IOJPE

ISSN: 1300 – 915X
www.iojpe.org

International Online Journal of Primary Education *2025, volume 14, issue 4*

CAN MUSEUMS BE USED IN MATHEMATICS EDUCATION? PRE-SERVICE PRIMARY SCHOOL MATHEMATICS TEACHERS' PERSPECTIVES AND A DESIGN PROPOSAL

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Received: March 21, 2025 **Accepted:** November 11, 2025 **Published:** December 31, 2025

Suggested Citation:
Sevimli, K., Aksakal, H., Narlı, S., & Us, K. (2025). Can museums be used in mathematics education? Pre-service primary school mathematics teachers' perspectives and a design proposal. *International Online Journal of Primary Education (IOJPE), 14*(4), 211-238. https://doi.org/10.55020/iojpe.1662219

Abstract

This study aimed to design a prototype mathematics museum for use in mathematics education, drawing on pre-service teachers' views following a museum education course and a visit to the Tales Mathematics Museum. Employing a basic qualitative research design, this study involved 20 pre-service mathematics teachers selected through criterion sampling. Data were collected via an interview form developed by researchers and analyzed using content analysis. Findings were presented in tables and supported by direct quotations from participants. The results demonstrated that both the course and the museum visit positively influenced pre-service teachers' perceptions of museums as out-of-school learning environments. According to participants, museums provide opportunities to establish interdisciplinary connections, enrich knowledge of mathematical history, model and concretize abstract concepts, engage students, and support diverse activities. Pre-service teachers recommended that a mathematics museum should incorporate technology-supported simulations, representations of mathematical history, concrete models of theorems, and connections to daily life and art, while being designed to sustain student engagement. In conclusion, a prototype mathematics museum was developed based on these suggestions, underscoring the potential of museum-based approaches to foster meaningful, interdisciplinary, and engaging mathematics learning experiences.

Keywords: Out-of-school learning environments, museum education, pedagogy, museum design, pre-service teachers.

INTRODUCTION

Mathematics is often regarded as one of the most challenging subjects for students due to its cumulative structure, the necessity of abstract thinking, the presence of abstract concepts, and the prevalence of various preconceptions about the discipline. For students to achieve meaningful learning in mathematics, develop their abstract thinking skills, establish connections among mathematical concepts, and attain the ability to engage in mathematical practices, numerous studies

have been conducted and continue to be conducted in the literature (Altun, 2006; Bahadır & Hırdıç, 2018; Yıldız & Göl, 2014).

In today's constantly evolving and transforming world, it has been observed that educational needs are undergoing significant transformation (Göğebakan, 2018). As a result, the education provided in schools proves to be sufficient only to a certain extent, and schools are gradually losing their status as the sole institutions associated with teaching and learning (Karakaş, 2020). Consequently, the demand for alternative learning environments has grown, and out-of-school learning settings have become an integral component of the educational process (Kır et al., 2021). Thus, it is considered essential to support formal education with out-of-school learning environments that can effectively meet the needs of today's students.

Out-of-School Learning Environments

Out-of-school learning environments offer opportunities for practices that are challenging or impossible to implement within the confines of the school (Seligmann, 2015) and facilitate the integration of knowledge acquired in school with real-life situations (Aydoğdu & Aydoğdu, 2025). Therefore, these environments hold significant potential for educational activities. Research has demonstrated that such environments offer students diverse experiences that foster cognitive, affective, and psychomotor skills; enhance observation skills and long-term retention of knowledge; support connections between daily life and interdisciplinary domains; and positively influence both learning motivation and academic achievement (Eshach, 2007; Guardino et al., 2019; İnce & Akcanca, 2021; Kır et al., 2021; Saraç, 2017; Usta et al., 2023). Furthermore, these environments help students concretize abstract concepts in disciplines such as mathematics (Kuş, 2024) and contribute to the development of inquiry, problem-solving, and higher-order thinking skills by stimulating curiosity (Waite & Aronsson, 2022). In their study, Mettis et al. also emphasized that out-of-school learning environments provide meaningful and lasting learning opportunities, particularly in numerical disciplines (e.g., mathematics and science). Consequently, incorporating more activities conducted in out-of-school settings into educational processes is considered beneficial. In this regard, it is essential to conduct up-to-date research that draws upon the perspectives and experiences of educators who play an active role in the teaching–learning process.

Examples of out-of-school learning environments include mathematics and science museums, history and art museums, science centers and camps, aquariums, planetariums, and historical sites (Ertaş, 2012; Kuş, 2024).

In this study, prospective mathematics teachers' views were examined before and after a museum education course, as well as following their visit to the Aydın Tales Mathematics Museum. Based on the findings obtained, recommendations are presented for the design of an alternative museum that could be an out-of-school learning environment for mathematics education.

Museums as Out-of-School Learning Environments

Since the 1920s, museums have been recognized across different periods and societies for their fundamental functions, such as collecting, preserving, documenting, and exhibiting—and for their prominent role in education (Binekci, 2023; Yılmaz, 1996). Conducting educational activities in museums is considered significant for facilitating meaningful and lasting learning, concretizing abstract concepts, and establishing connections between education and various disciplines (Binekci, 2023). With these opportunities, museums are regarded as crucial out-of-school learning environments that enrich the teaching and learning process (Yıldız & Göl, 2014).

Museums are learning environments that extend learning beyond the classroom by supporting individuals' cognitive and behavioral development, enabling students to discover through touch and inquiry, and allowing them to experience concepts from mathematics, art, and the social sciences meaningfully (Buyurgan, 2019). However, it is noteworthy that interaction and collaboration between museums and educational institutions have not yet reached a sufficient level. Moreover, educators' perspectives on the use of museums as educational environments remain limited and require further

development (Seligmann, 2015). Hence, since 2019, the course of museum education has been included in undergraduate programs of faculties of education as either a compulsory or elective course. This reform aimed to enhance prospective teachers' ability to establish connections across different disciplinary fields, thereby incorporating the concept of the museum into the educational system (Buyurgan, 2019). These developments have underscored the significance of museum education pedagogy as an approach that enhances the role of museums in education.

The Pedagogy of Museum Education

The pedagogy of museum education is a learning approach grounded in experiential pedagogy, where the learning environment extends beyond the classroom and individuals actively participate in the learning process (Hein, 1998). In this context, experiential learning theory provides a robust framework for explaining the pedagogical value of museum environments. The stages defined in Kolb's (1984) experiential learning cycle—concrete experience, reflective observation, abstract conceptualization, and active experimentation—are closely associated with the pedagogy of museum education, enabling learners to engage in multidimensional learning experiences. A museum-based learning approach supports not only cognitive development but also the enhancement of higher-order skills such as problem-solving, creativity, critical thinking, and analytical reasoning (Andre et al., 2017).

In the context of mathematics education, museum-based learning contributes to developing positive attitudes toward learning by enabling abstract concepts to be experienced through concrete materials (Kayhan-Altay & Yetkin Özdemir, 2023; Roldán-Zafra & Perea, 2022). Moreover, providing opportunities for interdisciplinary activities facilitates the implementation of STEM practices that build bridges across diverse fields such as science, technology, engineering, and mathematics (Casi & Sabena, 2024). Therefore, the pedagogy of museum education is a learning approach that enriches teaching and learning processes, enhances pedagogical competencies, strengthens the connection between formal and informal learning environments, and holds strategic significance in fostering 21st-century skills. It considered essential that preservice mathematics teachers in faculties of education develop competencies in these areas, receive appropriate training, and reach a level at which they can apply these skills in their professional practice, thereby contributing to the process.

