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Abstract: Mathematical modelling is an effective approach that helps students develop a deep understanding of mathematical concepts by connecting mathematics to real-life contexts and to other disciplines. Model Eliciting Activities (MEAs) are student-centred processes in which learners use modelling methods to solve complex real-world problems. This case study aimed to design interdisciplinary MEAs for pre-service teachers, to evaluate these activities according to modelling principles, and to examine participants' views after the implementation. The data consisted of the developed MEAs, video transcripts from the implementation process, and audio transcripts of semi-structured interviews. Content analysis, descriptive analysis, and rubric-based evaluation were used. The results showed that although the activities did not fully meet all modelling principles, they largely aligned with them and provided meaningful contributions to pre-service teachers' learning. Interview findings indicated that participants' initially general views became more specific over time, and that interdisciplinary modelling activities increased both motivation and classroom interaction.

Keywords: model eliciting activity; pre-service teacher; mathematical modelling; interdisciplinary approach; designing principles.

Introduction

In educational institutions, mathematics is often perceived as an abstract subject and there are difficulties in relating it to real life. However mathematical knowledge and skills are very much needed to make sense of and solve the problems encountered in daily life. In this context, mathematical modelling is a very effective teaching method to ensure the association of mathematics with real life and to alleviate the difficulties in association. With the implementation of activities involving mathematical modelling, daily life problems are transferred to the language of mathematics, making students aware of what mathematics does in real life and contributing to the development of students' mathematical knowledge and skills. Mathematical modelling is one of the most powerful components of the learning process, as it engages students in problem situations that they may encounter in their real lives or can imagine, thereby enabling the use and development of high-level cognitive skills (Borromeo Ferri, 2006; Lesh & Doerr, 2003; Stillman, Galbraith, Brown & Edwards, 2007).

Model-eliciting activities (MEAs) are designed to present problem situations, grounded in specific instructional principles, situated in real-world or hypothetical contexts, through which students are encouraged to develop and articulate mathematical models (Kaiser & Sriraman, 2006; Lesh & Yoon, 2004). Lesh and Doerr (2003) state that MEA was initially conceptualized by mathematics education researchers to enable students to reveal their modelling skills and to enable students to gain expertise in problem solving. Since its conceptualization, model eliciting activities have become a tool that can be used by teachers and students to help them develop their own competencies.

Furthermore, because mathematical modelling addresses real-life or hypothetical situations, it naturally connects with multiple disciplines (Borromeo Ferri & Mousoulides, 2017; English, 2017). Its use in teaching therefore supports the development of interdisciplinary learning environments by bringing together different fields of knowledge and fostering connections among them. Through this integration, students can approach topics or problems from multiple perspectives and develop deeper understanding by combining diverse knowledge and skills. Such learning environments encourage creative thinking and make learning more holistic and meaningful. In this respect, interdisciplinary teaching is closely aligned with the integration of STEM fields (Science, Technology, Engineering, and Mathematics), which frequently interact to address real-world problems. Many researchers emphasize that mathematical modelling serves as an effective tool for supporting interdisciplinary approaches such as STEM education (Banks & Barlex, 2014; Doğan et al., 2018; English, 2017; Kertil & Gürel, 2016). Accordingly, for both interdisciplinary teaching and mathematical modelling—key components of mathematics education—to be implemented effectively in schools, it is essential that pre-service teachers develop the necessary competencies.

It is known that interdisciplinary teaching approach and mathematical modelling skills have a critical importance in today's education systems. Therefore, pre-service teachers need to have the necessary knowledge and skills to implement effective teaching strategies in these areas. Since current teacher education programs do not focus enough on these requirements, pre-service teachers' acquisition of skills such as solving real-world problems, developing interdisciplinary approaches, and mathematical modelling is often lacking. This study aims to address these deficiencies among pre-service middle school mathematics teachers and to equip them with the competencies required by the interdisciplinary modelling approach. In order for pre-service teachers to be prepared for the problems they will face in their professional lives and to effectively teach these skills to their students, it is very important that they are introduced to this teaching method and mathematical modelling from the beginning of their education process. One of the main objectives of this study is to contribute to the development of these competencies by pre-service teachers and to have a positive impact on both their professional development and the education of their future students.

Unlike traditional educational approaches, interdisciplinary teaching approach and mathematical modelling emphasize students' active participation and problem-solving skills. Therefore, for pre-service teachers to apply these methods effectively, they need to receive a comprehensive education in these areas. This study aims to create a model to guide pre-service teachers on interdisciplinary teaching and mathematical modelling in existing teacher education programs. This model will both contribute to the improvement of educational processes and help pre-service teachers better understand how to use these methods in the classroom. In this context, the research problem was defined as follows: "What are the characteristics of modelling activities designed by pre-service teachers using the interdisciplinary teaching approach?" Accordingly, the following sub-questions have been investigated:

Q1 What is the compatibility of the model eliciting activities created with the interdisciplinary teaching approach with the MEA design principles?
Q2 How do pre-service teachers' views on STEM and MEA differ as a result of the implementation of model eliciting activities created with the interdisciplinary teaching approach?

Related Work

Research on the interdisciplinary teaching approach and mathematical modelling reveals that the combination of these two methods in education is very effective in improving the skills of students and teachers. Baker and Galanti (2017)'s study showed that mathematical modelling activities within the scope of interdisciplinary teaching contribute to teachers' professional development and that such activities make teachers' classroom practices more effective. Teachers' experience in interdisciplinary modelling processes strengthens both their teaching skills and students' problem solving and analytical thinking skills.

The positive effects of mathematical modelling activities on students' attitudes towards mathematics are also among the remarkable findings. Maiorca (2016)'s study showed that interdisciplinary modelling activities increased students' interest in learning mathematics and positively affected their motivation towards mathematical concepts. It was observed that interdisciplinary modelling activities not only provide students with mathematical skills but also improve their ability to relate to other disciplines.

