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Determination of Mistakes Made by Pre-Service Mathematics Teachers in Fermi Problem-Solving Performance and Solutions

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Abstract

One of the reasons why students fail in mathematics courses is that the problems used in the lessons are abstract. In this context, it is important to embody the problems used in the lessons. Fermi problems are open-ended problems, a type of problem that reflects real-life situations that are solved by making a series of predictions. In the future, with these problems involving real-life situations, it is today's pre-service mathematics teachers who are primarily responsible for carrying out an effective teaching process in school mathematics. This research was carried out within the scope of the case study design, which is one of the qualitative research designs, which aims to determine the errors made by primary school mathematics teacher candidates in their performance and solutions to solve the Fermi problem. The study group of the study consisted of 44 pre-service teachers studying in the 4th grade in the department of primary school mathematics teaching in a province located in the southern region of Turkey in the 2022-2023 academic year. As a result of the research, it was concluded that the scores obtained by the pre-service mathematics teachers from the solutions of Fermi problems were not at the desired level, and the performance of the teacher candidates was at a medium level. From the error detection, it was find that the source of this situation is mostly due to the weakness in the dimensional estimation process.

Introduction

Mathematics is a science of patterns and order rather than solving many examples or imitating the methods explained by the teacher. Finding this order and layout, discovering it, and then making sense of it is literally doing mathematics. In addition, doing mathematics means developing methods for solving problems, applying these methods, seeing whether they lead to a result and checking whether the answers given are meaningful. Doing life math in the classroom means being able to model situations where we actually use math, as faithfully as possible. In other words, an important part of doing math also involves problem solving. As a matter of fact, in the Recommendations for School Mathematics of the 1980's published by the National Council of Teachers of Mathematics (NCTM) regarding problem solving, it was indicated that the development of problem-solving skills in the next ten years is related to developments in mathematics education. In addition, it has been stated that problem solving skills will measure the effectiveness of individuals and nations. In order to develop problem-solving skills, the experiences offered to students in the classroom should be designed to provide the highest level of learning opportunities for students (Van De Walle, Karp, & Williams, 2016). Those who are primarily responsible for the provision of these environments are the teachers.

Estimation skill, like problem solving skill, is one of the skills that are emphasized in both mathematics curriculum and scientific studies. Situations that require individuals to make estimations are concrete examples of problem situations that require them to use mathematics in daily life. Creating a learning environment that will enable to do mathematics related to these skills will contribute to the development of these skills in students. Problem solving is a fundamental part of learning mathematics (NCTM, 2000). Fermi problems are a type of open-ended problem that is solved by making a series of predictions.

Fermi Problems

The term, Fermi problem, comes from Italian Enrico Fermi, winner of the 1938 Nobel Prize in physics. Enrico Fermi worked on problems that require chained assumptions where there is no single correct solution and the answers are uncertain, such as 'How many railroad cars are there in the USA?' (Goldberger, 1999) or 'How many piano tuners are there in the USA?' (Efthimiou & Llewellyn, 2007). Errors in these assumptions are thought to cancel each other out. Fermi stated that while solving these problems, correct answers can be obtained by making assumptions and using estimations. Fermi was of the opinion that each person can make quantitative estimates close to the true value of any quantity, simply "using his head." Fermi problems can be defined as open-ended, non-routine problems that require making assumptions and systematic estimations before starting the solution. Efthimiou and Llewellyn (2007) stated that Fermi problems should be used in the education process as they improve and accelerate students' critical thinking and reasoning. Sowder (1992) stated that there is no definite answer to Fermi problems and since there is no definite answer, the problems must be answered with a guess. Fermi problems allow students to arrive at the solution of the problem through guesses and assumptions. In these problems, it may not be possible to obtain a definite answer without obtaining more information. “How many papers are used in a month in your school?”, “How many vehicles are in the traffic in an area of 3 kilometers?” questions can be shown as examples to Fermi problems (Peter-Koop, 2005).