Literature Review

A review of the national and international literature reveals a considerable number of studies addressing museums and educational activities conducted within them as out-of-school learning environments (Akman et al., 2015; Aydoğdu et al., 2022; Aydoğdu et al., 2023; Buchholtz, 2023; Çiçek & Saraç, 2017; Demirel, 2019; Erem, 2021; Gürbey et al., 2020; Haji et al., 2019; Dere & Gökçınar, 2025; İlhan et al., 2021; Körükçü, 2019; Okoliš, 2018; Swanson & Williams, 2014; Yıldırım, 2017; Yurd & Varancı Uzun, 2024). Findings from several of these studies demonstrate that museums are effective out-of-school environments that support students' learning processes across various disciplines. For example, Akman et al. (2015) examined the views of preschool teachers on museum education. They reported that they emphasized the necessity of museum education in fostering meaningful learning in early childhood. Similarly, Gürbey et al. (2020) revealed that preservice science teachers most frequently preferred museums as out-of-school learning environments. However, they had not received any coursework on the subject, and highlighted the need for such a course. This underscores the importance of museum education courses within faculties of education. On the other hand, Demirel (2020), in a study with preservice primary school teachers, found that museum-based educational practices positively enhanced teacher candidates' self-efficacy perceptions. Likewise, Buchholtz (2023) reported that mathematics education supported by out-of-school environments such as museums provides opportunities to concretize abstract concepts, reinforce topics, and develop alternative problem-solving strategies, thereby enhancing learning motivation. Furthermore, Dere and Gökçınar (2025) investigated preschool teachers' views on out-of-school learning environments for mathematics activities and their utilization of such environments. Their findings revealed that preschool teachers considered these environments

beneficial for mathematics-related activities but encountered certain challenges during implementation. In the same study, Dere and Gökçınar (2025) also concluded that teachers preferred various out-of-school learning environments to connect subjects with everyday life, make lessons more engaging, and enable students to learn through authentic experiences. They further found that lessons conducted in these settings increased students' interest in mathematics and enhanced their problem-solving skills. Similarly, Swanson and Williams (2014) and Aydoğdu et al. (2023) reported that both preservice and in-service mathematics teachers recognized museums as having significant potential as out-of-school learning environments for mathematics education.

Significance and Purpose of this Study

In the field of literature, studies involving preservice or in-service mathematics teachers is limited, and existing research has largely remained confined to teachers' opinions. This indicates a significant gap in the field. Therefore, the present study aims to overcome this limitation by designing a prototype mathematics museum that can be utilized in mathematics education, based on the views of preservice mathematics teachers. The prototype mathematics museum, developed in line with these views, is expected to provide educators with an alternative out-of-school learning environment for teaching mathematics. This study holds considerable value in supporting the professional development of preservice teachers and in guiding innovative practices in mathematics instruction. At the same time, the research is anticipated to contribute to the literature by offering new insights how out-of-school learning environments can be effectively integrated into mathematics education.

Within the scope of the study, the research problem was defined as follows: *"What are the views of preservice mathematics teachers regarding the use of museums in mathematics education, and how can a mathematics museum be designed in line with these views?"* In addition, to examine the perspectives of preservice mathematics teachers following the introduction of the "museum education" course into education faculties as of 2019 and their visit to the Tales Mathematics Museum located in Aydın during the study, the following sub-problems were addressed.

a) What are preservice teachers' views who have taken the museum education course compared to those who have not?

b) What are preservice teachers' views after taking the museum education course?

c) What are preservice teachers' views after visiting the mathematics museum?

d) Can a mathematics museum be designed considering the views of preservice teachers?

METHOD

Research Design

In this study, a qualitative research paradigm was adopted. Qualitative research is an inductive approach that aims to transparently reveal phenomena and events from participants' perspectives within natural settings, without any intervention (Creswell, 2021; Yıldırım & Şimşek, 2021). This approach requires researcher to remain flexible throughout the process and to adjust the study's course based on the data, thereby adopting an inductive perspective (Merriam & Tisdell, 2016). In the present study, a basic qualitative research design was employed to examine the experiences of preservice mathematics teachers with the museum education course and the museum visit. The basic qualitative research design is utilized to uncover individuals' experiences and perceptions of a particular phenomenon (Merriam & Tisdell, 2016; Patton, 2014).

Participants

The study's participant group comprised 20 preservice mathematics teachers enrolled at a public university. Criterion sampling, a purposeful sampling method, was employed to determine the participant group. Criterion sampling is a method that enables the inclusion of participants who meet the criteria established in line with the study's purpose (Yıldırım & Şimşek, 2021). In this research, the criterion was defined as follows: at the beginning of the semester, 10 participants had chosen the

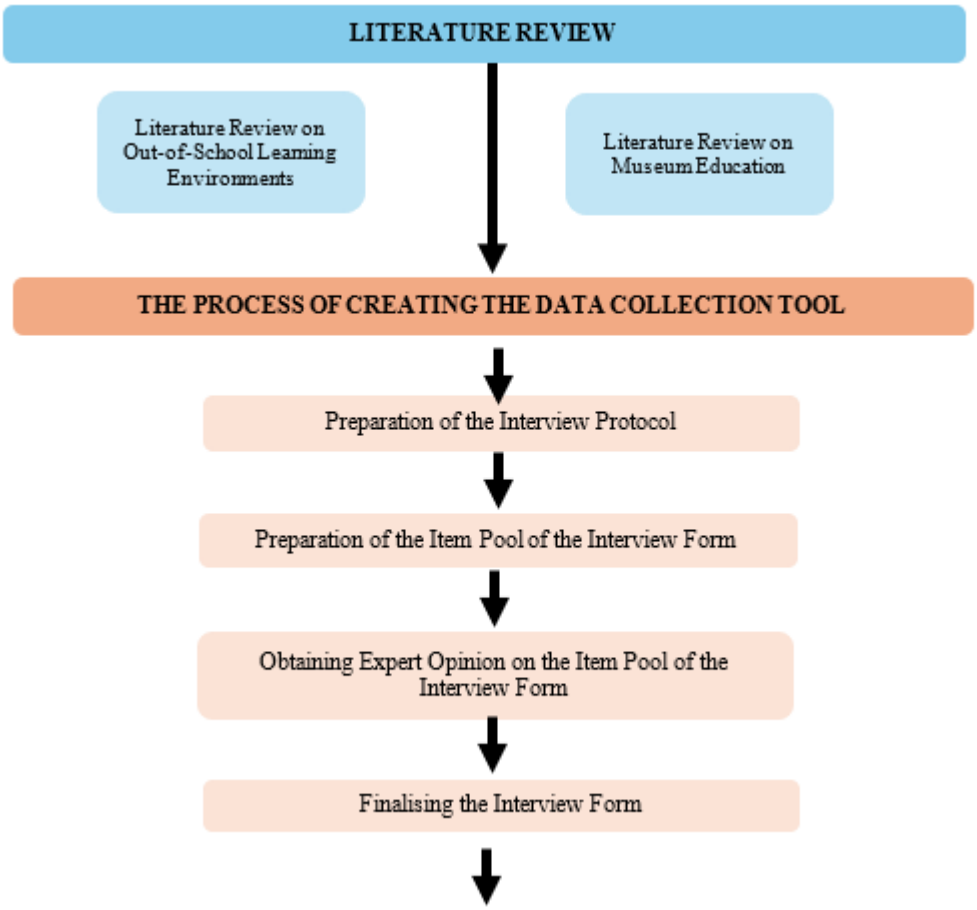
museum education course, while the other 10 had not. This allowed for the examination of the benefits of the museum education course and its impact on preservice teachers' perspectives.

Data Collection Tool and Process

An interview form was used as the data collection instrument. During the development process, the researchers conducted a literature review and subsequently generated an item pool for the interview form. In the final stage, expert opinion was obtained from a professor in mathematics education, and the interview form was finalized accordingly. The interview form is presented in Appendix 1.

The interview form was administered at the beginning of the semester to 20 preservice mathematics teachers (both those who had chosen and those who had not selected the museum education course). At the end of the semester, after completing the museum education course (14 weeks), all 20 preservice teachers visited the Tales Museum located in Aydın, where activities related to mathematics education were examined. Additionally, ideas were exchanged on how mathematics museums can be utilized in mathematics education. After the museum visit, the interview form was again administered to all preservice mathematics teachers, and the data were collected accordingly.

The research process cycle related to the development of the data collection instrument and the data collection procedure is presented in Figure 1.



