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Pre-Service Physics Teachers' Difficulties in Understanding Special Relativity Topics

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Abstract
The aim of this study is to identify the reasons why pre-service physics teachers have difficulties related to special relativity topics. In this study conducted with 25 pre-service physics teachers, the case study method, which is a qualitative research method, was used. Interviews were held with the participants about their reasons for difficulties in understanding special relativity topics. We used content analysis with the interview data and created eight categories. By doing so, we tried to identify the causes of difficulties experienced by the participants. As a result, it can be said that students are biased against relativity subjects and consider them to be difficult. Although the students found the subject interesting, problems such as mathematical difficulties, problems related to determining the reference system and transition from classical physics to relativistic physics made the learning process difficult for them. Additionally, we identified positive and negative opinions about the teaching method.
Keywords: Special relativity, Pre-Service Physics Teachers, Difficulty understanding.

INTRODUCTION

The theory of relativity is one of the most fundamental theories of physics. Recently, the teaching of this theory has been given more attention. At first, relativity was only taught at the level of higher education in Turkey, but it has begun to be taught in high schools since 2008. Accordingly, the number of science teaching researches on these topics have increased (Özcan, 2011; Selçuk, 2011; Yıldız, 2012).

Relativity contains topics that are difficult to learn and teach. Previous studies show that students have difficulties in understanding relativity related topics (Guisasola et al, 2009; Ireson, 1996; Scherr et al, 2001; Scherr et al, 2002; Selçuk, 2011). Dimitriadi and Halkia (2012) reported learning difficulties due to reference systems and students' tendency to combine theory of relativity with classical physics. Another study shows that students believe that there is a preferred/privileged observer; and time dilation and length contraction only occur according to the moving observer (Villani & Pacca, 1987). In the study that he performed with pre-service teachers from different academic levels, Selçuk (2011) identified significant learning difficulties in concepts of proper time, time dilation, proper length, mass and relativistic density. Even when students take advanced level lessons, they can't understand the implications of special relativity on interpreting the physical world (Scherr et al, 2002). From this perspective, it seems necessary to develop teaching approaches suited to special relativity. Some studies point out the positive contributions of using the history of science to teach relativity (Arriassecq & Greca, 2012; Villani & Arruda, 1998). Ogborn (2005) suggests a sequence consisting of four steps for teachers to teach relativity. Among studies on special relativity, studies focusing on teaching by visualisation occupy an important place (Carr & Bossomaier, 2011; Henriksen et al,2014; Kortemeyer et al, 2013; Kraus, 2008; McGrath et al, 2010; Savage et al, 2007; Smith, 2011; Wegener et al, 2012). Al-Khalili (2003) shares his ideas about teaching relativity using topics that most people find interesting, such as time travel. Some studies have suggestions on laboratory experiment about relativity (Singh, Singh & Hareet, 2011; Singh, 2013).

In studies that investigate the difficulties of students related to relativity, difficulties were identified based on students' answers to relativity-related questions. Although there are several studies in the literature in which difficulties experienced by students in physics are investigated, there is no study that investigates the reasons why students have relativity-related difficulties by asking students about these difficulties. Therefore, this study differs from other studies in terms of the method used to determine the reasons why students have difficulties in relativity topics. The aim of this study is to identify the reasons why pre-service physics teachers have difficulties related to relativity topics. The research question is "Why do pre-service physics teachers have difficulties related to relativity topics?"

METHOD

This study is a qualitative research. The reason for qualitative research is because it was intended to achieve analytic generalization rather than generalizing the results for the population. Analytical generalization aims to reach certain conclusions or theories through a limited number of participants or information sources (Altunışık et al., 2002). The research method of the study is similar to the case study. Case study is defined as "in-depth review focusing on a current case, event, situation or set" (Yin, 1994). In other words, case study is an in-depth study seeking answers for "how" and "why" questions (Yıldırım & Şimşek, 2006). Case study involves an interest towards the process rather than the results, the context rather than a specific variable, reviewing and finding rather than proving (Merriam, 1998). How the research was conducted as described below.

The study was performed during a special relativity course. The subject of special relativity was taught by dividing it into topics of Relativity of Time, Relativity of Length, Lorentz Transformation Equations, Lorentz Velocity Transformation Equations, Relative Momentum and Relative Energy.