Adapting the Fermi problem to biology, Schoenfeld (1985), examined the problem-solving processes of students using a problem such as "How many cells are in the human body?" which is difficult to answer at the beginning and which needs a hypothesis and guess. Schoenfeld stated that since students use the information stored in their long-term memory while solving these problems, it is important to use them in the problem-solving process in order to determine their level of knowledge. It is mentioned that Fermi problems are related to estimation and modeling in mathematics education. In addition, Fermi problems were also used in the development of students' critical thinking skills (Sriraman & Knott, 2009; Sriraman & Lesh, 2006).

Research Questions

The situations that require individuals to make estimations are the concrete examples of problem situations that require them to use mathematics in daily life. Fermi problems are the problems that involve daily life situations and the problem type that can be solved by making estimations and assumptions. In the literature, the studies (Albarracín & Gorgorió, 2014; Bergman Ärlebäck & Albarracín, 2023; Bergman & Bergsten, 2010; Brunet-Biarnes & Albarracín, 2022; Hıdıroğlu & Özkan, 2017; Ferrando & Albarracín, 2021; Ferrando, Albarracín, Gallart, Lluís, García-Raffi & Gorgorió, 2017; Abay & Gökbulut, 2017; Peter-Koop, 2005; Pla-Castells, Melchor & Chaparro, 2021) in which Fermi problems were used to figure out the modeling processes of the individuals have been more commonly encountered in the mathematics education researches.

Fermi problems are questions that involve both problem-solving skills and estimation skills involving real-life situations. Within the available sources, when the field literature is examined, there is no study examining the performance of pre-service mathematics teachers in solving Fermi problems and the mistakes they make in their solutions. With these problems involving real-life situations, it is today's pre-service mathematics teachers who will be primarily responsible for carrying out an effective teaching process in school mathematics. Therefore, it is important to determine the level of this skill and the mistakes they make. In this context, this research is based on the following research question: "What are the errors that pre-service primary school mathematics teachers make in their performance and solutions to solve the Fermi problem?". In line with the objective of the research, answers to the following questions are sought:

- How do pre-service teachers perform in solving the Fermi problem?
- What mistakes do pre-service teachers make when solving the Fermi problem?

Method

In this part of the research, information about the model of the research, study group, data collection tool and data analysis are included.

Research Model

In this research, qualitative research method was used. Qualitative research is a form of research in which qualitative data collection methods such as observation, interview and document analysis are used and a qualitative process is followed to reveal perceptions and events in a realistic and holistic way in the natural environment (Yıldırım & Şimşek, 2011). In this research, which aims to determine the errors made by pre-service primary school mathematics teachers in solving the Fermi problem and their solutions, the data were obtained by using the document analysis technique.

Study Group

The study group of this research consisted of 44 pre-service teachers (32 females, 12 males) attending their education in the 4th grade in the department of primary school mathematics teaching in a province located in the southern region of Turkey in the 2022-2023 academic year. The study group was determined according to the appropriate sampling method from non-probability-based sampling methods. The purpose of choosing the appropriate sampling method is that the researcher is close to the participants and easy to access (Patton, 2014).

Data Analysis and Data Collection Tool

The data were obtained using the document analysis technique. As a document, 44 answer sheets containing the answers of participants to the Fermi problem were used. The data collection tool was applied to each pre-service teacher individually. The Fermi Problem-Solving Worksheet (FPSW), which includes demographic information and a Fermi problem, was used as a data collection tool. During the implementation process, the teacher candidates were told that they were expected to make the first solutions to the Fermi problem that came to their minds and that they had 20 minutes. In the analysis phase, firstly, the solutions of the teacher candidates for Fermi problems were scored. These ratings are reflected in the findings.

The sub-problems related to the scoring of Fermi problems were handled separately according to the levels of forming-assumption, reasoning and solving, and was classified as the level to imporove **(**0≤ point <2), intermediate level (2 ≤point<3) and good level (3≤ point ≤4**).** Since there is only one problem in the data collection tool, the maximum score that can be obtained is determined as 4. Fermi problems are a type of open-ended problem that is solved by making a series of predictions. There are different approaches to the evaluation of estimation skill in the field literature. Van de Walle et al. (2016) indicated that the range of 10% can be taken for length estimates, and 30% for volume and weight estimates for acceptable estimative value. Baroody and Gatzke (1991) stated that the real answer would be to value between 25% less and more. Same researchers have used the 50% range in their studies (Crites, 1992). In this research, Van de Walle's approach was adopted while analyzing the answers of the students to Fermi problems. A diagram for scoring is presented in Figure 1.