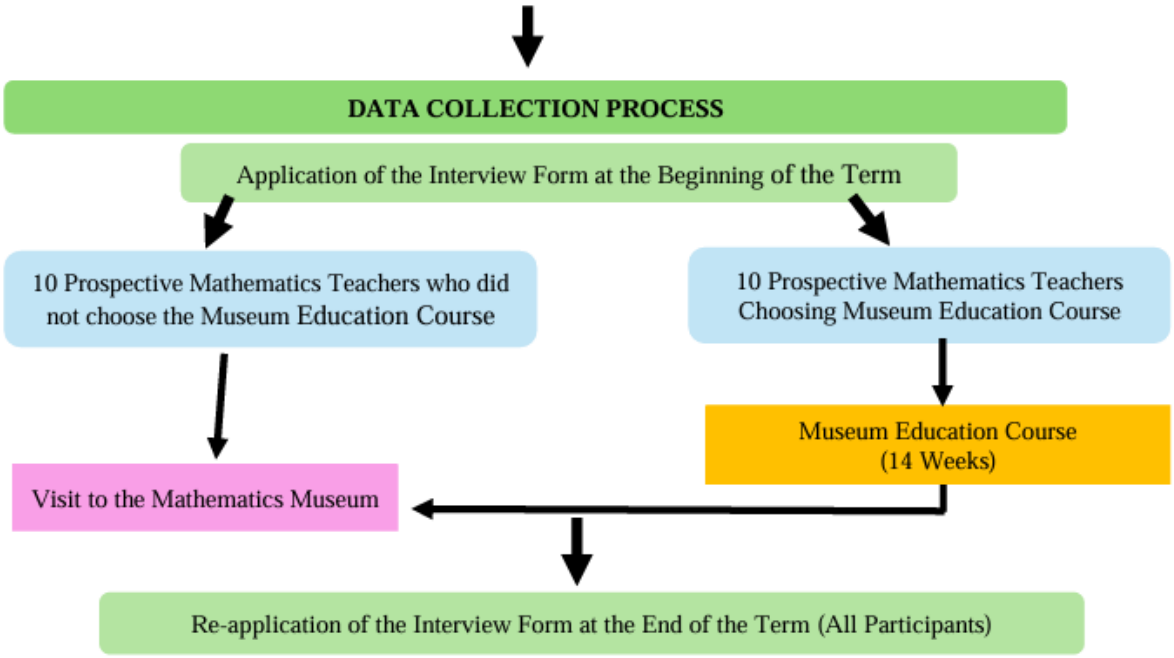


Figure 1. Research process cycle.

Data Analysis

In line with the aim of this study, the data were analyzed using content analysis, one of the qualitative research techniques. Content analysis is a systematic method that enables data of a similar nature to be organized within predetermined codes, categories, and themes, and subsequently interpreted from a holistic perspective to provide the reader with a clear and comprehensive understanding (Krippendorff, 2019; Yıldırım & Şimşek, 2021). The data subjected to content analysis were summarized and interpreted in tabular form within the categories determined in the context of the sub-problems.

In the data analysis process, two researchers in the research team initially examined the interview forms independently and simultaneously. Categories were created based on participants' responses in the interview forms. Subsequently, the two researchers came together to evaluate the categories they had developed. Categories with differences of opinion were identified, and to reach a consensus, another researcher from the research team was included in the analysis process. The three researchers discussed the categories with differing opinions and reviewed the literature to reach a joint decision. For instance, in the initial stage, the categories "modeling" and "concretization" were created separately; however, since responses related to modeling also encompassed aspects of concretization, the two categories were merged into "modeling and concretization" by consensus. Approximately five months after this initial analysis, the data were independently re-examined and discussed a second time. No changes to the categories from the first analysis were made during this second review, thereby confirming the final form of the categories. In the subsequent stage, the number of participant responses was determined, tabulated along with their frequencies, and presented in tables in the findings section. To ensure the objectivity and transferability of the research, direct excerpts from participants' responses were included and interpreted while presenting the findings. Based on the results obtained, a prototype mathematics museum was designed by the second and fourth authors of the research team.

RESULTS

At this stage of this study, the findings obtained from the analysis of participants' responses to the interview questions at the beginning and end of the semester (after the museum visit) are presented. As preservice teachers sometimes provided responses that could fall into more than one category, discrepancies may be observed in the total frequencies.

1. Findings on the Views of Preservice Teachers Who Have and have not Taken the Museum Education Course

The data obtained for the sub-problem of this study, "Are there differences in the views of preservice teachers who have and have not taken the museum education course?" are presented below.

In Table 1, the responses of preservice teachers who had not taken (f = 10) and those who had taken (f = 10) the museum education course to the interview question, "What does the concept of a museum evoke for you? What kind of place comes to mind when you think of a museum?" are examined.

Table 1. The connotations of the concept of museum in pre-service teachers who take and do not take museum education courses.

Categories	**Question 1: Answers of Teacher Candidates Who Have Not Taken Museum Education Course** Frequencies	**Question 1: Answers of pre-service teachers who have taken museum education courses** Frequencies
Exhibition (Item – Artwork-Art)	7	7
Historical Site	9	2
Informative EducationTeaching Environment	2	7
Institution Serving Its Purpose	0	1

The analysis revealed that preservice teachers who had not taken the museum education course predominantly associated the concept of a museum with exhibition spaces (38.8%) and historical sites (50%). In contrast, preservice teachers who had taken the museum education course more frequently described a museum as an informative educational environment (41.1%). It can be stated that there is a relative difference in the responses provided by preservice teachers who had taken the course and those who had not.

In the interview form administered to the participants, the question, "Have you visited a museum before? If yes: a) How frequently do you visit museums?, b) What types of museums have you visited? Please specify," elicited responses indicating that none of the preservice teachers had previously visited a mathematics museum.

In Table 2, the responses of preservice teachers who had not taken (f = 10) and those who had taken (f = 10) the museum education course to the interview question, "For what purposes do you think people can visit museums?" are examined.

Table 2. The thoughts of pre-service teachers who take and do not take museum education courses about the purposes for which they can go to museums.

Categories	**Question 3: Answers of Teacher Candidates Who Have Not Taken Museum Education Course** Frequencies	**Question 3: Answers of pre-service teachers who have taken museum education courses** Frequencies
For Hobby Purposes	5	1
For Travel-Observation Purposes	4	4
For Acculturation	3	4
For Educational Purposes	7	11

The analysis indicated that preservice teachers who had taken and those who had not taken the museum education course generally provided similar responses; however, preservice teachers' perspectives who had taken the course regarding the use of museums for educational purposes were more prominent.

In Table 3, the responses of preservice teachers who had not taken (f = 10) and those who had taken (f = 10) the museum education course to the interview question, "Do you think museums can be considered as out-of-school learning environments? If so, what types of educational activities can they be used for? Please explain," are examined.

Table 3. The thoughts of pre-service teachers who take and do not take museum education courses on what kind of educational activities museums can be used in.

Categories	**Question 4: Answers of Teacher Candidates Who Have Not Taken Museum Education Course** Frequencies	**Question 4: Answers of pre-service teachers who have taken museum education courses** Frequencies
Lessons	5	2
Interdisciplinary Activities	0	1
Material Usage	1	4
For Application Purposes	2	5
For Reinforcement Purposes	0	3
For Concretization Purposes	2	4

The analysis revealed that preservice teachers who believed museums could be used for instructional, reinforcement, and concretization purposes in educational activities were predominantly those who had taken the museum education course.

Analysis of the responses to the question, "Have you ever had the opportunity to receive training in any museum?" included in the interview form administered to the participants revealed that, except for one preservice teacher, none had previously received training in any museum.

In Table 4, the responses of preservice teachers who had not taken (f = 10) and those who had taken (f = 10) the museum education course to the interview question, "Do you think it is possible to utilize museums in mathematics education? Please explain," are examined.

Table 4. The thoughts of pre-service teachers who take and do not take museum education courses that museums can be used in mathematics education.

Categories	**Question 7: Answers of Teacher Candidates Who Have Not Taken Museum Education Course** Frequencies	**Question 7: Answers of pre-service teachers who have taken museum education courses** Frequencies
	Yes	**Yes**
Modeling and Concretization	2	8
Extracurricular Learning Activity	2	0
Association	2	1
History of Mathematics	4	1
Attract Attention	3	1
Make an Application	0	5
	No	**No**
No Idea/Unclear	4	0

Examination of the responses revealed differences in the views of preservice teachers who had taken and those who had not taken the museum education course. These differences were particularly evident in the categories of modeling and concretization (42.1%) and performing applications (26.3%). Notably, one preservice teacher who had not taken the museum education course expressed the view that it is not possible to utilize museums in mathematics education.

2. Findings on Preservice Teachers' Perspectives Following the Museum Education Course

The data obtained for the sub-problem, "Do preservice teachers' perspectives change after taking the museum education course?" are presented below. For this sub-problem, the interview form was administered twice to 10 preservice teachers: once before and once after taking the museum education course.

In Table 5, the responses of preservice teachers to the question, "What does the concept of museum evoke for you? What kind of place comes to mind when you think of the museum?" in the interview form are examined, comparing their answers before and after taking the museum education course.

Table 5. The connotations of the Concept of Museum in pre-service teachers before and after taking the museum education course.

Categories	Question 1: Answers Before the Museum Education Course Frequencies	Question 1: Answers After the Museum Education Course Frequencies
Exhibition (Item – Artwork-Art)	8	7
Historical Site	4	2
Informative EducationTeaching Environment	5	7
Institution Serving Its Purpose	0	1

The analysis revealed that, before taking the museum education course, 29.4% of the preservice teachers described the concept of museum as an informative educational environment, whereas after the course, this proportion increased to 41.1%.

