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THE VIEWPOINTS OF PHYSICS TEACHER CANDIDATES TOWARDS THE CONCEPTS IN SPECIAL THEORY OF RELATIVITY AND THEIR EVALUATION DESIGNS

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ABSTRACT

In this study, the viewpoints of physics teacher candidates at undergraduate level towards the concepts in special theory of relativity and the interpretations they made about these concepts were investigated. The viewpoints of the teacher candidates towards the concepts in the subject of special theory of relativity were revealed with six open ended questions prepared by the writers who are physics teachers as well. The research is a qualitative study and the study was conducted with eighteen teacher candidates. In this study, case study, one of the methods of qualitative research, was used. The study group of the research was chosen by convenience sampling. The data collected via open ended questions was analysed by descriptive analysis method. According to the results of the study, it was revealed that most of the students have not been introduced to the special theory of relativity and the concepts related to them. It could be stated that the candidates had difficulty with the relativity of time and its reference frame. Most of the teacher candidates could not make the interpretation that the speed of light was the limit speed and no other object could reach that speed.

Key words: modern physics, special relativity, physics education, teacher candidate

1. INTRODUCTION

Science and technology has been developing fast in our country and, education and teaching programs have been changing in parallel with these developments. Curriculums are one of the most important elements of education and instructional programme. Studies concerning the curriculum have been carried out in every level of education and they have been updated according to the needs of the time. Changes have been carried out in the physics curriculum of secondary education in Turkey within the content of these studies. The new curriculum was started to be implemented in the 9^{th} (14-15 years) grades in 2008-2009 education year, 10^{th} (15-16 years) grades in 2009-2010 education year and the 11^{th} (16-17 years) grades in 2010-2011 education year and the 12^{th} (17-18 years) grades in 2011-2012 education year. “Modern Physics” unit which has not been part of the physics education programs before was included in the 10^{th} grade physics education program which has been implemented since 2009-2010 education year. With Modern Physics unit, students are expected to acquire knowledge related to the events which caused the birth of Modern Physics, non-inertial and inertial reference systems, special relativity laws and their results. The teachers who are going to make the students acquire these gains are certainly required to have a good knowledge of this topic.

When physics education literature is analysed, the researches carried out about the subjects related to Modern Physics are quite few in number when compared to the researches related to the topics such as classical mechanic, electricity, magnetism and optics (Sezgin Selcuk and Caliskan, 2010). It was stated in some studies conducted about special relativity that undergraduate students and/or teacher candidates had difficulty in understanding the subject (Sezgin Selcuk, 2011; Scherr, Shaffer and Vokos, 2001, 2002; Belloni, Christian and Dancy, 2004; Sezgin Selcuk and Caliskan, 2010; Scherr, 2001; McGrath, Savage, Williamson, Wegener and McIntyre, 2008; Ozcan, 2009).

Special relativity is one of the topics told in modern physics courses. Paradoxes take part in its content and it draws the attention of the students with its interesting theories such as quantum mechanics (Belloni, Christian and Dancy, 2004). According to the results of the research done by McGrath et al.(2008), the students found special relativity more abstract than the other topics of the physics. It is rather difficult to learn and teach these abstract concepts conceptually. Many people are critically in conflict with the deductions of special relativity in their minds (Scherr, Shaffer and Vokos, 2001). Modern Physics is a very difficult field due to its abstract structure which is difficult to understand with daily instincts and its heavy mathematical features. Because of that, pedagogical researches to be conducted and giving more prominence to visualization will be more beneficial not only to reveal the conceptual and mathematical difficulties the students meet but also to help the students understand the subjects which they have difficulty in (Yalcin, Altun, Turgut and Aggul, 2009, Turgut, Gurbuz and Turgut, 2011). It is a requirement for the teacher candidates to comprehend this subject which they are going to teach all throughout their professional life. In this study, the viewpoints of physics teacher candidates towards the concepts in special relativity theory and their evaluation designs were investigated. The question “How did the teacher candidates comprehend, describe and evaluate the concepts in special relativity theory before and after teaching?” is sought an answer in the research.

2. METHOD

2.1. Methodology of the Research

Case study, one of the qualitative research methods, was used in this study. The factors related to a situation is analysed in a holistic approach and the changes which occur in the situation are investigated in a case study (Yildirim and Simsek, 2008).

