. Opinions on the Appropriateness of Integrating IMM Activities into the 5E Instructional Model

Category	Codes	Example Opinion	Frequency
Common Characteristics	Facilitating Teaching	"… since it is a 5-step model aiming to create their own concepts, IMM activities are suitable for the 5E model. Through these activities, a problem related to real life is found, and by searching for a solution, the topic is understood in an efficient way." (1.3)	3
	Philosophical Foundations	They are based on a constructivist approach. (2.4)	1
	Interdisciplinary Nature	In the exploration phase, activities allow students to use their math skills and enhance engineering skills by using both mathematics and science knowledge. (5.1)	3
	Including Similar Processes	The exploration phase of the 5E model aims to allow students to reach knowledge by asking questions and discussing answers. With IMM, they do this while making connections between different disciplines to solve real-life problems. (2.2)	4
Compatibility with the Structure of the 5E Instructional Model	Compatibility with 5E Instructional Phases	Since each phase of the 5E model involves different mental and physical activities, it is not difficult to integrate modeling into one of these phases. (2.1)	3
	Suitability for the Exploration Phase	Typically, the exploration phase of the 5E model uses experiments and discussion methods, and they didn't seem sufficient to me. However, adapting IMM activities to this phase significantly benefits higher-order thinking skills. It also allows for the use of both science and math disciplines together. (3.3)	7

When the opinions of the pre-service teachers were examined, it was found that the reasons for considering IMM activities suitable for the 5E instructional model fall under the categories of common features and structural compatibility. Although only one pre-service teacher mentioned that both applications share the same learning philosophy, it is considered an important point. It is evident that IMM activities are interdisciplinary. Some pre-service teachers (n=3) expressed that this relationship can be effectively made through the 5E instructional model. Particularly, with reasons related to the exploration phase of the 5E instructional model, the distinguishing features of IMM activities were emphasized (n=7). One of the common features of both the learning process of IMM activities and the 5E instructional model is that they contribute to the processes of constructing knowledge through active student participation (n=4).

Integration of IMM Activities into the 5E Instructional Model

Pre-service teachers were asked to prepare a lesson plan suitable for the 5E instructional model, including the IMM activity they had prepared. As detailed in the previous section, all of the lesson plans created included IMM activities in the exploration phase. Data regarding whether the pre-service teachers faced any difficulties in integrating IMM activities into the 5E instructional model show that all pre-service teachers, except for two participants, experienced certain challenges during this process. However, the challenges faced by the pre-service teachers were found to be related more to the process of preparing the IMM problem rather than the integration of the IMM problem into the 5E instructional model. The opinions regarding the difficulties faced by the pre-service teachers during the relevant process are presented in Table 9.

Table 9. Challenges Encountered in the Process of Integrating the IMM Activity into the 5E Instructional Model

Codes	Description	Example View	Frequency
Finding a problem suitable for the outcome	Difficulty in identifying real-life situations that are suitable for both science and mathematics outcomes	"The challenging part was preparing the activity in a way that suits both the science outcome and mathematical modeling." (2.2)	9
Establishing interdisciplinary links (mathematics aspect)	Difficulty in establishing interdisciplinary connections between science and mathematics	"While preparing the problem suggestion, it was difficult to catch the connection of the topic with mathematics and establish an interdisciplinary transition." (3.4)	6
Lack of mathematical knowledge	Insufficient mathematical knowledge while preparing IMM problems	"It was difficult due to my inexperience in IMM activities and my lack of necessary mathematical knowledge." (1.3)	2
No difficulties	No challenges encountered	"Since we were familiar with it, I can't say I had difficulty." (1.1)	2

Since the pre-service teachers had previous experience in preparing lesson plans according to the 5E instructional model and believed that modeling problems are an effective tool for this model, when asked about the challenges they encountered in the integration process, it is observed that they primarily reported challenges related to the problem preparation process. The responses of the two participants who indicated they did not face any challenges in the process support this finding. For example, pre-service teacher 4.1's statement, "Since we are proficient in preparing lesson plans according to the 5E method, we didn't struggle much. We mostly struggled with preparing the modeling activity," indicates that, although not explicitly stated by other participants, they did not experience difficulties in integrating modeling problems into the process.