In Table 6, the responses of preservice teachers to the question, "For what purposes do you think people can visit museums?" in the interview form are examined, comparing their answers before and after taking the museum education course.

Table 6. Before and after taking the museum education course, pre-service teachers' thoughts on the purposes of going to museums.

Categories	Question 3: Answers Before the Museum Education Course Frequencies	Question 3: Answers After the Museum Education Course Frequencies
For Hobby Purposes	3	1
For Travel-Observation Purposes	4	4
For Acculturation	4	4
For Educational Purposes	8	11

The analysis revealed that, after taking the museum education course, preservice teachers' views regarding visiting museums for recreational purposes decreased, whereas their perceptions of visiting museums for instructional purposes increased.

In Table 7, the responses of preservice teachers to the question, "Do you think museums can be considered as out-of-school learning environments? If so, in what types of instructional activities can they be utilized? Please explain," in the interview form are examined, comparing their answers before and after taking the museum education course.

Table 7. Teacher candidates' thoughts on what kind of educational activities museums can be used for before and after taking the museum education course.

Categories	Question 4: Answers Before the Museum Education Course Frequencies	Question 4: Answers After the Museum Education Course Frequencies
Lessons	4	2
Interdisciplinary Activities	1	1
Material Usage	3	4
For Application Purposes	1	5
For Reinforcement Purposes	0	3
For Concretization Purposes	0	4

The analysis revealed that, after taking the museum education course, preservice teachers demonstrated an understanding that museums can be utilized in instructional activities for practice, reinforcement, and concretization purposes. Based on this finding, it is suggested that the museum education course has a positive contribution to preservice teachers' awareness of the diversity of instructional activities in which museums can be employed.

When examining the responses to the question, "Do you think there can be a relationship between the concepts of mathematics and museums? Please explain," in the interview form applied to the participants, it was observed that, over the course of the term, preservice teachers who took the museum education course showed an increase in responses indicating "concretizing abstract mathematical concepts in the museum" at the end of the term.

In Table 8, the responses of preservice teachers to the question, "Do you think it is possible to utilize museums in mathematics education? Please explain," in the interview form are examined, comparing their answers before and after taking the museum education course.

Table 8. Before and after taking the museum education course, pre-service teachers' thoughts on the use of museums in mathematics education.

Categories	Question 7: Answers Before Museum Education Course Frequencies	Question 7: Answers After the Museum Education Course Frequencies
	Yes	**Yes**
Modeling and Concretization	2	8
Extracurricular Learning Activity	1	0
Material Usage	1	3
Association	2	1
History of Mathematics	2	1
Attract Attention	1	1
Make an Application	0	5
	No	**No**
No Idea/Unclear	3	0

As a result of this analysis, it was first observed that the perspectives of three preservice teachers, who initially believed that it was not possible to utilize museums in mathematics education, changed following the museum education course. Moreover, the perception that museums could be employed for modeling and concretizing mathematical concepts increased from 22.22% before the course to 42.1% after the course. Additionally, while preservice teachers did not initially consider that practice-oriented activities could be conducted in museums for mathematics education, 26.3% of them adopted this perspective after completing the museum education course.

3. Findings regarding Pre-Service Teachers' Perspectives Following the Museum Visit

The data obtained for the sub-problem of the study, "Does a difference emerge in pre-service teachers' perspectives after visiting the mathematics museum?" are presented below. For this sub-problem, the interview form was administered twice to 10 pre-service teachers who had not taken the museum education course: once before and once after visiting the mathematics museum.

In Table 9, the pre-service teachers' responses to the question, "What does the concept of museum evoke for you? What kind of place comes to mind when you think of the museum?" in the interview form administered to the participants were examined before and after they visit the mathematics museum.

Table 9. Connotations of the concept of museum in pre-service teachers before and after the museum visit.

Categories	Question 1: Answers Before the Museum Visit Frequencies	Question 1: Answers After the Museum Visit Frequencies
Exhibition (Item – Artwork-Art)	7	6
Historical Site	9	3
Informative EducationTeaching Environment	2	7

As a result of the examination, it was observed that before visiting the mathematics museum, the pre-service teachers described the concept of a museum as a historical site at a rate of 50%, whereas after the museum visit, this rate decreased to 18.75%. Another noteworthy finding is that the proportion of pre-service teachers characterizing museums as informative educational environments increased from 11.1% before the museum visit to 43.75% after the visit.

Table 10 presents the responses of pre-service teachers to the question, "For what purposes do you think people can visit museums?" in the interview form, examined before and after visiting the mathematics museum.

Table 10. Pre-service teachers' perceptions of the purposes for which museums can be visited, before and after the museum visit

Categories	Question 3: Answers Before the Museum Visit Frequencies	Question 3: Answers After the Museum Visit Frequencies
For Hobby Purposes	5	1
For Travel-Observation Purposes	4	4
For Acculturation	3	3
For Educational Purposes	7	8

As a result of the analysis, it was observed that pre-service teachers provided generally similar responses before and after the mathematics museum visit; however, their perceptions regarding the use of museums for recreational purposes showed a relative change following the visit.
Table 11 presents the responses of pre-service teachers, before and after the mathematics museum visit, to the question in the interview form: 'Do you think museums can be considered as out-of-school learning environments? If so, what types of educational activities can they be used for? Please explain.

Table 11. Pre-service teachers' perceptions of the types of educational activities in which museums can be utilized, before and after the museum visit.

Categories	Question 4: Answers Before the Museum Visit Frequencies	Question 4: Answers After the Museum Visit Frequencies
Lessons	5	5
Interdisciplinary Activities	0	2
Material Usage	1	4
For Application Purposes	2	4
For Reinforcement Purposes	0	2
For Concretization Purposes	2	4

As a result of the analysis, it is noteworthy that after the museum visit, the pre-service teachers' perceptions that museums can be utilized in educational activities for interdisciplinary purposes, material usage, practice, reinforcement, and concretization increased.

Table 12 presents the responses to the question, "Do you think it is possible to benefit from museums in mathematics education? Please explain," included in the interview form administered to the participants.

Table 12. Pre-service teachers' perspectives on the potential use of museums in mathematics education before and after the museum visit.

Categories	Question 7: Answers Before the Museum Visit Frequencies	Question 7: Answers After the Museum Visit Frequencies
	Yes	**Yes**
Modeling and Concretization	2	7
Extracurricular Learning Activity	2	0
Association	2	2
History of Mathematics	4	4
Attract Attention	3	3
Make an Application	0	4
	No	**No**
No Idea/Unclear	4	2

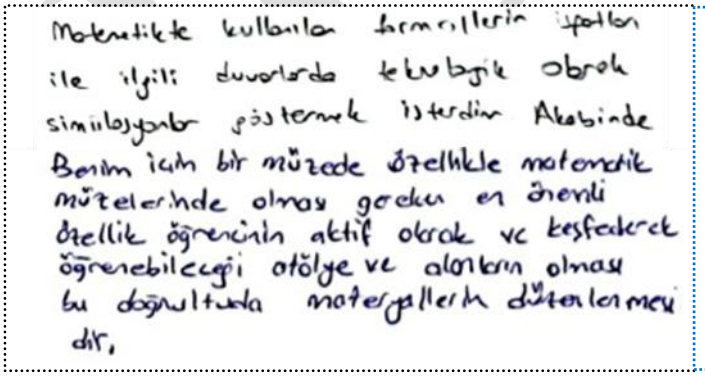
Based on the analysis, differences were observed in the pre-service teachers' perspectives before and after the mathematics museum visit. This variation is particularly evident in the categories of modeling and concretization (35%) and conducting practical activities (20%). Additionally, it is noteworthy that the views of two pre-service teachers regarding the impossibility of utilizing museums in mathematics education remained unchanged after the museum visit.

4. Findings Regarding the Design Features of a Mathematics Museum Based on Pre-Service Teachers' Perspectives

For the sub-problem of the study, "Can a mathematics museum be designed based on pre-service teachers' perspectives?", the responses provided by the pre-service teachers after completing the museum education course and visiting the museum were evaluated. In addition, mathematics museums in Turkey and around the world were examined to design a prototype mathematics museum that would serve the purposes of mathematics education.

In the museum design process, the pre-service teachers' suggestions, the aspects of these suggestions that distinguish them from existing mathematics museums, and the points in the visited mathematics museum that could be improved from the perspective of the pre-service teachers were considered, along with the insights of an architect. Based on all these criteria, excerpts related to the design of the planned prototype mathematics museum are presented below.