Participant Selection

This study was conducted with pre-service teachers taking the Special Relativity course. The study was conducted during the Spring Semester of 2014 with 25 pre-service physics teachers. Pre-service physics teachers take this course in the 6^{th} semester. In the semester in which this study was conducted, four of the participants were in the 6^{th} semester of their university education, nine participants were in the 8^{th} semester, nine participants were in the 10^{th} semester, and five participants were in the 12^{th} semester or above. The high number of pre-service teachers repeating the course, which is supposed to be taken in the 6^{th} semester, can be seen as an indicator of difficulties experienced in relation to the course. The aim of this study is to identify the reasons behind these difficulties. Therefore, purposive sampling was preferred and all students taking the course in the related semester were included in the study.

Data Collection Method

Data collection was carried out in two stages. In the first stage, the participants were asked to write down why they thought each topic was easy or difficult for them. There was no time limit at this stage.

In the second stage, interviews were held with the participants to further investigate their difficulties and better understand the papers written by the participants. During these interviews, some participants changed or made additions to some of their statements and explained them in detail. Thus, attempts were made to find out the opinions of the participants more clearly and deeply. There was no time limit for the interviews either.

Data Analysis Method

Description papers and interview notes, which are qualitative data sources, were considered as the raw data. The raw data was evaluated using the content analysis method. The main purpose of the content analysis is to find the concepts and relations that explain the data obtained (Yıldırım & Şimşek, 2006). The content analysis method was used in order to identify the data, bring the similar data together within the framework of certain concepts and themes and reveal the truth that might be hidden in the data (Aslan, 2009). To this end, the raw data was encoded. Samples for how the codes were identified are as follows:

Participant A11: *"I had trouble because they are abstract concepts, I couldn't imagine them.",*

"RE-3: It was difficult for me because the concepts were abstract" is taken as the code name.

Participant A24: "*I have difficulties because relativity of time is abstract. For example, the twins paradox. I can't associate it with daily life*.", "RT-18: I cannot adapt to daily life" is taken as the code name.

Participant A11: "*The formulas are not difficult. It is easy to solve the problems when you determine in which reference system the quantities were measured.*", "LTE-1: It's difficult to identify quantities in Reference Systems" and "LTE-6: The formulas are easy" are taken as the two different code names.

The codes were divided into categories and grouped together using their similar features. The principle of "coding according to concepts concluded from the data", which was suggested by Strauss and Corbin (1990) was used for coding. The codes were divided into eight categories in total. The said categories are shown in Table 1 with examples. The examples given in Table 1 were taken from written expressions of the participants or used during the interview as a description for that category. The participants were number from A1 to A25.

Table 1*. Categories and Descriptions*

Category	**Description**	**Examples**
C1	Difficulties in problem solving, difficulties related to correlations, difficulties related to mathematical competence, and difficulties related to measurements in different reference systems.	A4: "I get confused when I'm supposed to write which quantity in the equation (when solving a problem)." A7: "It is difficult to determine in which reference system the quantities were measured in the problems." A11: "The formulas are not difficult. It is easy to solve the problems when you determine in which reference system the quantities were measured."