Studies conducted with teachers and students indicate that the interdisciplinary teaching approach increases students' achievement. Güder and Gürbüz (2018)'s study revealed that interdisciplinary modelling activities improve students' interdisciplinary connection and analytical thinking skills. It was determined that both teachers and students learned more in-depth learning by making connections between different disciplines through interdisciplinary modelling activities. Teachers stated that students' problem-solving skills were strengthened in this process and that interdisciplinary learning led to positive results.

It is emphasized that interdisciplinary modelling activities increase students' critical and systematic thinking skills and lead them to find solutions to real-world problems. In Suh and Han (2019)'s study, it was shown that students developed more in-depth solutions to social problems through interdisciplinary modelling projects. Interdisciplinary teaching enables students to look at complex problems from different perspectives and in this context, it allows students to combine their theoretical knowledge with practical applications.

In general, interdisciplinary teaching and mathematical modelling activities have an important place in educational processes and develop students' skills in multiple ways. These approaches reinforce students' problem solving, analytical thinking and interdisciplinary connections skills, and encourage them to develop more effective solutions to real-world problems.

Methodology

Research Design

This application was planned as a case study. Case studies are a qualitative approach in which the researcher examines a current event in a specific period in detail and comprehensively using various data collection tools, defines the situation or reveals themes related to the situation (Creswell, 2013).

The reason for choosing a case study in this study is the desire to conduct an in-depth and comprehensive investigation in accordance with the purpose of the study. The case study design is an ideal method to understand and evaluate the effects of mathematical modelling activities designed by pre-service middle school mathematics teachers with an interdisciplinary teaching approach. The case study allows us to analyse the effects and outcomes of the practice in depth by examining events and processes in detail in a real-life context. This approach offers flexibility to collect and analyse qualitative data such as classroom observations, student evaluations and interviews, allowing us to determine the extent to which the teaching activities were effective. It also provides valuable insights for future practice by identifying strengths and areas for improvement that emerged during the implementation process. Therefore, the case study method is the most appropriate option for achieving the objectives of our study and providing in-depth information.

Participants

In this study, participants were selected through purposive sampling, which is one of the non-probability sampling methods for the determined purpose. The study group consists of eight pre-service middle school teachers who were enrolled in the third year of their university program during the spring semester of the 2021–2022 academic year at the university where the researcher is employed. These participants are preparing to qualify to teach at the middle school level upon graduation. Since the modelling course is at the 3rd grade level, pre-service teachers from this grade level were selected. Pre-service teachers' participation in the study was voluntary. Only students who could ensure continuity in the study process were asked to participate in the study. The most important characteristic of the participants was determined as the willingness of the participants to design and implement teaching practices for the purpose determined during the study process. Within the scope of the study, a session was organized in which pre-service teachers were trained about the interdisciplinary teaching approach and modelling activities.

The pre-service teachers who participated in the study were coded as T1, T2, ..., T8 and their names were not included in the study. The participants were asked to form groups of 2 people and give names to their groups. Tab. 1. shows the demographic information of the pre-service teachers and the names of the groups they formed.

Student Code	Group Name	Gender
T1	MATHTIB	Woman
T2	MATHTIB	Woman
T3	Environmental Engineers	Male
T4	Environmental Engineers	Male
T5	Turtles	Woman
T6	Turtles	Woman
T7	Foxes	Woman
T8	Foxes	Woman

Table 1: Names and demographic information of pre-service teachers' groups

Research Instrument

In this study, semi-structured pre and post interviews, audio recordings, video recordings and activities designed by the pre-service teachers were used as data collection tools. During the activity process, audio recordings were taken by placing audio recorders separately in each group (3 in total), and the groups were placed in the classroom as far away from each other as possible so that the voices would not interfere with each other. In qualitative research, it is very important that the data collected with data sources are as rich as the variety of data collection tools (Temurtaş & Gürbüz, 2023). For this purpose, all practices were video, and audio recorded to prevent any data loss during the research process. In order to analyse the recorded data, they were transcribed and written down and strengthen the accuracy of the transcripts and to make the analysis correctly, the audio recordings and videos were reviewed by another expert, and the transcript data were reviewed. The majority of the study consisted of transcripts of video and audio recordings recorded during the practices. In addition, the permission of each participant was obtained for video and audio recording before starting the study. The activities designed by the pre-service teachers were asked to be as original as possible, but if there were activities that they benefited from, they were asked to give references.

The implementation process and data collection were carried out face-to-face at the school and outside of class time in line with the consent forms obtained from the students and the permissions obtained from the university ethics committee. Each student was asked to participate in the application with a group of 2 people. At the same time, these activities should be interdisciplinary and should be planned according to the MEA steps, so the activity named "Global Warming" (Gürbüz & Doğan, 2019) was applied by the researcher as an example to clarify students' minds about the application before starting the teaching practice process. Students were asked to send their designs to the researcher before the implementation and to be checked by the researcher. During the teaching practice, each participant was asked to think aloud while solving the activity, to discuss the solution with his/her groupmate, and the discussions were audio recorded. They were also asked to show the solutions on the activity sheets provided.

The pre-service teachers were asked to design with their own ideas as much as possible, which may be similar to the studies, but not exactly the same. In addition, it was reported that since they will teach mathematics at the middle school level in their future professional lives, the MEA activities created with the interdisciplinary teaching approach they designed in accordance with their field knowledge should be at a level that can be applied to middle school students.

Reliability and Validity

In qualitative research, the concept of trustworthiness is used instead of validity and reliability. The accuracy of qualitative research can be ensured within the framework of four factors: credibility, transferability, consistency and confirmability (Lincoln & Guba, 1985). What was done to ensure validity and reliability in this study is briefly explained below.