An analysis of the pre-service teachers' responses revealed that they suggested exploratory activities within the museum, varying workshop programs, and the integration of technology into the mathematics education process (see Figure 2).



"I'd like to display technological simulations on the walls to demonstrate the proofs of mathematical formulas. For me, the most important feature of a museum, especially a mathematics museum, is the availability of workshops and spaces where students can learn actively and through exploration, and the organization of materials accordingly."

Figure 2. Excerpts from the suggestions of the pre-service teachers.

Taking the suggestions into account, a panoramic space was designed at the upper section of the museum (see Figure 2). In this space, a prototype hall for mathematics education was designed with simulation and technology support. The simulation of the designated topic was intended to be

projected at the center of the hall so that visitors could easily observe it. It was envisaged that the designated topic would be updated cyclically on a monthly basis, thereby ensuring the dynamism and continuity of visits to the museum.

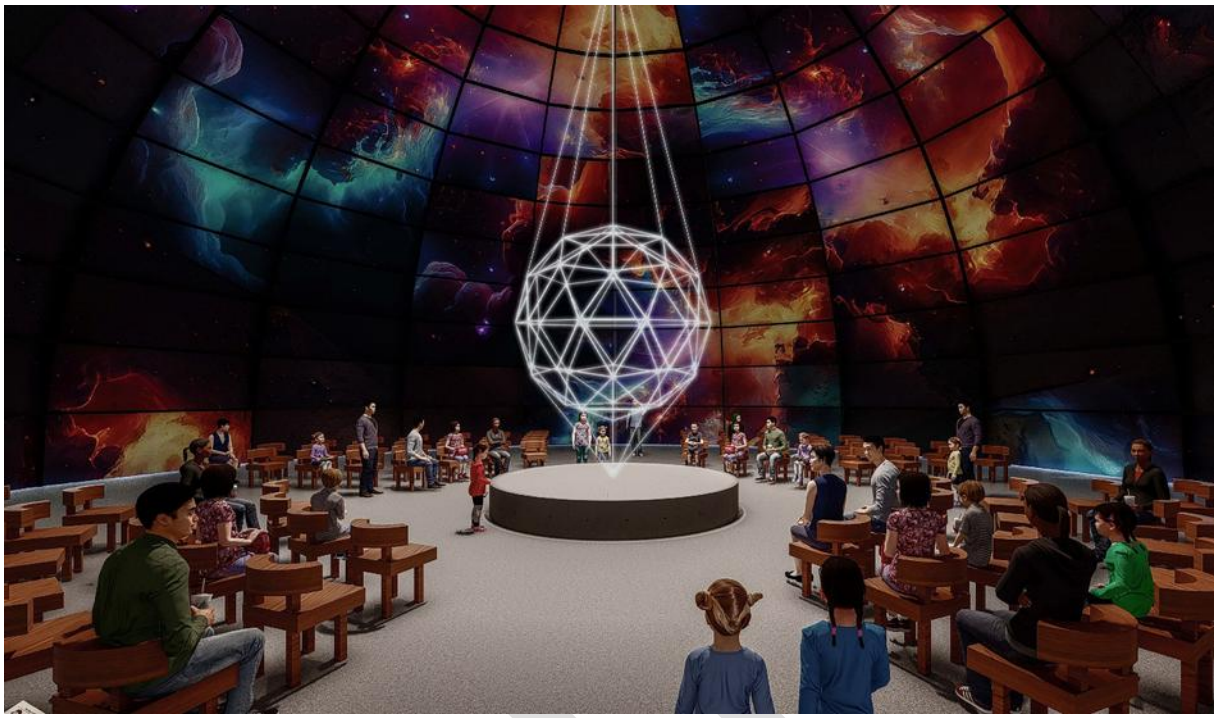
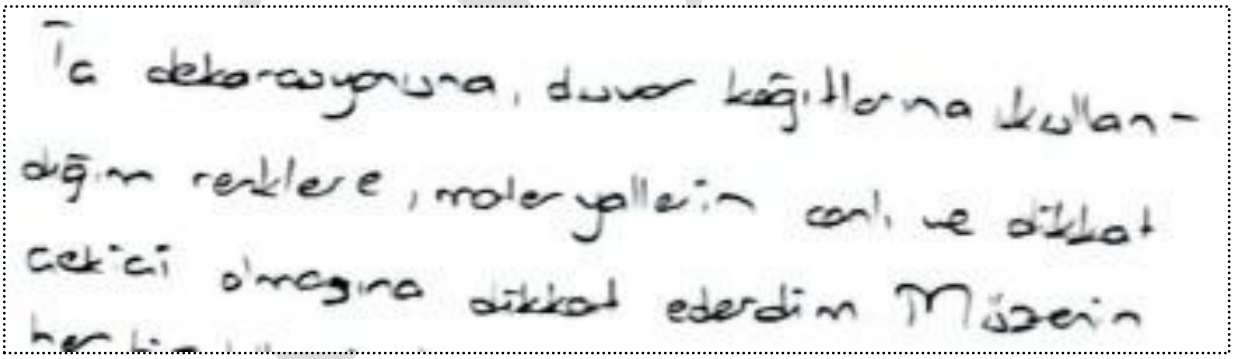


Figure 3. Panorama and simulation hall.

An analysis of the pre-service teachers' responses revealed that they suggested the museum's interior design should be vibrant and eye-catching, incorporate various geometric forms in the design, and potentially utilize fractal geometry, among other recommendations (see Figure 3a).



"I would pay attention to interior decoration, the colors I used in wallpapers, and the materials to make them vibrant and eye-catching."

Figure 3a. Excerpts from the suggestions of the pre-service teachers.

Based on the suggestions of the pre-service teachers, a transitional space was designed within the museum (see Figure 4). In this design, fractal geometry, patterns, and ornamental elements were utilized to make the interior environment engaging, with a strong emphasis on aesthetic perception.

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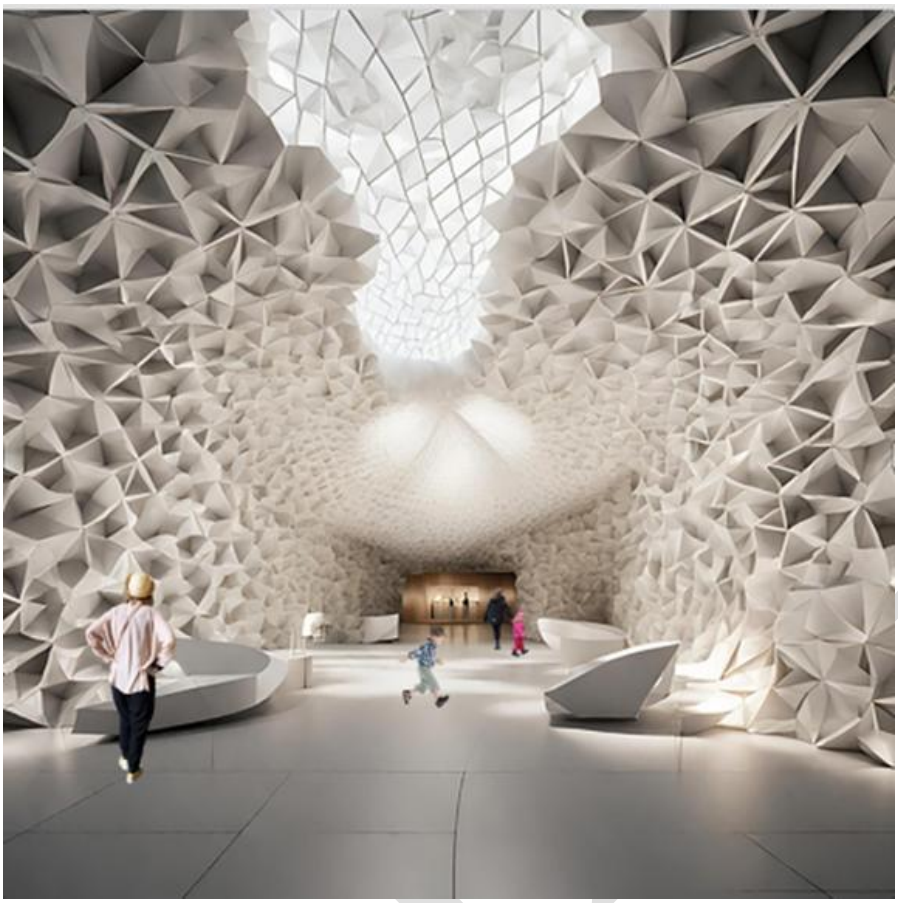
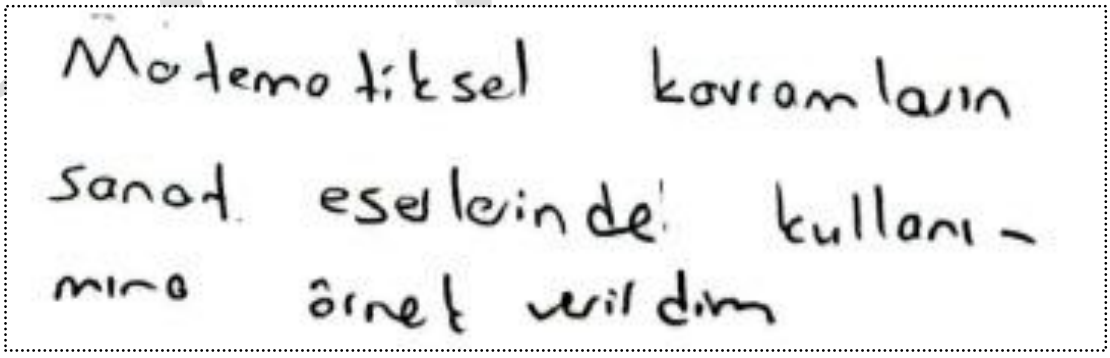