C2	Explaining the topic by giving examples from real life, using thought experiments, by dramatizing, watching documentaries.	A5: "Understanding the thought experiences requires effort." A15: "It was not hard for me to accept the relativity of time, I had read a book before because I had thought time travel was interesting." A18: "It is easier to solve problems with pictures and images, but it is hard to imagine other problems."
C3	Bias, interest/liking towards the topic, caring/not caring for the topic, contradiction to common sense/anticipations.	A19: "… there were conclusions that contradicted with my common sense in the snake example, such as the closing times of the doors." A22: "…they scared me saying this course was very difficult, I was influenced by them." A2: "…nothing is easy in modern physics."
C4	Difficulties related to transition from classical physics to modern physics, difficulties from classical physics, difficulties related to separating and associating classical physics and relativistic physics, difficulties related to changes in definitions of some concepts.	A3: "…(in classical physics) we were only talking about a single time (compared to reference systems). It is very difficult to transit from the idea of classical time to relative time." A17: "I have always found the topic of energy very confusing. ... I passed the mechanics course by memorizing." A19: "I clearly understood the concept of relative momentum, because I had understood the concept of momentum in classical physics very clearly."
C5	Difficulties in associating the topics of relativity with each other.	A4: "It is confusing that the length shortens while the time expands." A6: "After learning the concept of relativity in the beginning, it was easier to understand (relative moment)." A24: "…I understand the length shortening. But I can't associate it with Lorentz transformation equations."
C6	Difficulties related to its requiring effort, studying and extra time to understand, difficulties related to memorising, whether the student took the class before or not.	A1: "…it is difficult because it requires effort, it's not easy to understand." A6: "I didn't understand the topic the first time I took the course. It is possible to understand it when you study." A25: "…It took me 2-3 months to change the concept of time that I was used to."
C7	Difficulties related to concreteness and abstractness of the concepts involved.	A13: "I can accept the change easily because time is not (a) concrete (quantity). But it is hard to accept length shortening because it is related to a concrete substance." A24: "I have difficulties because relativity of time is abstract. For example; the twins paradox. I can't associate it with daily life." A25: "I easily understood length because it is a concrete quantity."
C8	Difficulties related to whether mass is relative or not, difficulties related to conflicting resources.	A3: "Relative mass used to be accepted, now it's not. It is hard to understand that." A13: "The greatest difficulty of relative momentum is that how the momentum can be relative, if the mass is not?"

Categorized codes, categories and topics of relativity were comparatively evaluated and we tried to understand the reasons why participants had difficulties understanding.

Validity and Reliability

According to Lincoln and Guba (1985), it is more appropriate to use the concepts of trustworthiness instead of internal validity, transferability instead of external validity, dependability instead of internal reliability and confirmability instead of external reliability in qualitative studies. The trustworthiness was ensured by using two different data sources. These data sources are mentioned above. Purposive sampling was used in order to increase the external validity of the study. Also, the validity of the data obtained from the participants was increased by quoting the participants directly. The data obtained from the participants using different data collection tools was often compared and tested for consistency. In the same way, the consistency of comments was also tested. The results found were often compared with the raw data in an attempt to increase confirmability. Also, data analyses and conclusions were evaluated separately by two researchers and then researchers' evaluation results adjusted as well.

RESULTS

The raw data obtained in the study was coded and categorized. Some of the codes were positive and some were negative. For example; codes stating that the student had no difficulties or codes that explain the reasons that make it easier to learn the subject were considered to be "positive". On the other hand, codes stating that the student had difficulties and explaining the reasons that make it difficult to understand the subject were considered to be "negative". These codes and categories were evaluated both separately for each topic and as a whole. A total of 96 code types, 38 positive and 58 negative, were identified. These codes were repeated by 25 participants a total of 296 times; 107 of them positive, 189 of them negative. It shows that if participants repeat a code frequently, they want to say something about this topic and they give importance to the thought that expresses the code. In addition, it indicates that in a category the more type of codes we have in that category, the more different difficulties are experienced. The number of code types and the distribution of categories according to the topics are given in Table 2.

Table 2. *Distribution of codes and categories in the topics of the Special Relativity*

Topics	Number of Code Types	Number of Categories	Categories
Relativity of Time	20 (9+11)	7	C1, C2, C3, C4, C5, C6, C7
Relativity of Length	16 (8+8)	7	C1, C2, C3, C4, C5, C6, C7
Lorentz Transformation Equations	14 (4+10)	4	C1, C3, C4, C6
Lorentz Velocity Transformation Equations	11 (3+8)	4	C1, C3, C4, C6
Relative Momentum	16 (4+12)	7	C1, C3, C4, C5, C6, C7, C8
Relative Energy	19 (10+9)	8	C1, C2, C3, C4, C5, C6, C7, C8

As seen in Table 2, a minimum of 11 and a maximum of 20 codes were determined in Special Relativity topics. The minimum number of codes were in the Lorentz Velocity Transformation Equations topic and the maximum number of topics were in the Relativity of Time topic. The numbers shown in parentheses in the code number column are "positive" and "negative" number of codes, respectively. Proportionately, the Relative Energy topic had the highest number of codes, while Relative Momentum had the lowest number of codes.