Credibility is related to the extent to which the findings of the study are compatible with reality. In order for the study to be credible, individuals' thinking processes and observed events should be conveyed as accurately as possible (Miles & Huberman, 1994). In this study, long-term interaction, continuous observation, triangulation, use of tactics that support participant honesty, short interval meetings, expert opinion and detailed description of the phenomenon were used to increase credibility (Arastaman, Fidan & Fidan, 2018).

Transferability is related to the generalizability of qualitative research results. The generalizability of qualitative research is associated with the extent to which the findings obtained from the context of the research can be applied to other researches in a similar context by preserving their meaning and inferences. (Merriam, 2009; Miles & Huberman, 1994). For this reason, in this study, clear and comprehensive explanations were provided about the research questions, purpose of the research, participant characteristics, data collection tools, data collection process, data analysis, implementation process of the activities, stages of the teaching practice, and student opinions. Consistency is related to the extent to which the meanings that the participants want to express are reflected in the findings of the research. It is important to use objective tools in qualitative research to increase consistency (Arslan, 2022). Therefore, the audio and video recordings taken during the teaching implementation process were evaluated together with the participants' worksheets and the consistency between them was examined. Verifiability is related to the degree to which the data obtained as a result of the research reflects reality and the researcher presents the data in a way that is free from a subjective approach. To ensure the reliability and transparency of the findings, the study's structure and data analysis process were clearly documented, ensuring that the results were derived directly from the participants' experiences rather than the researchers' personal influences. In this context, expert opinions were sought during the analysis phase. Furthermore, to maintain objectivity, all data collection sessions were video, and audio recorded with the participants' explicit permission and stored for verification.

Data Analyses

This study focused on the development, micro-teaching implementation, and evaluation of interdisciplinary Model Eliciting Activities (MEAs) by pre-service mathematics teachers. The resulting data were analysed through content analysis, descriptive analysis, and rubric evaluation based on model-building principles. Video recordings of the application processes and audio recordings of the students' solution processes were transcribed at the end of the application. Category and code lists were created for content analysis of the data obtained. In addition, the pre- and post-interviews conducted with the pre-service teachers were transcribed and organised into predetermined categories. Selected statements were included in the findings section as direct quotations, accompanied by interpretive comments related to the pre- and post-interviews. The interview questions and responses were originally collected in Turkish and were translated into English for analysis and reporting purposes.

Activities designed in the context of the MEA need to have certain principles. These principles ensure that each MEA carries the desired curriculum and learning characteristics. In this study, each MEA designed by the students was examined within the framework of the principles of reality, model building, self-evaluation, documenting the structure, effective prototype, and model generalization in line with the indicators in Tab. 2.

Categories	Indicators
Reality principle	-Selecting a problem that can be encountered in real life -The problem is meaningful for everyone -The problem meets a need arising from real life
Model building principle	-The problem situation requires the creation of a model -The problem situation is suitable for creating a model
Principle of self-assessment	-Be able to evaluate own solutions -To be able to evaluate independently from the teacher -Be able to recognize whether they have successfully completed the solution without any confirmation
Principle of documenting the structure	-Effective presentation of the models created -The models created are clear and understandable
Principle of effective prototyping (Simplicity)	-The activity is simple and clear enough for all students to understand
Model generalization principle	-The developed model can be easily adapted for other situations -Reusability of the developed model

Table 2: MEA principles and indicators

Based on the categories and indicators presented above, a single analytic rubric was developed by the researcher. The categories (reality principle, model building, self-assessment, documenting the structure, effective prototyping, and model generalization) were derived from the relevant literature on Model-Eliciting Activities, while the rubric itself was constructed by the researcher in alignment with these theoretical principles. The rubric is presented in Tab. 3.

The rubric consisted of three performance levels ("Fully Meets," "Partially Meets," and "Does Not Meet") and was used to evaluate the instructional methods designed by the pre-service teachers during their teaching practice. In this context, the rubric served both as an evaluation tool used during teaching practice and as a data source for the research analysis.

Scores obtained from the rubric were used to systematically examine the extent to which the instructional methods reflected the principles of model-eliciting activities. Thus, the rubric functioned not only as a formative assessment instrument within the teaching practice but also as a framework ensuring consistency and transparency in the research analysis.

	Fully Meets	Partially Meets	Does Not Meet
Reality			
Model creation			
Self-assessment			
Documenting the structure			
Effective Prototype (Simplicity)			
Model generalization			

Table 3: Evaluation of activity according to MEA principles using an analytic rubric

Findings

Findings Related the First Sub-Problem

The first sub-problem of the study was determined as "What is the conformity of the model eliciting activities created with the interdisciplinary teaching approach to the MEA design principles?". For this purpose, the activities in question were examined on the basis of the design principles of model eliciting activities in the literature and the conformity of the

activities with the principles was evaluated as fully meets, partially meets and does not meet. The reality principle refers to the selection of problems that can be encountered in real life, are meaningful and correspond to a need. The principle of model building implies that the selected problems require building a model and are appropriate for this situation. The principle of self-evaluation involves students being able to independently evaluate their solutions and recognize whether the solution is successful or not without the need for a teacher. The principle of documenting the structure is about presenting the models created in a clear, understandable and effective way. The principle of effective prototyping explains that activities should be simple and clear enough to be understood by all students. Finally, the principle of model generalization refers to ensuring that the model developed is easily adaptable and reusable in different situations.