The research was carried out with the undergraduate students studying in the physics teaching department in a state university. The students were asked six open ended questions before “Modern Physics” course was studied at the beginning of the term and after the course was taught at the end of the term. Within the content of the modern physics course, the subjects of relativity (Galilean Relativity Theory, Einstein Relativity Theory and its results), the Lorentz Transformation Equations, Relative Momentum and Energy, Black Body, Photoelectric Effect, Compton Effect, Atom Spectrums, X-rays, Wave-Particle Duality, Heisenberg’s Uncertainty Principle were explained by direct speech method.

2.2. Study Group

The study group of the research was chosen by convenience (available) sampling. In convenience sampling, one of the purposive sampling methods, the researcher chooses an event which is close and easy to have an access (Yildirim and Simsek, 2008). 30 undergraduate students taking “Modern Physics” course in physics teaching department in a state university in 2011-2012 academic year were told the purpose of the study and how it was going to be carried out. 18 students out of 30 students who were willing to take part in the research formed the population of the study.

2.3. Data Collection Tools

Six open ended questions about modern physics which are prepared by the researchers were asked in the research. Although open ended questions offer flexibility, they are costly during the collection of data and analysis of data in terms of waste of time and energy (Ekiz, 2009). The open ended questions used in the study were designed by the experts in the field in such a way that they could include special relativity topics. Table of specifications belonging to the questions were given in Table 1.

Table 1. Table of Specifications

Subject	Question Number	Number of Questions
Postulates of special relativity	6	1
Length contraction	1,2	2
Time dilation	4,5	2
Relativistic mass	2,3	2

2.4. Data Analysis

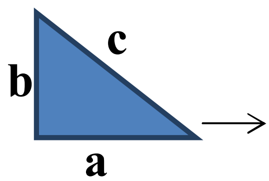
The data collected with open ended questions were analysed with descriptive analysis method. The purpose of such an analysis is to present the findings obtained to the reader in an organized and interpreted way (Yildirim and Simsek, 2008). The researchers grouped the answers given to each question and determined the frequency in order to organize the findings. Therefore, the answers given to the questions by the students were put in order. The researchers interpreted these findings which they had organized. The answers the students gave to the questions before modern physics course was studied were examined as “before” and their answers after the course was studied were examined as “after”. This analysis for each question was given below.

3. FINDINGS

3.1 Findings for Question 1

The first question of the study is:

“An object whose dimensions are a, b, and c and as depicted in the figure on the right travels in front of your eyes in a speed close to the speed of light in the direction of the arrow. What kind of shape do you observe if you can see it? Please explain by drawing.”



This question is about length contraction in special relativity. A contraction will occur in the direction of the movement and so the sides of a and c will go under contraction. Some of the answers given to this question by the students in application performed before the course were given below:

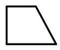
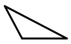
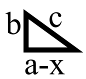
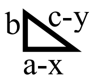
- “It is seen as a line because it is in a high speed.”
- “The speed of light is very high. As a result, we see the object as a speckle”
- “When the objects get very close to the speed of light, elongation occurs in the length of the objects. Its length will elongate towards the direction.”
- “Only a beam of light, something like laser occurs.”
- “We cannot see it. The possibility of seeing an object moving in the speed of light is little.”

When the answers given before the course were examined, it was revealed that the students were prepossessed with the subject of sight and they could not interpret in what form the object would take or the students determined that even if the object was seen, it would be seen as a line or a speckle. Some of the answers given by the students in the exercise after the course was studied were given below:

- “There will be contractions in the length of the particles travelling close to the speed of light toward the direction of the movement.”
- “The figure remains the same but “a” contraction appears with the length of “a”.”
- “If the figure travels with the speed of light, there will be “x” amount of contraction on the side of “a” and “y” amount of contraction on the side of “c”. The contraction will exist only in the direction of the movement, which means that there is no change on the side of “b”.”

When the answers given after the course were examined, it was revealed that the students interpreted length contraction; usually they only thought about the contraction on the side of “a” but they could not think about the contraction on the side of “c”. Frequency analysis for question 1 was given in Table 2.