Figure 4. Transitional space.

When examining the responses of the pre-service teachers, it was observed that they emphasized the need to reflect the relationships between mathematics and other disciplines within the museum. Furthermore, suggestions were also made regarding the integration of mathematics and the arts within the museum (see Figure 5).



"I would give examples of the use of mathematical concepts in works of art."

Figure 5. Excerpts from the suggestions of the pre-service teachers.

Based on the suggestions of the pre-service teachers, illusion halls were designed where visitors can both engage and take photographs, enjoy their time, and simultaneously experience the integration of mathematics and art through the works of the renowned painter and graphic artist M. C. Escher. In this way, an emphasis was placed on highlighting the multifaceted nature of mathematics (see Figure 6, and Figure 7).

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Figure 6. Room of illusion: Escher.

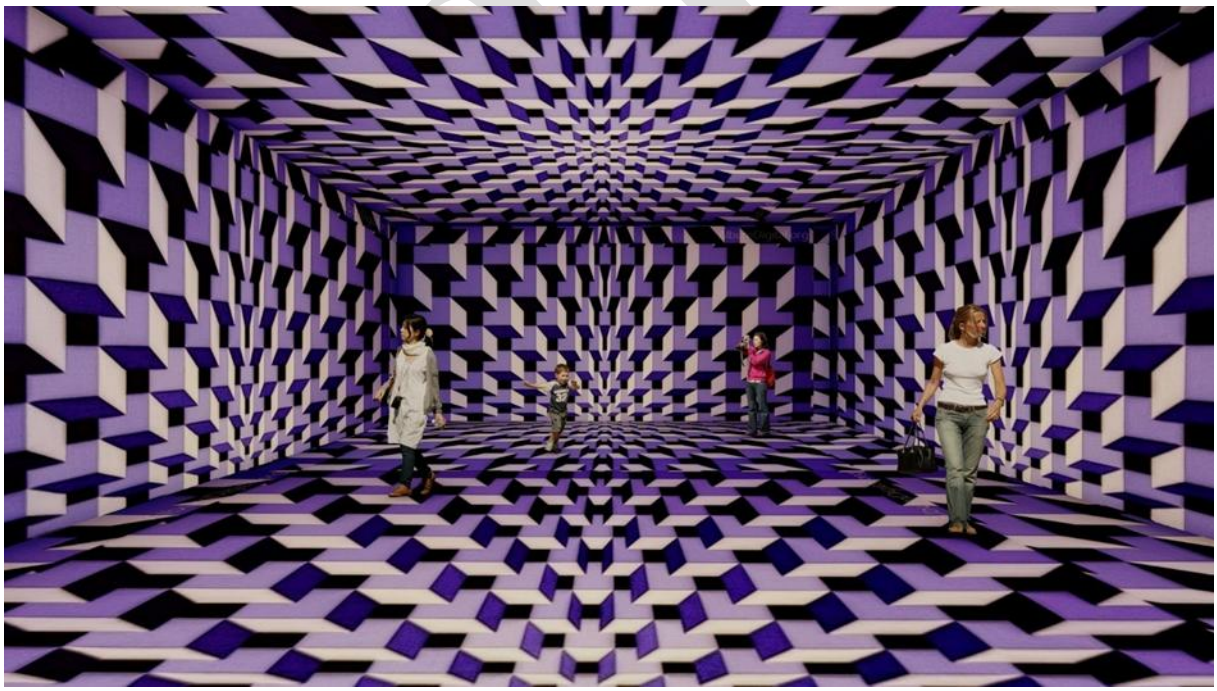

Figure 7. Illusion room perspective.

An analysis of the pre-service teachers' responses revealed that they suggested concretizing concepts in mathematics such as theorems and proofs, exhibiting them in the form of materials, and creating 3D models (see Figure 8).

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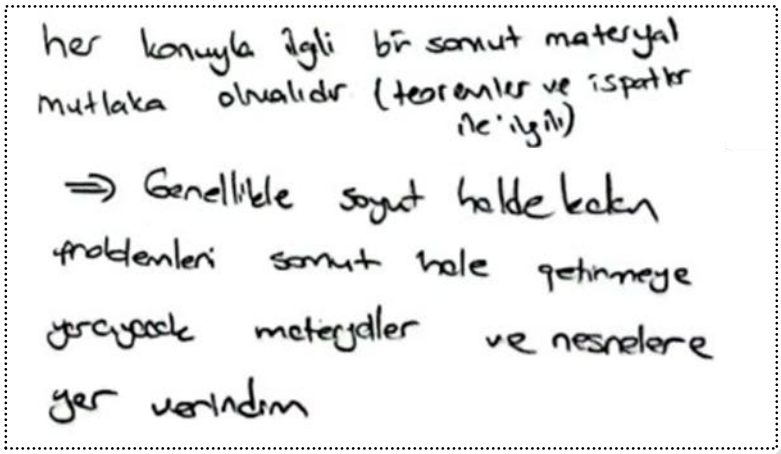

"I would usually include materials and objects that would help make abstract problems concrete."

"There must be concrete material related to every topic (related to theorems and proofs)."

Figure 8. Excerpts from the suggestions of the pre-service teachers.

Based on the suggestions of the pre-service teachers, proof rooms were designed with the aim of presenting to visitors, in a tangible form through models, concepts such as the Klein bottle and Möbius strip using abstraction, as well as the set of points equidistant from a given point forming a circle (see Figure 9, and Figure 10).

Figure 9. Proof room: 1

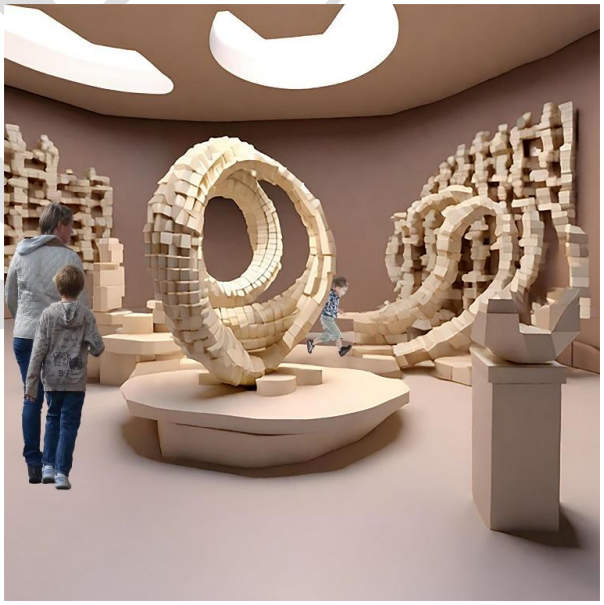

Figure 10. Proof room: 2

An examination of the pre-service teachers' responses indicated that their suggestions included the design of museum spaces that, through engaging and enjoyable activities, could foster a positive attitude toward mathematics and capture the interest of both students and visitors (see Figure 11).