When the codes were divided into categories, the codes belonging to Lorentz Transformation Equations and Lorentz Velocity Transformation Equations were divided into the least number of categories (4). The codes belonging to the Relative Energy topic were divided into the highest number of categories (8). Categories seen in all topics were C1, C3, C4 and C6. Category C8, which was only seen in two topics, was the least common category.

The number of codes were divided according to their positiveness or negativeness, and Special Relativity topic. The resulting distribution is given in Table 3.

***Table 3**. Distribution of Number of Codes According to Special Relativity Topics and Categories*

Topics	Positive Negative	C1	C2	C3	C4	C5	C6	C7	C8	Total
Relativity of Time	Positive	7	5	1	0	0	6	1	0	20
	Negative	14	2	2	10	2	6	3	0	39
Relativity of Length	Positive	9	6	0	0	1	7	1	0	24
	Negative	9	0	1	5	1	6	1	0	23
Lorentz Transformation Equations	Positive	9	0	0	1	0	0	0	0	10
	Negative	33	0	3	0	0	4	0	0	40
Lorentz Velocity Transformation Equations	Positive	4	0	0	1	0	0	0	0	5
	Negative	30	0	1	2	0	4	0	0	37
Relative Momentum	Positive	11	0	0	4	6	0	0	0	21
	Negative	2	0	3	10	0	5	1	3	24
Relative Energy	Positive	8	3	4	6	3	3	0	0	27
	Negative	3	0	2	9	0	6	4	2	26
Total	Positive	48	14	5	12	10	16	2	0	107
	Negative	91	2	12	36	3	31	9	5	189

Examining the distribution of codes according to categories as shown in Table 3, it is seen that the negative codes were the majority in most categories except for C2 and C5. Examining on the basis of topics, the number of positive codes were higher in the Relativity of Length and Relative Energy topics with a narrow margin, while the number of negative codes were higher in the Relative Momentum topic with a narrow margin. In all other categories, the number of negative codes were significantly higher.

The C1 category had the highest number of codes in total, both positive and negative. The number of codes in this category was almost equal to half the total number of codes in all categories. Looking at the data in the C1 category as given in Table 3, it is seen that negative opinions were generally dominant. This is especially evident in the Lorentz Transformation Equations and Lorentz Velocity Transformation Equations topics. On the other hand, it is undeniable that positive opinions were the majority in the Relative Energy and Relative Momentum topics. It is also noticeable that the number of positive and negative opinions were equal in the Relativity of Length topic. Examining the negative opinions, which dominated the majority of the topics, it is seen that a considerable number of negative opinions were related to difficulties in determining the reference system and this difficulty was reflected in problem solving and using connections. Participant A1's remark of *"I'm having trouble with determining the reference system. I can't make out which reference system the quantity was measured with"'* is a good example that demonstrates the effect of difficulties in determining the reference system in problem solving.

In most of the topics, there were no positive or negative codes related to C2. Accordingly, it may be thought that there were no methodological problems affecting the learning process. It is noteworthy that the most of the codes in Relativity of Time, Relativity of Length and Relative Energy were positive. Examining the content of the codes, it is seen that adjusting the explanation of the topic according to the context, watching documentaries and using thought experiments had positive effects on teaching. For example, participant A5's remark of *"...it's easier to understand the topic (time dilation) with the Twin Paradox"*, and participant A3's remark of *"The topic (length shortening) becomes more understandable when we use examples with objects that we are used to (use in everyday life)"* emphasize the importance of thought experiments and points to the importance of adjusting the explanation of the topic according to the context.

C3 draws a poor image in all topics in terms of the number of opinions. The codes are generally negative except for Relative Energy. Examining the content of the codes; it is seen that there was a bias about the difficulty of the topic. The participants indicated that they found the contents of the topic to be contradictory with their common sense and everyday experiences. Participant A24's remark of *"I can't associate it (Relativity of Time) with daily life. It contradicts with all my experiences since childhood. It (Relativity of Time) is a situation that I have never felt/experienced before"*, is a good example for this. The remark of participant A9: *"It is not strange for me anymore that the connection are different (from classical physics)"*, stands out among the positive opinions in Relative Energy. This situation may be an indicator that the students accepted the concepts and the phase of finding the new ideas odd was overlooked as they proceeded to the Special Relativity topic. Additionally, it may be concluded from the codes that the popularity of the $E = mc^2$ equation suggested by Einstein for relative energy was quite effective. The topic was interesting for the participants and the high curiosity about the topic was reflected positively in the codes. For example, participant A6's remark of *"I found $E = mc^2$ to be interesting because it's such a popular formula and..."* and participant A21's remark of *"... I think of Einstein when I think of physics and I think of $E = mc^2$ when I think of Einstein and this made me curious"*, exemplify this fact.