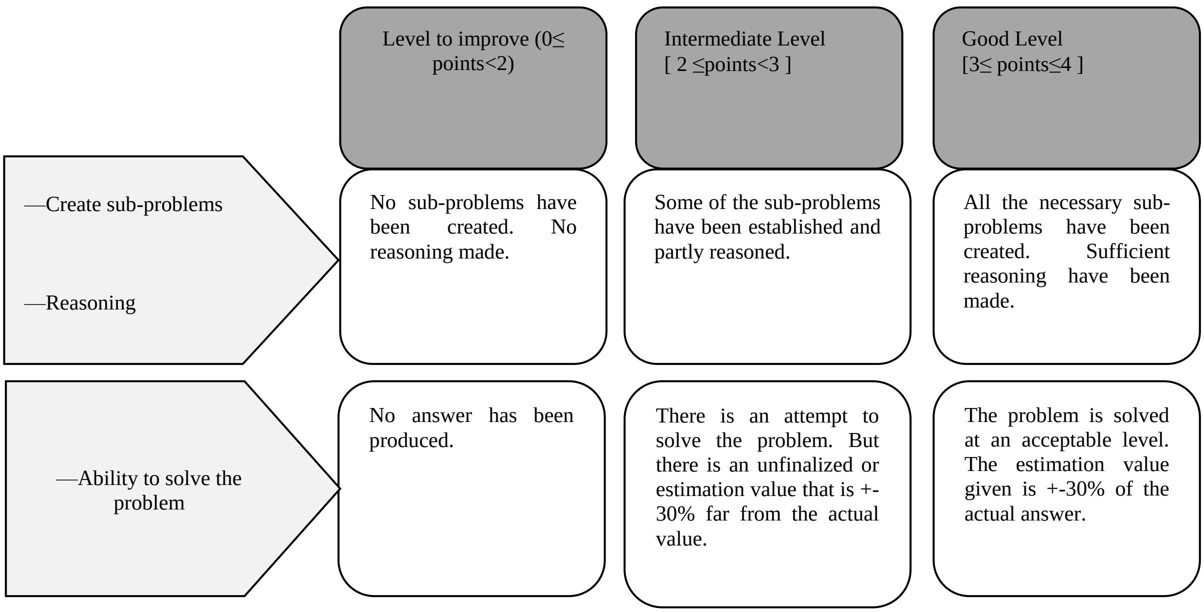


Figure 1. Scoring the Solution of the Fermi Problem

To ensure reliability in scoring the performance of pre-service teachers in Fermi problems, scoring was also performed by an academician who is an expert in the field of mathematics education, independent of the researcher. Reliability was calculated as 0.91 using the encoder reliability formula (Miles & Huberman, 1994) to determine the agreement between the obtained scores. Since this value is greater than 0.70, the scoring can be said to be consistent. Pre-service teachers were coded in the form of T1, T2, T3.... .

Then, it was determined which mistakes the teacher candidates made while solving the problem. Content analysis was used from qualitative data analysis techniques to detect the mistakes made by pre-service teachers in their answers to the Fermi problem. Content analysis is the thematic analysis of data in terms of certain categories by scanning it in a systematic way. With the data obtained in content analysis, there is identification, counting and interpretation of recurring topics, problems and concepts (Denzin & Lincoln, 2008; Miles & Huberman, 1994; Silverman, 2000). To ensure reliability in the detection of errors, we came side by side with the specialist in mathematics education and each error detected was noted and checked.

Findings

In this section, the findings and interpretations obtained as a result of the research data are included.