In the ramp construction activity, the aim was to design an accessible ramp for the entrance of a building located in a designated area. The ramp was required to accommodate not only individuals with disabilities but also other user groups such as older adults and families with children. Pre-service teachers were asked to design a ramp that had a non-slip surface, was easy to use, had a maximum slope of 5%, and a minimum width of 100 cm. The designs were developed in accordance with these criteria. When the suitability of the reality principle is examined, it is clearly seen that this designed problem situation is a problem that is appropriate to reality and can be encountered in real life. In other words, it answers "yes" to the question "can this activity be encountered by students in real life?" (Lesh & Caylor, 2007). Students started the activity with the idea of helping people they might encounter in their real lives. When the existence of the principle of model building is investigated, it is necessary for the pre-service teachers to design a ramp using mathematical models and to show the properties of the ramps they designed. In this context, the problem situation requires students to make a design instead of producing a word or a number as a product. For this reason, it is considered as providing the principle of model building. According to another principle, the principle of self-evaluation, the problem situation examines the extent to which students can decide the validity of the solutions they have developed by discussing them with their groupmates, in this context, the conversations between them while solving the MATHTİB ramp construction activity were analysed. The students discussed whether the calculations they made had a real-life equivalent and then evaluated the closeness of the drawing they made and the values they found to the normal and decided that their models were good without teacher approval. From this point of view, it is thought that the ramp construction activity provided the principle of self-evaluation. In case of a problem, the students were asked to help the engineers with the ramps they would propose, but they were not asked to prepare any report, so each group showed their ramp designs only by drawing and did not put their thinking stages in writing. In this respect, the activity partially fulfils the principle of documenting the construct. The drawings of the two groups showing how they solved the problem are given as Fig. 1. as examples of how this principle was evaluated.

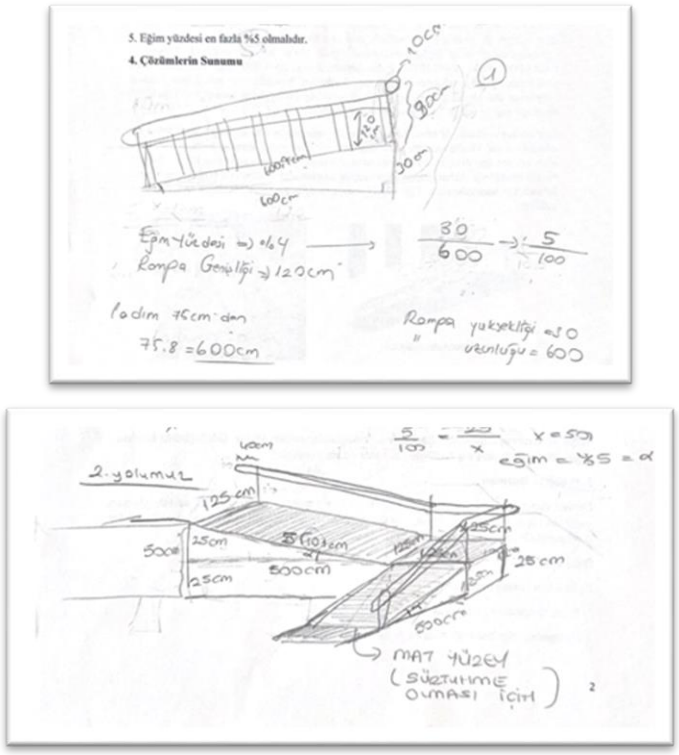

Figure 1: Solution sheet of two groups for the ramp construction activity

When the existence of the effective prototype principle in the activity is evaluated, it is sought that the activity should be simple and clear enough for all students to understand in order for this principle to exist. Because Lesh and Caylor (2007) stated that students should think in the same way when they encounter a similar problem even months later. However, in this study, it was not possible to analyse students' thoughts months later. Therefore, the existence of this principle was analysed only with the criterion that the activity was clearly understood by all students. Although the problem situation of the ramp construction activity was generally expressed clearly and comprehensibly, one of the features to be considered was "There should be railings on the sides of the ramps, and these railings should be at least 70 and 90 cm and at most 100 cm." Since this feature created confusion among the students, it was evaluated as partially fulfilling the principle of effective prototype. Finally, during the activity, no situation was encountered to generalize the model created. In this case, it can be said that the principle of generalization of the model was not met.

	Fully Meets	Partially Meets	Does Not Meet
Reality	X		
Model creation	X		
Self-assessment	X		
Documenting the structure		X	
Effective Prototype (Simplicity)		X	
Model generalization			X

Table 4: Evaluation of the ramp construction activity according to MEA principles

The other activity is "I am designing a birdhouse". In the problem context of this activity, students were asked to design a birdhouse by taking the specified criteria into account. Within this framework, students were expected to design a birdhouse suitable for forested or green areas in their local environment and to base their designs on the dimensions of a bird species that is rarely observed in the region. To prevent birds from being harmed during entry and to provide a natural appearance, the design criteria included a circular entrance, the inclusion of a thin, cylindrical perch to allow birds to perch comfortably, and the placement of the birdhouse at an appropriate height to ensure protection from potential dangers. In addition, students were required to select materials that are durable under adverse weather conditions.

Since birdhouses are objects that students can encounter or envision in their real lives, the activity "I am designing a birdhouse" was evaluated as providing the reality principle. When the existence of the principle of model building is examined, in the given problem situation, students need to design a birdhouse by making mathematical inferences and calculations to be suitable for the estimated volumes of the birds they choose. When the solution papers of the students were analysed, the groups researched the approximate measurements of the bird they chose from the internet and made plans accordingly. They also included many details reflecting the thinking steps in their drawings. For this reason, the activity "I am designing a birdhouse" was evaluated as providing the principle of model building. When the existence of the principle of self-evaluation was investigated, when the audio recording transcripts of the student solutions were examined, the environmental engineers group decided to finish the solution after examining whether there was anything else to do with their groupmate, the turtles group asked for support from the teacher about the material to be used for the birdhouse, and the MATHTIB group felt the need to ask the teacher several times during the solution phase. For this reason, when considered in general, the activity "I am designing a birdhouse" was evaluated as partially fulfilling the principle of self-evaluation. Students were asked to design a birdhouse by considering the features given in the problem situation. When the solution papers of the students were analysed, it was observed that the groups presented their designs and calculations in detail. For this reason, the birdhouse activity was evaluated as meeting the principle of documenting the structure. The solution papers of MATHTIB and the turtles' group are given below.