Table 2. Analysis for Question 1

	Statement of the student	Frequency
BEFORE	Blank	5
	Not seen with eyes	4
	Because it is very fast, it is seen as a line.	3
	It is seen as a speckle.	1
	 (trapezium)	1
	 (square)	1
	 (the side of b changes)	1
	The sides of a and c will elongate	1
	No change in its shape.	1
AFTER	Blank	1
	There is a contraction in the direction of the movement of the object. 	9
	While the length of b does not change, the lengths of a and c contracts. 	6
	Both three sides contract.	1
	No change in their sizes. Only optical illusion occurs.	1

When Table 2 is examined, it can be stated that the students do not have preliminary knowledge about length contraction, and a lot of different shapes about the answer appear in their imaginations. After the course was taught, 15 students realized the concept of length contraction but 9 of them had made a mistake about the geometric shapes.

a. Findings for Question 2

The second question of the study is:

“Does mass change with speed? Explain it.”

This question is related to relative mass in special theory of relativity. The relativistic mass of the objects increases as the objects’ speed increases when it travels close to the speed of light. Some of the answers given to this question by the students in application performed before the course was studied were given below:

- “Yes. Mass may sometimes change in the speed of light.”
- “Mass does not change with speed. Mass does not depend on any factors according to the law of conservation of mass.”
- “Mass changes with speed. If we accept that force is constant (F=m*a according to Newton’s second law), mass will change with acceleration.”

- "Mass changes with speed. When the object travels close to the speed of light, a decrease occurs in the mass."

When the answers given before the course were examined, some of the students stated that mass would not change where as some stated that mass would change. Some of the answers given by the students in the practice performed after the course was studied were given below:

- "Yes, it changes. Mass increases. As the object gets to the speed of light, energy is converted into mass."
- "According to $m=m_o \cdot \gamma$ formula, mass changes with velocity."
- "Yes, it changes. The mass of the objects increase when they travel close to the speed of light."

When the answers given after the course were examined, most of the students answered the question correctly. The students who answered the question correctly supported their view either with verbal expressions or mathematical formula. Frequency analysis for question 2 was given in Table 3.

Table 3. Analysis for Question 2

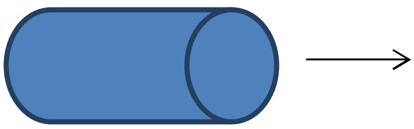
	Statement of the Student	Frequency
BEFORE	Blank	2
	It does not change.	9
	It may change in the speed of light.	6
	If force is constant, mass may change.	1
AFTER	Yes. The mass of the object which travel close to the speed of light increases.	10
	Mass changes with speed according to $m=m_o \cdot \gamma$ formula.	7
	The mass of the object decreases as it approaches to the speed of light.	1

Although 6 of the participants stated that mass might change before the lesson, they could not state the direction of the change. It was revealed that one of the students misinterpreted the second law of Newton incorrectly. Most of the students stated that mass would not change by depending on their classical physics knowledge. The students explained the change in the mass correctly after the lesson except one student. One student explained the direction of the change incorrectly.

3.2. Findings for Question 3

The second question used in the study is:

"*A solid cylinder travels in front of your eyes in a speed close to the speed of light in the direction of the arrow. Does the density of the cylinder change? Please explain.*"



This question includes the topics of length contraction and the relativistic mass in special theory of relativity. The length of a cylinder which travels close to the speed of light will contract and its mass will increase relatively. Therefore, its density will increase. Some of the answers given to this question by the students in application performed before the course was studied were given below:

- "If the object travels close to the speed of light, its mass is less. Therefore, its density decreases."
- "Because its weight and volume does not change, density does not change."
- "If we think that it travels with the speed of light due to its certain volume, there will not be any change in the density."
- "Mass turns into energy. Density should not be a concept."

When the answers given before the lesson were examined, the students with an approach to classical physics courses emphasised that density is the ratio of mass to volume and because there won't be a change in the mass or volume of the cylinder, its density won't change. Some of the answers given by the students to this question in the practice performed after the course was studied were given below:

- "Because the object travels in the speed of light, there will be a change in the mass and length of the object, which means that the density of the object changes."
- "The length of the cylinder contracts and the volume of the cylinder changes. Its density changes, too."
- "When the speed increases, mass increases If it moves towards right, there will be a change in its length. Naturally, its volume changes, but its density remains the same."
- "Its density increases because there appears length contraction and increase with the mass."

When the answers given after the lesson were examined, some students concentrated on either length contraction or the mass increase but they ignored the fact that both of them had changed. Frequency analysis for question 3 was given in Table 4.