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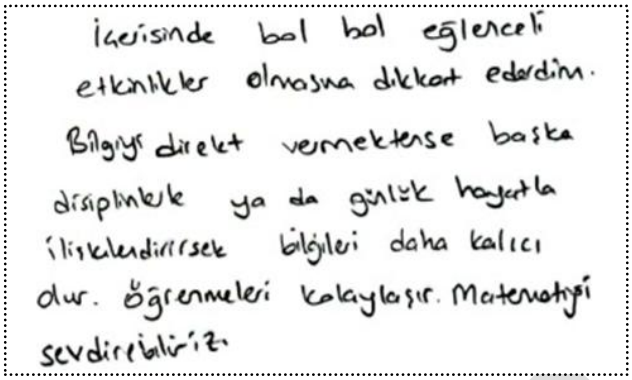

"I would make sure to include plenty of fun activities. Rather than simply imparting information directly, connecting it to other disciplines or daily life will make it more memorable. It makes learning easier. We can foster a love of math."

Figure 11. Excerpts from the suggestions of the pre-service teachers

In line with the pre-service teachers' suggestions, a movable wall design was created based on geometric structures with the aim of attracting visitors' interest and fostering a positive attitude toward mathematics (see Figure 12). In this way, it was intended that visitors could rearrange the geometric shapes on the wall to generate different figures. For instance, the museum guide might set specific goals for visitors with questions such as, "Can you create a rabbit from geometric structures?" thereby enhancing engagement. Furthermore, through the designed geometry room (see Figure 13), it was planned that visitors would gain a better understanding of the properties of geometric shapes (e.g., number of sides, edges, and vertices), while the dimensions of the shapes would capture their attention and stimulate curiosity.

Figure 12. Puzzle room

Figure 13. Geometry room

Upon evaluating the responses of the pre-service teachers, it was observed that they proposed the inclusion of spaces reflecting mathematics from different cultures within the museum to be designed (see Figure 14).

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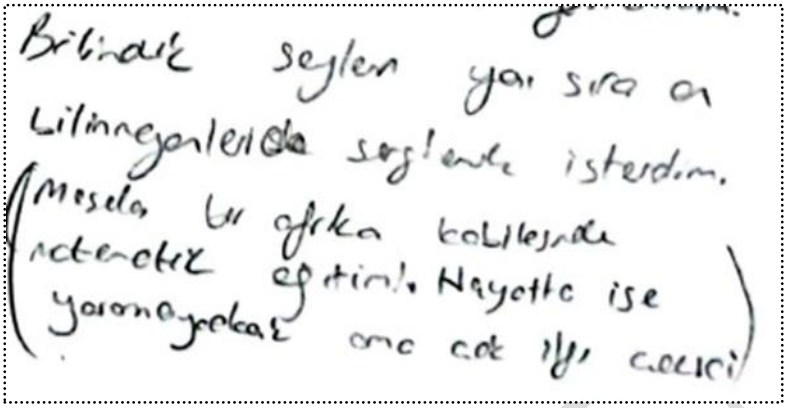

"I'd like to learn about unknown things as well as familiar ones. (For example, math education in an African tribe. It won't be useful in real life, but it's very interesting.)"

Figure 14. Excerpts from the suggestions of the pre-service teachers

Based on the recommendations of the pre-service teachers, the design sought to construct a space intended to illuminate the relationship of mathematics within diverse cultural contexts (see Figure 15). Within this design framework, particular emphasis was placed on the figures traditionally inscribed in the sand, representing foundational manifestations of mathematics in African tribal practices.

Figure 15. Culture and mathematics room.

An examination of the pre-service teachers' responses revealed suggestions for including space within the museum that addresses the relationship between mathematics and history (see Figure 16).

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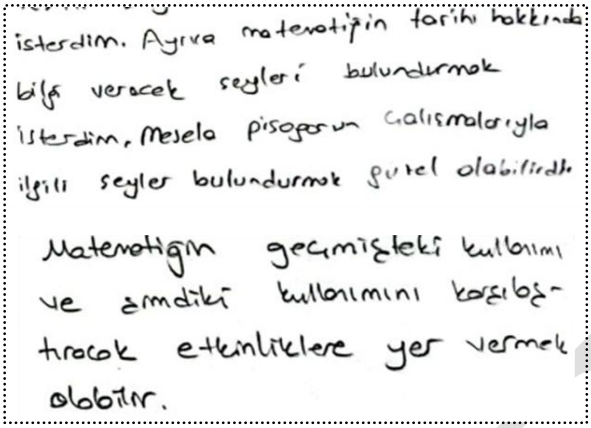

"I'd also like to include some information about the history of mathematics. For example, it would be nice to include information about the works of Pythagoras."

"It may be to include activities that compare the past and present use of mathematics."

Figure 16. Excerpts from the suggestions of the pre-service teachers.

Drawing upon the recommendations of the pre-service teachers, the present design sought to establish a space that effectively conveys the intricate relationship between mathematics and history (see Figure 17, Figure 18, and Figure 19). In this context, the environment was meticulously conceived to allow visitors to gain comprehensive insights into the lives of eminent mathematicians and critically examine their contributions to the field, while simultaneously experiencing the historical periods in which they lived. Moreover, the designed space is intended to provide visitors with a platform to engage in a comparative analysis of the applications of mathematics across past and contemporary contexts, thereby fostering a deeper appreciation of its evolution and relevance.

Figure 17. History of mathematics room: 1

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Figure 18. History of mathematics room: 2

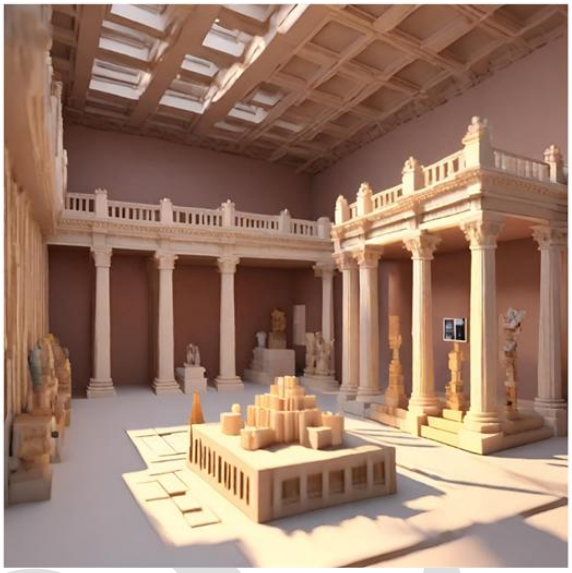

Figure 19. History of mathematics room: 3

As presented above, the recommendations provided by the pre-service teachers were thoroughly examined and systematically coded by the researchers. Subsequently, the coded suggestions were submitted to an architect for professional evaluation. Drawing upon the architect's feedback, the necessary interpretative refinements were incorporated, thereby facilitating the transition to the museum design phase. The resulting designs were primarily developed as interior layouts, aligned with the predetermined categories. Upon implementation, it is anticipated that these designs would be consolidated into a cohesive and comprehensive spatial arrangement.

DISCUSSION, CONCLUSION, and RECOMMENDATIONS

Analysis of the responses provided by pre-service teachers at the beginning of the semester (prior to the museum visit) indicated that they predominantly associated the concept of a museum with learning about the past and acquiring historical knowledge. From this perspective, it can be inferred that pre-service mathematics teachers exhibit limited awareness of the existence and role of mathematics and science museums. A possible explanation for this finding, as reflected in the data, is that most of these teachers had not previously visited any mathematics museum. This result aligns with the findings of Aydoğdu et al. (2022), who investigated the use of virtual museums as an instructional tool in mathematics education.

An analysis of the initial responses provided by pre-service teachers indicated that they were unable to establish any connection between mathematics education and museums. Subsequent responses, however, revealed a notable shift in their perspectives. This change is likely attributable to the museum education course undertaken during the semester, combined with the mathematics museum visit conducted at the end of the term. Moreover, most participants reported that, following the museum education course, they perceived museums as valuable out-of-school learning environments that improve instruction across various topics and concepts in mathematics. These findings are consistent with existing literature. For example, Bahadır and Hırdıç (2018) highlighted that learning activities conducted within a mathematics museum enhanced students' ability to relate mathematics to daily life and supported conceptual understanding. Similarly, Casi and Sabena (2024) examined the potential of museums for the professional development of primary and secondary school teachers, demonstrating that the use of museums as out-of-school learning environments holds considerable promise. Based on the findings of the present study, it was also determined that incorporating museum education courses as compulsory, rather than elective, components within undergraduate teacher education programs could positively influence pre-service teachers' capacity to establish

interdisciplinary connections, actively utilize museums as out-of-school learning environments, and cultivate innovative perspectives. This outcome aligns with Erem's (2019) study, which reported that museum education courses provided innovative opportunities for classroom teachers and fostered changes in their perspectives. Furthermore, Erem (2019) recommended that such courses be made compulsory during undergraduate training, reflecting a parallel with the current findings. Yıldırım (2017) similarly advocated for the inclusion of museum-focused courses in teacher education programs, emphasizing the educational potential of museums. The finding that pre-service teachers perceive museums as environments conducive to learning further supports the perspectives expressed by mathematics teacher candidates in the present study. In addition, Dumont et al. (2025) found that digital museum education activities facilitate knowledge exploration and promote interdisciplinary engagement, corroborating the present results. Finally, Okvuran, and Karadeniz (2022) demonstrated that the "museum-school" model developed in Turkey fosters discovery and creativity, underscoring the importance of providing teachers with professional training on effectively implementing educational activities within museums. These findings highlight the critical role of equipping educators with the necessary knowledge and skills to conduct teaching and learning activities within museums as alternative out-of-school learning environments.