Findings and Comments on the Performance of Pre-service Teachers in Fermi Problem Solutions

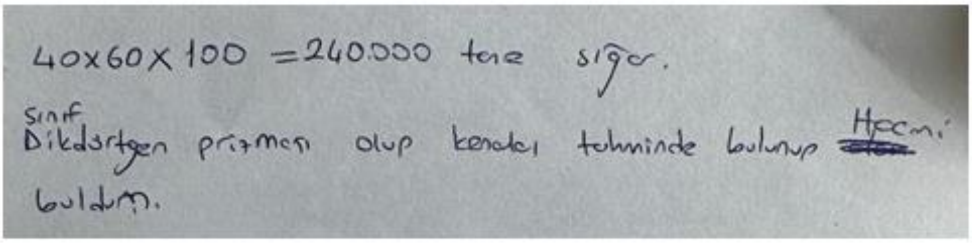
The arithmetic mean value of the scores of the pre-service teachers from the solution of Fermi problems was calculated as 2.59, and the standard deviation values were calculated as 0.972. It can be said that pre-service teachers' scores from the solution of Fermi scores are between intermediate and good level. The findings regarding the classification of teacher candidates according to the scores they received from the solution of the Fermi problem are given in Table 1.

Table 1.Levels of Pre-service Teachers

Levels	**Code**	f
Level to improve	Ö5, Ö6, Ö7,Ö13, Ö38,	5
Intermediate Level	Ö3, Ö4, Ö9, Ö11, Ö14, Ö17, Ö18, Ö19, Ö20, Ö24, Ö26, Ö27, Ö28, Ö32, Ö33, Ö40, Ö43, Ö44	18
Good Level	Ö1, Ö2, Ö8, Ö10, Ö12, Ö15, Ö16, Ö21, Ö22, Ö23, Ö25, Ö29, Ö30, Ö31, Ö34, Ö35, Ö36, Ö37, Ö39, Ö41, Ö42,	21

According to Table 1, from the analysis of the scores obtained from the solution of Fermi problems; 21 of the mathematics pre-service teachers are at a good level; 18 are at an intermediate level; 5 are at the level that needs improvement. In addition, it can be said that the majority of the scores of the pre-service teachers from the solution of the Fermi problem are at the middle and improving levels (f: 5 + 8 = 23). When the average score of pre-service mathematics teachers from the solution of Fermi problems (2.59) and the levels they are at are taken together, it can be said that the teacher candidates are at the intermediate level. In Figure 2, the sample solution of the teacher candidate who received 1 point from the solution of the problem is presented.

Turkish:

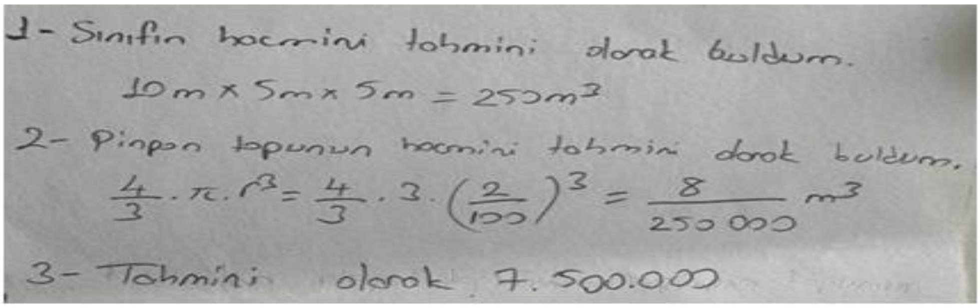

40x60x100 = 240.000 tane sığar.
Sınıf Dikdörtgen prizması olup kenarları tahminde bulunup Hacmi buldum.

English: I thought the class was a rectangular prism. I estimated the side lengths and calculated the volume.

.Figure 2. T13’s Solution to the Fermi Problem

T13 did not identify the sub-problems required for the solution of the problem and made an estimate (see Figure 2). The estimation value given by T13 to the answer to the problem was found to be less than the actual value and far from the acceptable range of predictions (-+30% of the actual value). Here, T13 received 1 point from the solution of the problem. In Figure 3, the sample solution of the pre-service teacher (T26) who received 2 points from the solution of the problem is presented.