The challenge most pre-service teachers faced during the modeling problem preparation process was determining a problem situation that is both relevant to the topic or learning outcomes and solvable using mathematics (n=9). The following participant's comment is explanatory regarding this challenge:

"The part that challenged us the most during this process, in my opinion, was ensuring the mathematical model's suitability for the problem situation. Because even though we were familiar with the topic, initially, we couldn't find a modeling problem related to acids and bases. After a lot of effort, we eventually reached a common ground." (2.1)

When preparing the modeling problems, making the connection between science and mathematics was one of the challenges the pre-service teachers faced. They particularly stated that they had difficulty relating science topics to mathematics. For example, pre-service teacher 4.2 expressed this challenge as follows:

"The most challenging aspect for us during this process was balancing the problem situation from both scientific and mathematical perspectives. It might have been more dominant from the science perspective, but we made efforts to keep it balanced."

A different, but related challenge in interdisciplinary integration was the inability to make this connection due to a lack of mathematical knowledge. The following participant's comment illustrates this difficulty:

"We also struggled a bit with the mathematics part. The calculations were somewhat confusing." (4.3)

The findings show that pre-service teachers particularly faced difficulties during the modeling problem preparation process, but they did not experience any issues in integrating these problems into the 5E instructional model.

Discussion, Conclusion and Recommendations

The main objective of this study is to examine the suitability of IMM activities for the 5E instructional model based on the pre-service teachers' work and opinions. When the research findings are considered holistically, it can be said that the results both support and contribute to the existing literature. Previous studies in the literature that argue mathematical modeling is an effective tool for interdisciplinary integration (Zawojewski, 2016; Borromeo Ferri & Mousoulides, 2017; Doğan et al., 2018), as well as those examining the role of IMM activities, particularly in STEM education (e.g., Doğan et al., 2018; Şahin, et al., 2020), have had a triggering effect on the realization of this study. Furthermore, the compatibility of modeling activities with the structure of the 5E instructional model (Tezer & Cumhur, 2017) provided the theoretical framework. The findings support the notion that the theoretical framework of this study has a suitable foundation.

The lesson plans in which pre-service teachers integrated IMM activities into the 5E instructional model show that the integration process defined in the theoretical framework has been largely realized. According to the theoretical framework, the introductory article and preparatory questions of the IMM activities can be addressed in the Engagement phase, while the data and problem situation can be tackled in the Exploration phase. The reports containing the proposed solutions can be presented in the Explanation phase, allowing for an interactive teaching process between the teacher and the students. When examining the lesson plans, it was determined that all groups integrated the IMM activities into the 5E instructional model in a way that is consistent with this process. The theoretical framework also mentions that in the Elaboration phase of the 5E instructional model, the models created can be generalized into a form that is applicable to other situations. However, all groups concluded the IMM integration in the Explanation phase. The pre-service teachers' knowledge and experience with 5E model-based lesson planning may suggest that a different application should be made in the Elaboration phase. The fact that all lesson plans were structured in this way supports this inference. Furthermore, although not specified in the theoretical framework, IMM activities can also be applied in the Elaboration phase, depending on the characteristics of the activities and the teacher's objectives. By nature, IMM activities allow students to create models in which they test their knowledge, make observations, gain experience, and discover information (Şahin et al., 2020). In this regard, the Exploration phase of the 5E instructional model is thought to be most appropriate. However, the exploration process in modeling is not the same as the exploration process in the 5E instructional model. In this context, when examining other phases of the relevant lesson plan, it was found that the use of the Fossil Fuels vs. Solar Energy activity in the Exploration phase was not appropriate. Before moving to the problem situation in this activity, information on how acid rain forms is provided. The Engagement phase also includes a documentary and newspaper article detailing how acid rain forms, how it threatens life, and how to deal with its adverse effects. Therefore, while the problem story by itself may not cause issues and is even necessary, its use in the 5E instructional model led to redundancy. Consequently, it is suggested that moving the Acid Rain experiment from the Elaboration phase to the Exploration phase and integrating the Fossil Fuels vs. Solar Energy activity in the Exploration phase would be more applicable and effective in terms of lesson flow.