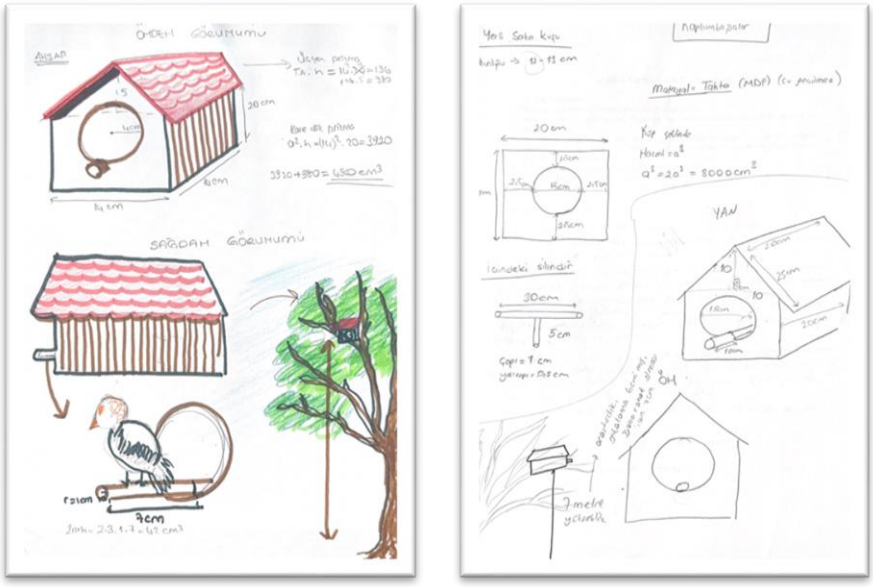

Figure 2: Solution sheets of two groups for the I design a birdhouse activity

The problem situation of the activity "I am designing a birdhouse" is clear and understandable. When the students' in-group conversations were analyzed, it was observed that they had no difficulty in understanding the problem statement of the activity. For this reason, I am designing a birdhouse activity was evaluated as providing the principle of effective prototype. Since the activity did not create the need to generalize the models created by the students for similar situations, I am designing a birdhouse activity was evaluated as not providing the principle of model generalization.

	Fully Meets	Partially Meets	Does Not Meet
Reality	X		
Model creation	X		
Self-assessment		X	
Documenting the structure	X		
Effective Prototype (Simplicity)	X		
Model generalization			X

Table 5: Evaluation of I design a birdhouse activity according to MEA principles

Findings Related the Second Sub-Problem

The second sub-problem of the study is "How do pre-service teachers' views on STEM and MEA differ as a result of the implementation of model eliciting activities created with the interdisciplinary teaching approach?". In the analysis of this question, semi-structured interviews conducted with pre and post interview questions with pre-service teachers were examined, and thematic analysis method was used. It is thought that the applied thematic analysis provides valuable information to understand how modelling activities created with the interdisciplinary teaching approach can be used more effectively in education and to develop teaching strategies. Through such analyses, educators can monitor the development of students' learning processes in detail and adapt their teaching methods accordingly.

When the data obtained from the pre and post interviews were analysed, the themes given in Tab. 5. emerged. As examples of these themes, some of the pre-service teachers' answers are given as quotations. In addition, holistic inferences and interpretations obtained by analysing the responses of the pre-service teachers are also included in the Tab. 6.

Theme	Initial Interview Excerpts	Final Interview Quotes	Inference/Comment
STEM Education	S5: "I heard the abbreviations STEM and STEM for the first time in a lecture of one of our professors at the university. I know that STEM is a way of teaching that is presented more through modelling, that is, by making connections with daily life." S6: "Yes, I heard the concept of STEM at school."	S5: "STEM education approach, as I said, is teaching these disciplines by intertwining them with each other. I think it benefits students a lot." S6: "STEM is a word formed by combining the initials of science, technology, mathematics and engineering in English."	Students' understanding of STEM education has expanded over time and has developed as an educational approach that includes science, technology, engineering and mathematics disciplines and where these disciplines are taught interactively.
Interdisciplinary Relationship	S8: Many subjects in mathematics constitute the infrastructure of science. For example, a subject seen in sixth grade science may appear in mathematics later."	S8: "When we design anything, for example, when designing a birdhouse, the dimensions, proportions, the size of the bird in the fan, mathematical calculations need to be made. All of these come out by associating them."	Students' awareness of interdisciplinary connections and depth of knowledge increased.
Modelling and Problem Solving	S3: "I thought mathematical modelling and concrete materials were the same thing, but in the lessons, I have seen recently, I realized that modelling is different from concrete materials."	S3: Mathematical modelling, being able to mathematically express a mathematical situation or problem that we encounter in real life."	Students' understanding of mathematical modelling has become deeper and more applicable.
The Impact of Model Eliciting Activities Created with Interdisciplinary Approach on Education	S8: "The aim of model eliciting activities is to make the individual establish a relationship with daily life and to reach a solution by using mathematical language with the relationships they establish."	S8: "In model eliciting activities, there is usually more than one solution alternative. And students have a choice. They can shape and produce solutions according to their own situations with their own logic."	Students' understanding of the impact of modelling activities on education became deeper and more applicable.