Turkish:


1- Sınıfın hacmini tahmini olarak buldum.
$10m \times 5m \times 5m = 250m^3$
2- Pinpon topunun hacmini tahmini olarak buldum.
$\frac{4}{3} \cdot \pi \cdot r^3 = \frac{4}{3} \cdot 3 \cdot \left(\frac{2}{100}\right)^3 = \frac{8}{250000} m^3$
3- Tahmini olarak 7.500.000

English:
1.I found the size of the class as an approximation
2.I estimated the volume of the ping-pong ball.
3.Answer is estimated at 7.500.000

Figure 3. T26’s Solution to the Fermi Problem

T26 identified and solved the sub-problems necessary for the solution of the by halves problem, and made predictions and assumptions (see Figure 3). The estimation value that T26 gives to the answer to the problem is far from the acceptable range of predictions (-+30% of the actual value), more than the actual value. In Figure 4, the sample solution of the pre-service teacher (T30) who received 3 points from the solution of the problem is presented.

T30 identified and solved the sub-problems necessary for the solution of the problem, and made estimations and assumptions (see Figure 4). However, T30 estimated the length of one side of the ping-pong ball less than its actual value and made his calculations. Therefore, the estimation value that T30 gives to the answer to the problem is far from the acceptable range of predictions (-+30% of the actual value), which is more than the actual value. In Figure 5, the sample solution of the pre-service teacher (T23) who received 4 points from the solution of the problem is presented.