Examining the distribution of codes in the C4 category, which involved the codes related to the transition from classical physics to relativistic physics, it is seen that the negative codes were in the majority. Also, the number of codes was higher than for most other categories as well. Category C4 had the highest number of codes after C1. The reason that there was a concentration of negative opinions in the Relativity of Time and Relativity of Length topics may be due to the fact that they constitute the first step in understanding Special Relativity. Participant A2's remark of *"I found the concepts and imagining them in my mind to be difficult, because it (Relativity of Time) is the first topic of the transition from classical physics to relativity"*, clearly shows this. However, it is also seen that there was a concentration of negative opinions about Relative Energy and Relative Momentum as well. Examining the content of these codes, difficulties experienced with the momentum and energy topics in classical physics were also evident in the relative momentum and relative energy topics. Participant A24's remark of *"I'm having difficulties with momentum in classical physics a well. It's not a topic that I can get a grasp of. That's why I'm having trouble with relative momentum too"*, emphasizes this situation. Additionally, the participants indicated that they were not able to distinguish between momentum and energy when they were supposed to use these concepts according to the classical approach and when they were supposed to use them according to the relativist approach. It was found that the participants had trouble with understanding why they needed concepts of relative energy and relative momentum. Also, not being able to fully rationalize the mass-energy equivalence was among the negative opinions.

The number of codes was not high in the C5 category, which involved the codes related to relations between the relativity topics and there were no codes in this category in the Lorentz Transformation Equations and Lorentz Velocity Transformation Equations topics. The codes in Relative Momentum and Relative Energy were all positive. Although the relations between the Special Relativity topics were not generally considered to be difficult, the only topic that did not involve positive opinions but only negative ones was Relativity of Time. Looking at the content of negative opinions, the participants stated that they had difficulty in handling Relativity of Time with Lorentz Transformation Equations. It was emphasized that the opposite actions of time and length under relativity conditions (shortening of length while time dilates) caused confusion. Considering the positive codes in Relative Momentum and Relative Energy on the other hand, since they had already understood the logic of Special Relativity, the participants stated that they had no difficulty in associating Relative Momentum and Relative Energy with other topics of relativity.

C6 is another category which had a high number of codes derived from the opinions of the participants. The majority of these codes were negative in nature. Although the number of positive and negative codes was almost equal in Relativity of Time and Relativity of Length topics, the negative codes were dominant in other topics. Considering the content of negative opinions, it was emphasized that the subject required effort and time. It is also noteworthy that the number of students repeating the course were quite high. The participants emphasized that they did not understand Special Relativity the first time, but they were able to understand it after repeating the course. The content of positive codes in Relativity of Time and Relativity of Length generally consisted of opinions related to the ease of understanding of the topics.

There were a relatively low number of codes in the C7 category, which involved opinions related to concreteness or abstractness of the topic. There were no positive or negative codes in the Lorentz Transformation Equations and Lorentz Velocity Transformation Equations topics. However, the number of negative codes was high especially for Relativity of Time and Relative Energy. Participant A11's remark of *"I had trouble because they are abstract concepts, I couldn't imagine them"*, is an example. It is seen that the participants generally considered the concepts of time and energy to be abstract and difficult. In addition, participant A25's remark of *"I easily understood length because it is a concrete quantity"*, demonstrates the ease of understanding associated with concrete objects. On the other hand, participant A13's remark of *'"I can accept the change easily because time is not concrete. But it is hard to accept length shortening because it is related to a concrete substance"*, represents a divergent opinion.