Table 6: Thematic analysis of the data obtained from pre and post interviews

As seen in Tab. 6. pre-service teachers' understanding of STEM education expanded at the end of the implementation and developed as an educational approach that includes science, technology, engineering and mathematics disciplines and where these disciplines are taught interactively. The pre-service teachers, who initially stated that they had only heard of the concept of STEM, better explained how STEM disciplines were integrated and their effects on students in the final interviews. Pre-service teachers' awareness and depth of knowledge about interdisciplinary connections increased. Pre-service teachers, who initially stated that disciplines such as science and mathematics can be related, explained in more detail how these disciplines are intertwined and how they are related to practical applications

in the last interviews. The pre-service teachers' understanding of mathematical modelling became more in-depth and applicable. In the pre-interviews, the pre-service teachers provided a general definition of mathematical modelling, but in the post-interviews, they expressed more clearly the applications of modelling in daily life and how it is used in problem solving processes. The pre-service teachers' understanding of the impact of modelling activities on education deepened. The students, who initially stated that modelling activities concretize abstract concepts, emphasized in the last interviews that these activities improve students' thinking skills and offer more than one solution alternative.

In general, it is seen that pre-service teachers' understanding of STEM education, interdisciplinary association, mathematical modelling and the impact of model eliciting activities created with an interdisciplinary approach on education has deepened and developed over time. While more general statements were used in the preliminary interviews, more detailed and specific explanations were made in the final interviews. In addition, it is understood that modelling activities created with an interdisciplinary approach are effective in increasing student motivation and interaction. In addition, model eliciting activities created with an interdisciplinary approach offer students a more enjoyable learning experience.

Discussion

When the design principles of the model eliciting activities are examined in general, the principles of reality and model eliciting are provided, while the principles of self-evaluation, documenting the structure and effective prototype are provided in one activity and partially provided in the other activity. The principle of model generalization was evaluated as not being met for both activities. In another study conducted by Yu and Chang (20011), the researchers examined the MEA designs prepared by four groups of middle school teachers. In the study, four activities prepared by the teachers were evaluated according to the principles of MEA design. Similar to the findings of this study, the researchers concluded that all the activities complied with the principles of reality and modelling but did not fully comply with the other four principles. The reasons why the MEA designs did not comply with the principles of self-evaluation, documenting the structure, model generalization and effective prototype (simplicity) may be due to various factors. For example, students' difficulty in clearly documenting their problem-solving processes, lack of sufficient guidance on how to generalize models to different situations and contexts, the complexity of the prototype development process, and teachers' lack of adequate training on these principles are among the factors that cause this situation. In addition, teachers' shortcomings in planning or implementing activities may also negatively affect the conformity of designs to these principles. These situations are the main factors that make it difficult for MEA designs to comply with certain principles.

In the context of the second research question, the findings obtained from the semi-structured pre- and post-interviews are presented within the themes. Within the framework of the theme STEM education, pre-service teachers were asked questions such as "Have you heard the abbreviations STEM before?", "If yes; where did you hear it?", "Can you explain what it means?", "Can you explain your thoughts about the STEM education approach?". When the findings were analysed, most of the pre-service teachers stated that they had heard the acronym STEM in the preliminary interviews but could not explain exactly what it meant. In the final interviews, each pre-service teacher was able to explain what the concept of STEM is. From this point of view, with this study, it was observed that pre-service teachers' understanding of STEM education expanded over time and developed as an educational approach that includes science, technology, engineering and mathematics disciplines and that

these disciplines are taught interactively. Similar to this result, Weinberg et al. (2021) stated in their study that pre-service teachers initially had a limited understanding of STEM concepts, but their understanding increased significantly through training and practical experiences.

Within the framework of the theme of interdisciplinary relations, pre-service teachers were asked questions such as "Do you think technology, science, engineering and mathematics disciplines can be related to each other?", "If yes, how can this relationship be?", "Can science, technology, engineering and mathematics disciplines take place in education in relation to each other?", "How can they take place?", "What can be the positive and negative aspects of being related in this way?". When the findings obtained were analysed, it was seen that while the pre-service teachers gave examples of more general relationships between disciplines in the preliminary interviews, they gave more detailed explanations by giving examples from the activities carried out during the study in the final interviews. For this reason, it is thought that pre-service teachers' awareness and depth of knowledge about interdisciplinary connections increased. Similar to this result, Gainsburg (2013) stated in his study that the most inclusive activities in interdisciplinary connections are MEAS.

Within the framework of the modelling and problem-solving theme, pre-service teachers were asked questions such as "Have you heard of the concept of mathematical modelling before?", "If yes, can you explain it?", "If no, what do you think mathematical modelling can be and where can it be used?". When the findings obtained were examined, it was seen that pre-service teachers' understanding of mathematical modelling became more in-depth and applicable. In the pre-interviews, the pre-service teachers made a general definition of mathematical modelling, but in the post-interviews, they expressed more clearly the applications of modelling in daily life and how it is used in problem solving processes. Similar to this result, Zbiek et al. (2024) found that pre-service teachers had general knowledge about mathematical modelling at the beginning of the study, but during the training process, they better understood the concept of mathematical modelling and expressed its applications in daily life more clearly.

Within the framework of the theme of the impact of model eliciting activities created with an interdisciplinary approach on education, pre-service teachers were asked questions such as "Do you think model eliciting activities can be designed to cover STEM disciplines?" and "What are the positive and negative aspects of this situation?". When the findings obtained were analysed, the pre-service teachers stated in the pre-interviews that they thought that MEA could be applied in a way to cover STEM disciplines, but they thought that it could be challenging and confusing because they had not experienced this kind of activity before. In the last interviews, most of the pre-service teachers stated that model eliciting activities include STEM disciplines due to their structure and stated that such an application can be done. As a result, when the answers of the pre-service teachers are evaluated, it is observed that students' understanding of the impact of modelling activities on education has become deeper and more applicable. Like this result, O'Dwyer et al. (2023) concluded in their study that with the practical experience of STEM-based modelling activities, pre-service teachers' ability to teach STEM disciplines in a unifying way increased.