The visit to the Tales Mathematics Museum led to a positive transformation in pre-service mathematics teachers' perspectives on mathematics education. Existing literature suggests that museum visits and educational activities conducted within museums can facilitate meaningful changes in both learners and educators. For example, Casi and Sabena (2024) reported that in-service training provided to mathematics teacher candidates in the context of Art and History Museums demonstrated that museum visits or experiential activities effectively enhanced candidates' interdisciplinary mathematical understanding and pedagogical strategies. Similarly, Holmes (2011) found that hands-on science museum experiences significantly improved students' science achievement in Louisiana, whereas Kisida et al. (2016) observed that art museums fostered the development of critical thinking and inquiry skills. Furthermore, İlhan et al. (2021) concluded that museum visits contributed to long-term retention and learning among social studies teacher candidates. Gürbey et al. (2020) examined pre-service science teachers' perceptions of museum education as part of out-of-school learning environments. They underscored the importance of combining theoretical instruction with practical experiences, facilitating museum visits, increasing their frequency, and promoting diverse museum options to enhance the effectiveness of educational activities. The study also highlighted that teacher candidates emphasized the necessity of raising teachers' awareness, establishing new mathematics museums, and organizing visits to integrate museums effectively into mathematics education. In addition, participants suggested that topics frequently included in mathematics curricula—such as probability, geometry, and the history of mathematics—should be represented within museum contexts. However, this finding differs from that of Kayhan-Altay and Yetkin-Özdemir (2023), who reported that although middle school mathematics teacher candidates incorporated museum resources into lesson plans across various mathematical concepts, geometry topics were included to a lesser extent compared with other subjects.

Contemporary museums are increasingly evolving from their traditional functions to provide spaces that integrate entertainment and educational purposes (Okvuran & Karadeniz, 2022). Observations suggest that these institutions seek to engage visitors through architectural design and functional features (Uysal, 2013). At present, there is a discernible shift from a static museum paradigm toward a more dynamic and interactive model (Sezgin Özrili & Özrili, 2021). This development is consistent with the findings of Dumont et al. (2025), who reported that digital museum experiences effectively capture learners' attention, according to educators' perspectives.

Each museum serves a distinct audience, resulting in diverse needs, communication strategies, and visitor preferences across different types of institutions (Acar, 2017). Within the museum's articulated vision framework, two key communication parameters—target audience and resource allocation—warrant careful consideration throughout the museum design process (Acar, 2017). Considering these

factors and aligned with the objectives of the present study, it was deemed appropriate to base the design on the perspectives and recommendations of pre-service mathematics teachers.

The design priorities identified by pre-service teachers for a mathematics museum correspond closely with the defining features of interactive museums. Such museums aim to provide visitors with memorable experiences by conveying the narratives of exhibited objects, situating them within their historical and intellectual context, and fostering critical thinking, analytical reasoning, and interpretative skills. Acar (2017) asserts that the incorporation of interactive design elements constitutes one of the most effective strategies for facilitating active learning. Given the similarities between the target audiences of science and mathematics museums, interactive technological spaces are commonly employed in these institutions to satisfy visitors' inherent expectations. Within these technologically enhanced, interactive environments, tools such as simulators, virtual reality applications, and 3D printers are utilized to engage visitors with the central subject matter (Uysal, 2013). In the present study, the panorama and simulation hall designed based on pre-service teachers' recommendations exemplifies this approach (see Figure 1).

Analysis of pre-service teachers' recommendations indicates that they perceive learning environments enabling students to engage in direct, hands-on interactions and to learn mathematics through active participation as conducive to enjoyable and enduring learning. This finding is consistent with the results reported by Hamurcu et al. (2007), Dumont et al. (2025), and Casi and Sabena (2024). Accordingly, mathematics museums are expected to provide multidimensional benefits enhancing students' academic achievement and fostering positive attitudes toward learning and supporting the application of mathematical concepts to real-life contexts. Evidence from the literature on informal learning environments, which underscores their role in developing problem-solving, critical thinking, and mathematical creativity skills, further corroborates the findings of the present study (Zoldosova & Prokop, 2006; Rennie et al., 2003).

Recommendations

- ✓ Pre-service teachers could receive targeted training on how to effectively integrate museums into mathematics education. Additionally, since mathematics museums remain relatively unfamiliar to many teacher candidates, introductory orientation sessions, and informational brochures and posters could be provided to increase their awareness and understanding.
- ✓ The position of museum education courses, currently offered as elective subjects within teacher education programs, could be critically examined. If deemed necessary, such courses may be transitioned from elective to compulsory status and incorporated as mandatory components within the undergraduate curriculum of education faculties.
- ✓ Pre-service teachers who enroll in museum education courses could be provided with opportunities to engage in practical, hands-on activities within museums during their undergraduate studies.
- ✓ Insights from pre-service teachers, along with evidence from the literature, suggest that the number of mathematics museums in Turkey remains insufficient. Therefore, the development of additional mathematics museums as out-of-school learning environments is strongly recommended.
- ✓ Informed by the recommendations of pre-service teachers, mathematics museums can be designed to provide engaging and enjoyable experiences for visitors. To maintain their ongoing development and ensure relevance, museums should also administer visitor evaluation surveys.
- ✓ Pre-service teachers highlighted the significance of fostering collaboration between schools and museums, alongside ensuring sufficient guides to support visitors. These strategies are anticipated to enhance both the functionality and overall effectiveness of mathematics museums.

- ✓ Research integrating museums into mathematics education in Turkey remains scarce (Aydoğdu et al., 2022). Expanding the body of research on mathematics museums as out-of-school learning environments is recommended, with an emphasis on examining diverse and contemporary aspects of the subject.
- ✓ The insights and recommendations of mathematics educators should inform the design of mathematics and science museums.

Ethics and Conflict of Interest
This research was conducted with the permission obtained from the Ethics Committee of Dokuz Eylül University Legal Counsel, dated 06.01.2022 and numbered E-87347630-659-173775. The authors declare that they acted in accordance with ethical rules in all processes of the research. The authors declare that they have no conflict of interest.

Author Contribution
All authors contributed equally to the research.

Data availability
The data that support the findings of this study are available on request from the corresponding author.

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IOJPE
ISSN: 1300 – 915X
www.iojpe.org
International Online Journal of Primary Education 2025, volume 14, issue 4

APPENDIX 1.

INTERVIEW FORM ON THE INTEGRATION OF MUSEUMS INTO MATHEMATICS EDUCATION

This form seeks to collect pre-service elementary mathematics teachers' views on museum education and their perspectives on integrating museums into mathematics education. The information obtained will be used within the scope of the TÜBİTAK 2209-A research project. The form consists of nine open-ended questions and is expected to take approximately 30 minutes to complete. After carefully reading each question, you are kindly asked to provide responses reflecting your views. Please ensure that no questions are left unanswered. We sincerely thank you for your voluntary participation in this study.

Questions:

1. What does the concept of a museum evoke for you, and what kind of place comes to mind when you think of a museum?
2. Have you previously participated in any educational activities conducted in a museum setting?
   a) How frequently do you visit museums?
   b) What types of museums have you visited? Please specify.
3. In your opinion, for what purposes can individuals visit museums?
4. In your opinion, can museums be considered as out-of-school learning environments? If so, what types of educational activities might they be utilized for? Please elaborate.
5. Have you previously participated in any educational activities conducted in a museum setting?
6. In your opinion, could there be a relationship between the concepts of mathematics and museums? Please explain.
7. In your opinion, is it possible to utilize museums in mathematics education? Please explain.
8. Do you have any suggestions for integrating museums into mathematics education?
9. What aspects would you consider if you were to design a mathematics museum?