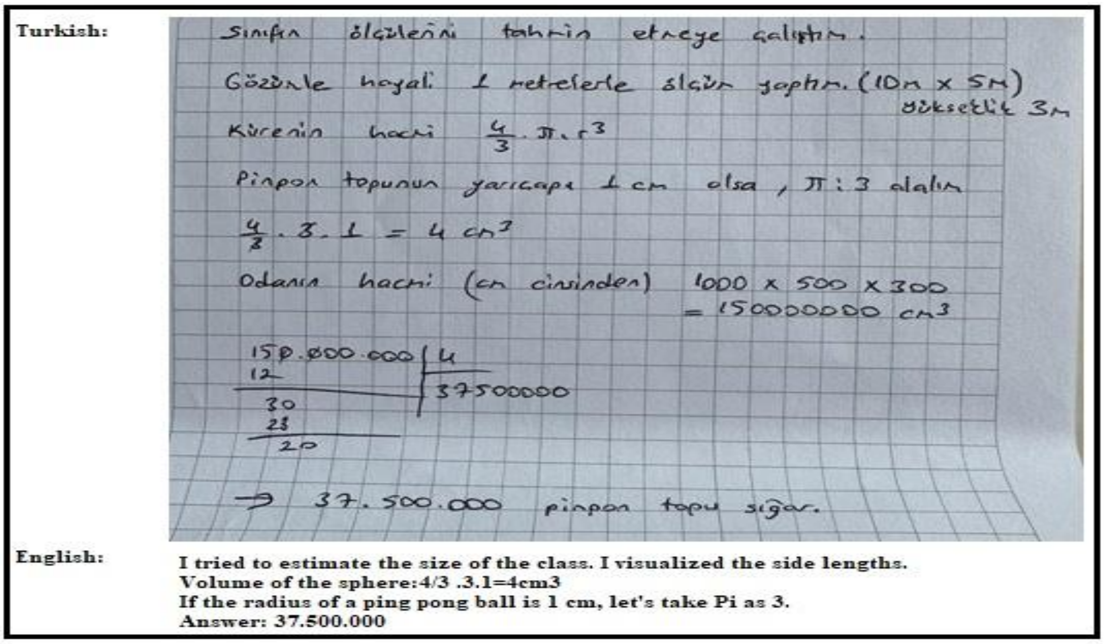


Figure 4. T30’s Solution to the Fermi Problem

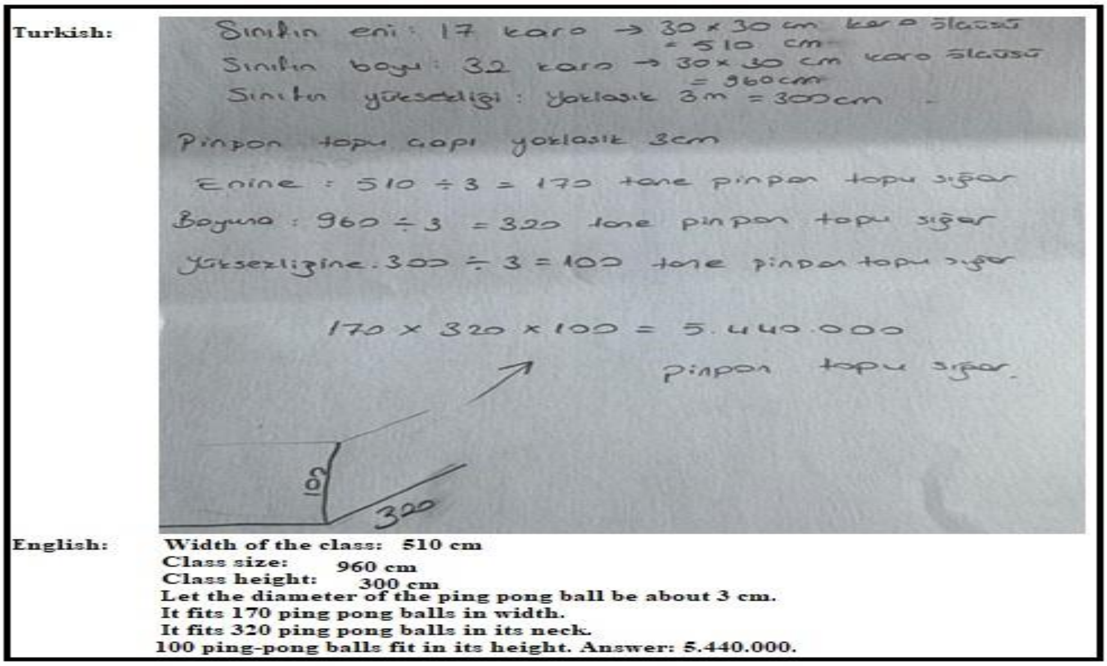


Figure 5. T23’s Solution to the Fermi Problem

T23 identified and solved the sub-problems necessary for the solution of the problem, and made predictions and assumptions (see Figure 5). The predictive value that T30 gives to the answer to the problem is in the acceptable range of predictions, close to the actual value (-+30% of the actual value)

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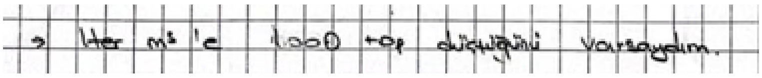
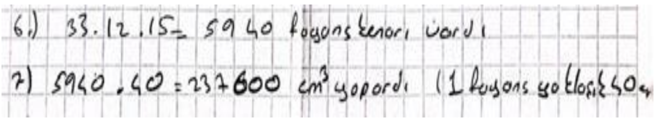
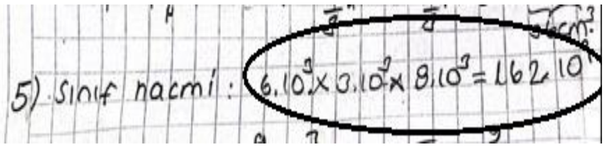
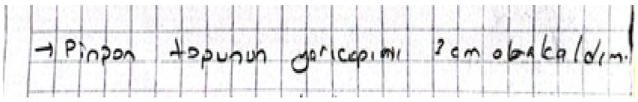
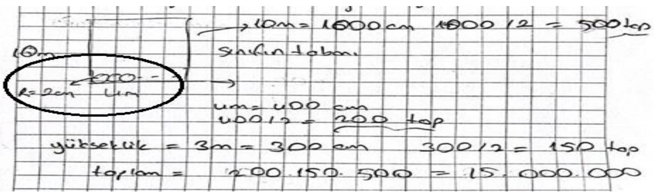
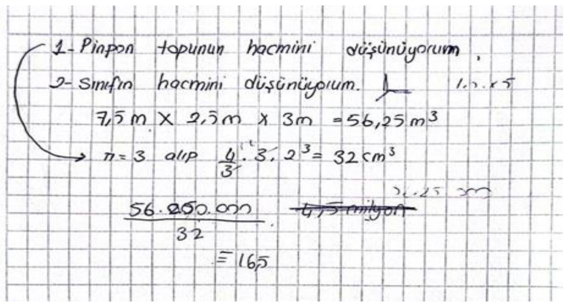
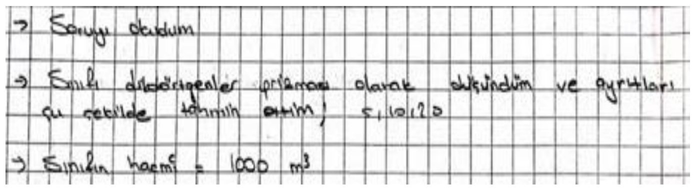
Findings and Comments on the Error of Pre-service Teachers in Fermi Problem Solutions