In addition, in the final interview, the pre-service teachers were also asked questions such as "What did our activity process bring you?", "Is there anything you think would be better if we did this during the activity?", "Which activity did you like more? Why?", "Is there anything you want to add?" were also asked. In this context, the pre-service teachers stated that the information they learned and the experiences they gained through the activity process helped them better understand the concepts of STEM and modelling. The pre-service teachers suggested some improvements such as, increasing the number of groups could

diversify the solution methods and reveal variety to be seen. Most of the pre-service teachers stated that the activity process was very productive for them and they were generally satisfied with the activities, that the activity process provided them with in-depth knowledge about STEM and modelling, and that they had the opportunity to experience this knowledge in practice and learned a lot.

Conclusion and Future Work

As a result, the difficulty of applying all principles together in modelling activities is accepted by many researchers. However, it is stated that missing one or more of the design principles does not mean that the activities are unsuccessful (Carlson, Lersen, & Lesh, 2003; Paolucci & Wessels, 2017). Within the scope of this study, although not all the principles were fully met, it was concluded that the principles were met to a significant extent and thus activities that could be useful for pre-service teachers were designed.

The general findings of the study show that pre-service teachers' understanding of STEM education, interdisciplinary connections, and mathematical modelling deepened and developed throughout the process. The pre-service teachers, who addressed the topic with more general statements at the beginning of the research, made more specific and detailed evaluations as the process progressed. This supports that modelling activities contribute to a deep and integrated understanding of mathematical content and practices necessary for STEM disciplines, as stated in Lehrer and Schauble (2015)’s study.

In addition, it was observed that modelling activities designed with an interdisciplinary approach were effective in increasing pre-service teachers' motivation and in-class interactions. Such activities provide a more engaging and fun learning environment for pre-service teachers, increasing their interest in learning and providing a positive learning experience.

Based on the results of our study, we offer the following recommendations. In this study, it was concluded that some design principles were not fully met in the activities designed by pre-service teachers. In order to provide the design principles that do not fully meet the criteria, renewing the activities by focusing on these principles and taking into account the results obtained can ensure the production of model eliciting activities created with a better-quality interdisciplinary approach.

In recent years, mathematical modelling has been taught as a course in universities. Within the scope of these courses, pre-service teachers' gaining experience in the use of mathematical modelling method can contribute to their more effective use of mathematical modelling in their professional lives.

Although there are many emphases on the importance of STEM education, MEAs can be used as a tool in the transition to interdisciplinary education in our country, where there are limited studies on the implementation of the STEM education approach.

Ethics Committee Decision

Ethics committee permission for this research was obtained from Istanbul Medipol University Social Sciences Ethics Committee on 13.04.2022

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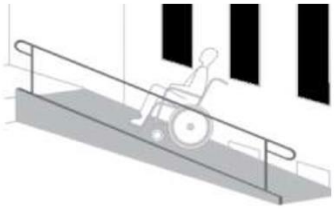
Appendix 1 – Ramp Construction Activity

RAMPA YAPIMI

1. Tanıtıcı Makale

Fiziksel, ruhsal, zihinsel ve duyusal yetilerinde çeşitli düzeyde kayıplarından dolayı topluma diğer bireyler ile birlikte eşit koşullarda tam ve etkin katılımını kısıtlayan tutum ve çevre koşullarından etkilenen kişiler günümüzde engelli olarak adlandırılmaktadır. Türkiye'de 1.414.643'ü erkek, 1.097.307'si kadın olmak üzere 2.511.950 kişi engellidir. Özel gereksinimleri karşılandığında ve ihtiyaç duydukları hizmetler ve eşit erişim hakkını hedefleyen düzenlemeler sunulduğunda, toplumsal yaşama uyumları artacak ve "engellilik" durumu, "engellenmişlik" durumuna dönüşmeyecektir.

Farz edelim okulumuzda tekerlekli sandalye ile yaşamına devam etmek zorunda kalan bir arkadaşınız var. Okulunuzun girişinde merdiven var ama engelli rampası bulunmuyor. Okul idaresi bunun önemli bir eksiklik olduğunu ve çözüm geliştirilmesi gerektiğine karar vermiştir. Sizden istediğimiz okulun girişine eğim rampası tasarlamanız ve bu alanın 1/10 oranında planı ile maketini hazırlamanızdır. Eğer yapabilirseniz modelin gerçeğini tasarlayıp kullanılır hale getiriniz.



ENGELLİ RAMPASI GENİŞLİĞİ

2. Hazır Oluş Soruları

a) Dik yokuşlara çıkarken bazı zamanlarda zorlanabilmekteyiz. Sizce bunun sebebi ne olabilir?

b) Şehirlerarası seyahatlerde eğimi gösteren tabelalara rastlamaktayız. Gördüğümüz tabelanın değeri de %10 olsun. Peki bu değer nasıl elde edilmiş olabilir?

3. Problem Durumu

Denizli'de yeni yapılan bina girişine engelli rampası yapılması isteniyor. Bina sakinleri hemen yapılması için talepte bulunuyor. Çünkü binanın içinde engelli, yaşlı ve çocuklu aileler bulunmaktadır. Sizin önereceğiniz rampa ile mühendislere yardımınız bekleniyor.