The codes that resulted from the contradictions in sources were collected in the C8 category. This is the category that had the least number of codes. In this category, there were no codes in any topics other than Relative Momentum and Relative Energy, and all codes were negative. In some of the sources, it is mentioned that mass relatively varied with velocity. In some other sources on the other hand, it is indicated that this was wrong and mass did not vary with velocity. The participants stated that they were confused because there was different information in different sources. For example, participant A3 explains this situation clearly: *"The fact that there are two different explanations for the relativity of mass leads to confusion."* and *"It seems as if there were two different masses in the (relative) kinetic energy formula. It is very difficult to understand this topic (Relative Energy)."*

CONCLUSION AND DISCUSSION

Based on the study data, in conclusion, it can be said that the participants found the subject of Special Relativity interesting. According to Ogborn (2005), although students find Special Relativity very interesting when they first hear about the concept of time dilation and the mysterious formula of $E=mc^2$, the mathematical difficulties that they experience when they meet the Lorentz transformations cause them to lose interest. In the present study, the mathematical difficulties stand out as one of the problems that the participants faced when learning about relativity. Especially in Lorenz Transformation Equations, these difficulties are seen to be more dominant. The problems related to determining the reference system were the mathematical problems. The participants mentioned that, when solving problems, they had had difficulty in understanding which quantity was measured by which observer or which reference system, even if they comprehended that the issues belonged to the Special Relativity topic. Aslanides and Savage (2013) identified that the students couldn't comprehend the correct relativistic thinking and couldn't define the symmetry between these two references. In the present work, the participants mentioned that they had comprehended relativity. Maybe the problem was that they could not define the correct relativistic thought exactly. To expose this situation, it can be researched in more detail. Some studies emphasize challenges experienced by students with reference systems at various levels, which are similar to challenges observed in this study (Dimitriadi & Halkia, 2012; Scherr et al, 2002). Additionally, difficulties related to visual and spatial skills, remembering the formulas, constructing the problems and applying mathematical skills in problems were observed. Taking the statements of the participants into account, it was seen that using storytelling and visualization in the presentation of the problem was useful. Therefore, use of such methods in problem presentations could be increased.

However, it was also found that the participants were biased about the difficulty of the topic. The fact that there are a lot of rumors about the very difficult nature of relativity caused students to have a bias concerning the course. According to the participants, another reason why the topics of relativistic physics are so difficult to learn is that it requires extra effort and time.

Another point where students have difficulties related to learning is the classical physics-modern physics paradigm shift, because events encountered by the participants in their everyday lives can generally be explained in accordance with the classical physics paradigm. Besides, it is possible to conduct real experiments with classical physics. On the other hand, relativistic physics is a subject that is not encountered in everyday life and it is not suitable to perform real experiments. In addition, relativistic physics usually produces results that contradict with real everyday experiments and perceptions. Scherr (2007), in her work, identified that it can be because of beliefs which we acquired in daily life, it is difficult for students to learn the relativity of simultaneity. According to Scherr (2007), the experience which we have gained in everyday life allows us to believe that the relativity of simultaneity is absolute. Among the difficulties that the participants faced when learning about relativity, this situation can be seemed clearly to be evident. Difficulties related to abstractness of relativistic physics, problems associating it with everyday life and imaging the concepts in mind were clearly stated by the participants. In order to overcome these difficulties, it is suggested in some studies that special relativity is taught by visualisations, using computer programs such as animations, simulations and games (Carr & Bossomaier,2011; Henriksen, 2014; Kortemeyer et al, 2013; Kraus, 2008; McGrath et al, 2010; Savage et al, 2007; Wegener et al, 2012). The use of thought experiments in teaching of the special relativity as an effective tool is also common (Cacioppo & Gangopadhyaya, 2012; Cornier & Steinberg, 2010; Franklin, 2010). Although the statements of the participants underlined the importance of thought experiments, they also indicated the difficulties in understanding them.

It is seen in some sources (Born, 1962; Feynman, 1997) that mass varied depending on velocity based on the experimental validation of the predictions of special relativity. In recent years, it has been indicated that the concept of velocity-dependent mass was a misunderstanding and this fact had to be changed in all books and curricula (Hecht, 2009; Okun, 1989). Some books featuring special relativity changed the parts about the concept of "relative mass" in later editions (Serway & Beichner, 2000; Ünlü et al, 2014). Thus, the contradictory explanations about “relative mass” in sources featuring special relativity caused confusion. The pre-service teachers who participated in this study stated their difficulties in this regard. Selçuk (2011) addressed a similar situation in detail in his study.

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