As stated in the literature, the reflection of the relationship between mathematics and science in practice is typically addressed within the scope of STEM education, with a stronger emphasis on the science dimension — these studies are generally conducted by science educators. In this process, rather than focusing on teaching mathematics, mathematics is often involved in a supporting role (English, 2015; Şahin et al., 2020; Every et al., 2025). In research where this relationship is carried out through mathematical modeling — these studies are typically conducted by mathematics educators — the planned teaching of both disciplines has been discussed (Güder & Gürbüz, 2018; Şahin et al., 2020). In this study, particularly for science teacher candidates, the aim was to contribute to a balanced relationship between mathematics and science by asking them to integrate the IMM activities they prepared into the 5E instructional model. Although the lesson plans were prepared according to science curriculum outcomes, it was observed that the teacher candidates also considered mathematics instruction. The views regarding the meaningful and lasting teaching of both disciplines, particularly based on mathematical thinking skills such as problem-solving and logical thinking, are significant in this regard. Additionally, the views on the affective contributions of IMM activities, such as valuing mathematics, understanding its role in real life, and making it enjoyable and engaging (n=11), support the idea of modeling being seen as a motivational tool for the teacher candidates (Stillman & Brown, 2011; Kang & Ellis, 2024). This result indicates that IMM activities are likely to increase science teacher candidates' motivation to integrate IMM activities into classroom practices. It should also be noted that while teacher candidates emphasize mathematics instruction in their views, they have limited content knowledge in mathematics education, and thus, this limitation prevented them from stepping outside the narrow framework in preparing lesson plans. Therefore, their thoughts do not entirely align with their practical applications.

The fact that teacher candidates generally emphasize the real-life aspect, which is a fundamental feature of mathematical modeling problems, and believe that IMM activities are highly effective in both science-real life and mathematics-science integration due to this feature, is evident (n=18). As Borromeo Ferri and Mousoulides (2017) also pointed out, the real-life basis of the problem situation in modeling is more related to science than mathematics, and this study clearly shows that teacher candidates are aware of this.

Two key outcomes of this study are that IMM activities are an effective tool for teaching mathematics and science in an integrated manner, and that the 5E instructional model is viewed as an effective teaching method for integrating these activities into the classroom. Teacher candidates highlighted that IMM activities and the 5E instructional model share common goals, such as facilitating teaching and supporting interdisciplinary instruction, as well as common features, such as including similar processes and being based on the same philosophical foundations. Beyond these convergences, the IMM–5E coupling appeared to foster higher-order thinking (via model formulation, shifts among representations, and validation), support problem solving as iterative mathematization across the 5E phases, and strengthen core modeling competencies (articulating assumptions, coordinating representations, and judging model adequacy). It is known that modeling activities share similar goals and features with STEM activities (Maass et al., 2019; Gravemeijer et al., 2017). This study has revealed that mathematical modeling activities with an interdisciplinary dimension share common structural features and goals with the core characteristics of the 5E instructional model, which is frequently used in STEM education. Although this finding supports the literature, it should not be overlooked that further experimental studies are needed in this area to validate this result. The fact that some participants (n=7) specifically referred to the exploration phase in their views on the alignment of IMM activities with the structure of the 5E instructional model is also considered a result that strengthens the validity of the theoretical framework of the study.

In this study, it was found that the responses given by the participants to the questions regarding the difficulties they encountered in the process of integrating IMM activities into the 5E instructional model did not fully reflect the actual process. The most common difficulties identified were finding a problem situation suitable for the learning outcome (n=9) and establishing interdisciplinary connections (n=6). It should be noted that these difficulties are related to the preparation process of IMM activities. As mentioned earlier, this study is part of a more comprehensive research that follows the pre-service teachers' views on the relationship between mathematics and science, their skills in preparing IMM activities, and their integration processes into the 5E instructional model. Therefore, it can be said that the difficulties expressed by the pre-service teachers are related to the activity preparation process, rather than the integration process itself. Although this is beyond the scope of the purpose of this study and is not discussed, it should be noted that important findings regarding the activity preparation process were obtained. Considering that the primary source of these difficulties is not science content knowledge per se but shortcomings in problem posing and interdisciplinary integration, this finding suggests that mathematics–science integration is not sufficiently embedded in teacher education. Indeed, many science teacher education programs at universities do not include courses on mathematics pedagogy or on linking mathematics and science. In line with a multidisciplinary perspective, incorporating such courses into teacher education curricula would likely be effective.

The pre-service science teachers' level of integration of IMM activities into the 5E instructional model and their positive views about this process demonstrate that when they possess the necessary disciplinary and pedagogical knowledge for interdisciplinary teaching, they are motivated to effectively use mathematics in science teaching. In learning environments focused on mathematical modeling, as in this study, the perceptions of pre-service science teachers about mathematical thinking have shown positive changes in other studies as well (e.g., Hıdıroğlu & Can, 2020). The necessity of providing pedagogical content knowledge education at the interdisciplinary level, particularly in the fields of mathematics and science, in teacher education programs is emphasized once again by this study (Frykholm & Glasson, 2005).

Ethics Statement

This study was approved by the Ethics Committee of Kilis 7 Aralık University (Approval Number: 2021/09; Date: April 7, 2021).

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