The findings of the mistakes made by the teacher candidates in solving the Fermi problems are given in Table 2.

Table 2. Errors in Solutions, Examples and Frequency of Errors

Errors	**Pre-service teacher codes**	**Examples of pre-service teachers' solutions and explanations**	**f**
Error caused by too little of the estimation value or assumption	*Ö4, Ö5, Ö6, Ö7,Ö11,Ö13,Ö19, Ö20,Ö21,Ö24, Ö36, Ö40, Ö43*	*T43: I assumed that 1000 ping-pong balls would fit in a volume of 1m³.* 	13
Error caused by not understanding the problem	*Ö3*	*T3:*  *(He calculated the height of the class by counting the tiles on the base. But he multiplied the total number of tiles by the approximate length of a tile, 40 cm, and evaluated this value as the volume of the class)*	1
Volume failure	*Ö3, Ö17*	*T17:*  *(One margin of the class is calculated as 6 m = 6.10³cm. Similarly, the same is true in other segment lengths of the class.)*	2
Error caused by taking the radius of the ping pong ball more than its actual value	*Ö9, Ö14, Ö28*	*T14: I took the radius of the ping pong ball as 3cm.*  *(It is the case that the radius of the ping pong ball is calculated as 3 cm)*	3
Errors caused by the radius of the ping pong ball being less than its actual value	*Ö29, Ö30,Ö31*	*T29:*  *(It is the case that the diameter of the ping pong ball is calculated as 2 cm)*	3
Error caused by taking the	*Ö10, Ö12, Ö14, Ö18, Ö26,*	*T18: 1. I think about the volume of the ping pong ball.* *2. I think about the volume of the class*	8

Errors	Pre-service teacher codes	Examples of pre-service teachers' solutions and explanations	f
class detail lengths less than their actual value	*Ö27,Ö34,Ö37*	*7.m x 2.5m x 3m=56.25m^3……*  *(In the case of the class having a distinction length less than the actual value)*	
Error caused by overestimating the class detail lengths	*Ö43*	*T43: I read the question. I thought of the class as a prism of rectangles and took the distinctions as 5, 10, 20.* *Volume of class = 1000cm^3*  *(It is the case that the class has more detail lengths than the actual value)*	1

According to Table 2, the errors made by the pre-service math teachers are listed as error due to the fact that the estimation value or assumption is really too low (f:13), error caused by taking the class detail lengths less than the actual value (f:8), errors caused by taking less than the actual value of the radius of the ping pong ball (f:3) or more than the actual value (f:39). In addition, it is seen that two pre-service teachers make a unit error and one pre-service teacher makes a mistake due to taking the separate lengths of the class more than the real value. It can be said that the errors made from this are mostly errors involving estimation situations.

Discussion and Conclusion

This research, which aims to determine the errors made by pre-service primary school mathematics teachers in their performance and solutions to solve the Fermi problem, is based on the data obtained from 44 teacher candidates. In line with the first research question, from the analysis of the scores obtained from the solution of Fermi problems, it was concluded that 21 of the participants were at a good level, 18 of them were at an intermediate level and 5 of them were at the level that needed improvement. When the average score of the mathematics teacher candidates from the solution of the Fermi problems (2.59) and the levels they are at are taken together and the research sample is taken into consideration that the mathematics teacher candidates are taken into consideration, the result of the research is also thought-provoking.