Buna göre;

Rampa için aranan özellikler:

1. Eğim rampasının zemini kaygan olmamalı.

2. Rampadan çıkarken zorlanılmamalı, rahatlıkla çıkılmalıdır.

3. Rampaların kenarlarında bulunan korkuluklar olmalı ve bu korkuluklar en az 70 ve 90 cm en fazla 100 cm olmalıdır.

4. Rampanın genişliği en az 100 cm olmalıdır.

5. Eğim yüzdesi en fazla %5 olmalıdır.

4. Çözümlerin Sunumu

Appendix 2 - Desing a Birdhouse Activity

Kuş Yuvası Tasarlıyorum

1. Tanıtıcı Makale

Dünyada ortalama 11.000 kuş türü, Türkiye'de 456 farklı tür, İstanbul'da ise 224 tür kuş bulunmaktadır. Mevsime göre kuş çeşitliliğinde değişimler olsa da paylaşılan ortalama değerler standarda göre kuş çeşitliliği konusunda ülkemizin zengin olduğunu ortaya koymaktadır.

Hızlı kentleşmenin etkisiyle kuşların ekosistemi daralmış ve tür çeşitliliği hakkında ciddi endişeler hayat bulmuştur. Bu yüzden ilgili olan gönüllüler ve bilinçli kimseler tarafından yapılan araştırmalarla problem analizleri yapılmaya başlanmıştır. Bu problemlerden en ciddi olanı barınmadır.

Gönüllülük projeleri ve belediye çalışmaları kapsamında kuş evleri yapılıp sokaklara yerleştirilerek barınma sorununa çözüm getirilmeye çalışılmıştır. Bu yapılan kuş evlerinin tasarımlarında kuş çeşitlerinin boyları göz önünde bulundurulur. Kuş evlerinin yerden yüksekliği de önemli faktörlerden birisidir. Çünkü kuş evlerinde konaklayan kuşlar için meraklı davetsiz misafirler bir tehdit unsuru olabilir. Kuş evinin giriş kısmının rüzgâr akımına ters yönde olması gerekir gibi birçok parametre göz önünde bulundurulmalıdır.

2. Hazır oluş soruları

- Aranızdan kaç kişi uyandığı zaman kuş seslerini duyabiliyor?
- Evden okula giderken kaç farklı kuş sesiyle karşılaşıyorsunuz, hiç dikkat ettiniz mi?
- Daha önce "Kuş Gözlemciliği" diye bir şey duydunuz mu?
- Bir kuş gördüğünüzde aklınıza neler geliyor?

3. Problem durumu

Yeşilay'ın Üsküdar'da düzenlediği Kuş Evi Hazırlıyorum Projesine katılmaya karar verdiğiniz. Etkinlik hakkında araştırma yapıp bir kuş evi tasarlamak için gerekli olan bilgileri ediniyorsunuz. Bulunduğunuz semtin ormanı veya yeşilliği olan bir parkı için kuş evi tasarlamaya karar veriyorsunuz. Bunun için yaşadığınız yerde çok sık görmediğiniz bir kuş türü tespit edip onun boyutlarına göre kuş evi tasarlamalısınız. Ardından kuş evinizi asmak için uygun yerden yüksekliği bulmalısınız.

- Kuşlar eve girerken vücutlarını girişin köşelerine çarpmaması ve doğadaki gerçek ev izlenimi vermesi için evinin girişi daire şeklinde olmalıdır.

- Kuş yuvalarının içine, kuşların ayak ortopedisine uygun ince uzun silindir şeklinde kuşların tutunabileceği bir tahta yerleştirilmelidir.

- Kuş evlerinin yerden yüksekliği tehlikelerden korunmaları için uygun yükseklikte tasarlanmalıdır.

- Seçtiğiniz kuş türünün özelliklerine göre yapacağınız kuş yuvasının hacmi 2000 – 8000 cm^3 aralığında olmalıdır.

- Kuş evine uygun malzemeyi seçiniz.

- Kötü hava koşullarını da göz önünde bulundurunuz.

4. Çözümlerin sunumu

Appendix 1 and appendix 2 are original student worksheets from the study are presented in their native Turkish in the Appendix; however, for the sake of clarity, comprehensive descriptions of these activities are provided in English within the main body of the text.

Appendix 3 - Semi Structured Interview Questions

Instructions and Introduction

First, thank you for volunteering to participate in my study. The purpose of our interview is to gather information about your views and thoughts regarding STEM education and Model Eliciting Activities (MEA) that you will be participating in. For this reason, I will ask you some questions. There are no right or wrong answers; therefore, you can express your feelings and thoughts freely. With your permission, I will record our interview, but your identity will remain completely confidential. I estimate that our interview will take approximately 15 minutes.

Semi-Structured Interview Questions

1. Have you heard of the abbreviations STEM before?
    - If yes; where did you hear it?
    - Can you explain what it means?
    - Can you explain your thoughts on the STEM education approach?
2. In your opinion, can the disciplines of science, technology, engineering, and mathematics be interrelated? If yes, how might this relationship be?
3. Can science, technology, engineering, and mathematics disciplines take place in education in relation to each other? How can they be integrated? What could be the positive and negative aspects of such an integrated approach?
4. Have you heard of the concept of mathematical modelling before?
    - If yes, can you explain it?
    - If no, what do you think mathematical modelling might be and where could it be used?
5. Do you have an idea about Model Eliciting Activities?
    - If yes, can you explain it?
    - If no, what do you think model eliciting activities could be?
6. How do you think model eliciting activities should be created? What would your guess be?
7. What do you think about including modelling activities in schools?
8. Do you think model eliciting activities can be designed to cover STEM disciplines? What could be the positive and negative aspects of this situation?
9. Do you think the use of STEM-based Model Eliciting Activities can contribute to the development of 21st-century skills such as critical thinking and problem solving, communication and collaboration, creativity and innovation? How?
10. What did our activity process provide for you?
11. Is there anything you would say, "it would have been better if we did this" during the activity process?
12. Which activity did you like the most? Why?
13. Is there anything else you would like to add?

The following interview questions were originally prepared in Turkish for data collection and have been translated into English for better understanding.