Fermi problems are a type of problem that is solved by making a series of predictions. Therefore, if the estimation values during the process are close to the actual value, the solution of the Fermi problem is also close to the real value. In the studies where the measurement estimation performance of individuals in the field literature is discussed (Boz Yaman & Bulut, 2017; Er, 2023; Kumandaş & Gündüz, 2014; Satan & Yetin, 2022) has been shown to have poor or moderate metric forecasting skills. Boz-Yaman and Bulut (2017) found that although teachers expressed the importance of estimation skills in their studies with teachers, they did not practice estimation in the lessons. Considering the result obtained from the study, it can be thought that the fact that teachers give education focused on finding clear results to the students instead of running the estimation skills to work in the lessons leads to this result. Ev Çimen and Bilgiç (2022) investigated the types of estimation skills included in secondary school mathematics textbooks and their distribution according to learning areas and chapters in the textbook. As a result of the research, it was seen that while the most used estimation type at each grade level was operational prediction, there was a limited amount of content for heap prediction. In addition, the researchers stated that the contents of estimation in the textbooks are generally concentrated in the sections such as exercises and solved examples, there is very little content in the activity sections, and even there is no place in the 7th grade textbook. The limited use of this skill in textbooks may be one of the reasons for the findings obtained in this study. In this research, the failure of the participants' performance to solve the Fermi problem at the desired level may be due to the learning habits of the periods they were students.

In line with the second research question, it was concluded that the most common mistakes made by the participants were errors caused by the fact that the estimate value or assumption was really too little, and that the class lengths were taken less than the real value. In addition, other errors made were determined as error caused by not understanding the problem, unit error, error caused by taking the class of the detail lengths more than the actual value, error caused by taking more or less than the actual value of the radius of the ping pong ball. In this research, it is seen that the mistakes made by pre-service teachers are mostly concentrated in situations that require estimation during the solution of the problem. Segure and Fernando (2023) examined the flexibility and performance of teacher candidates in solving Fermi problems, and found that three-quarters of pre-service teachers made mistakes in solving Fermi problems; more than two-thirds of the participants were moderately or very flexible in their solutions. Measurement and estimation procedures are related to the Fermi problem-solving process (Hagena, 2015). The fraction of teachers in the study of Copur Gençtürk (2022) examined their estimation of its size. As a result of the research, the teachers' estimations were only partially accurate and reasonable, particularly when fraction division was involved. In the studies where the mistakes made in the problem-solving process in the field literature are addressed (Copur Gençtürk, 2022; Copur-Gencturk & Doleck, 2021;Segure& Fernando 2023), it has been observed that individuals make errors during measurement estimation rather than calculation errors. From here, it can be said that the findings of the literature and these research findings are similar.

In summary, it was concluded that the scores obtained by the pre-service mathematics teachers from the solutions of Fermi problems were not at the desired level, and the performance of the teacher candidates was at a medium level. From the error detection, it can be said that the source of this situation is mostly due to the weakness in the dimensional estimation process.

Suggestions

Problem solving and estimating skills are important skills in mathematics education. To achieve the desired success in Fermi problems, it is important to have effective teaching aimed at developing the ability to estimate the measure. First of all, it is necessary to develop the knowledge of pre-service teachers and teachers in the field on this subject and their skills in teaching this subject. Mathematics teachers should also be supported to develop in terms of dimensional estimation skills and problem solving with in-service trainings, courses and seminars to be given by the Ministry of National Education. This research also used a Fermi problem in the data collection tool. In addition, it is recommended to give more space to activities involving estimation skills and Fermi problems in textbooks, and to increase the number of acquisitions for these subjects in the mathematics curriculum. With more Fermi problems and different samples, it is recommended to repeat this research.

Limitations

This research, which aims to determine the performance of pre-service primary school mathematics teachers in solving the Fermi problem and the mistakes they make in their solutions, is limited to the data obtained from 44 pre-service primary school mathematics teachers. Another limitation of the research is that the data collection tool involves one Fermi problem.

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