Table 4. Analysis for Question 3

	Statement of the student	Frequency
BEFORE	Blank	3
	It does not change.	10
	Density decreases because its mass increases.	2
	It changes because mass changes.	1
	Density decreases.	1
	Mass turns into energy so it does not have density.	1
AFTER	Blank	1
	Its density changes because its mass changes.	4
	Its density increases because its mass will increases and its length will contract.	4
	Its density increases due to its length contraction.	3
	Its density changes because the length and mass of the object will change.	3
	Change is observed.	2
	Density does not change as mass and volume will change together.	1

Before the lesson, ten students relying on their preliminary knowledge emphasised that density would not change. Although four students stated that it would change, they were not able to explain the direction of the change and/or its reason. After the course, they were aware of the fact that there would be a change in density except two participants. But, only four students could think that both the increase in the mass and the length contraction would cause an increase in density. Four students attributed the change in density to change in mass only and three students to length contraction.

3.4. Findings for Question 4

The fourth question used in the study is:

"Does time change with speed? If we assume that as human life span, can people live 1000 years? Please explain."

This question is about the time dilation in special theory of relativity.The elapsed time between two events (such as consecutively lightning flash) can change with respect to two observers. Relative speed of the observers to each other is important here. An 80 year time period for an observer can be 1000 years for another observer. Some of the answers given to this question by the students in an application performed before the course was studied were given below:

- "Time goes slowly when we can travel at near speed of light and this provides an opportunity for the human beings to live 1000 years."
- "Time does not change. If time changed with velocity, people could age faster."
- "Time changes with speed. $X=V{\cdot}t$. We cannot carry this into human life. It is valid for the objects."
- "Time changes. Since velocity is different on another planet as observed with the twin paradox, the human being can live up to 1000 years on another planet. "

When the answers given before the lesson were evaluated, it was revealed that although the preliminary knowledge of some students about the subject was not adequate, it existed and some of the students relied on their classical physics knowledge. Some of the answers given by the students to this question in the practice performed after the course was studied were given below:

- "Yes, it changes. If you travel close to the speed of light, you are exposed to time dilation and it can be experienced. It is possible to live 1000 years."
- "Time changes with velocity. It is relativistic."
- "No. They cannot live because our vital functions will be exposed to time, too."

When the answers given after the lesson were examined, all of the students mentioned time dilation. Only one student stated that it was not possible to live 1000 years. Frequency analysis for question 4 was given in Table 5.

Table 5. Analysis for Question 4

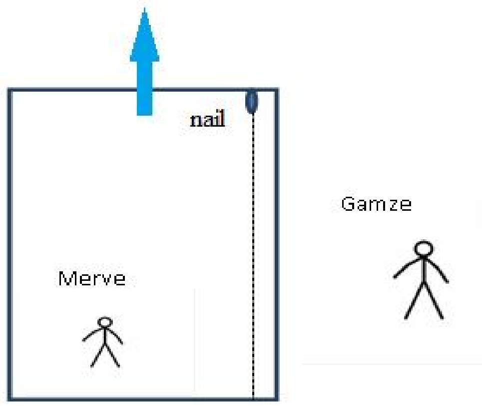
	Statement of the Student	Frequency
BEFORE	Blank	4
	Time changes. The faster you travel, the slower time goes.	4
	Time does not change.	3
	Time changes. $X=V{\cdot}t$. Time and speed are inversely correlated.	2
	$t=t_o{\cdot}\gamma$. It is possible.	2
	Time changes.	2
	Time changes. Like the twin paradox, you can live 1000 years.	1
AFTER	If you travel close to the speed of light, there will be time dilation. It is possible to live 1000 years.	17
	Yes. Time is relativistic but it is not possible to live 1000 years.	1

Before the lesson, most of the students relying on their classical physics knowledge either stated that time did not change or they said that time changed according to X=V·t formula. Three students who associated time to the relativity made an explanation correctly. After the lesson, nearly all of the students gave the same answers. It is possible to live 1000 years as in the twin paradox. Of course, 1000 years passed in another observation framework. Only one student tackled the event from his observation framework, not as mentioned above and he thought that it was not possible to live 1000 years.

3.5. Findings for Question 5

The fifth question used in the study is:

"While Gamze is steady on the ground, Merve is in a lift which goes up close to the speed of light in the direction of the arrow. The nail which is on the ceiling of the lift falls down and hits the floor of the lift. Suppose that Merve measures the duration of this movement in t seconds. What is the measurement of Gamze about this duration? Please explain."



This question is about the time relativity in special theory of relativity. Gamze who is steady on the ground measures the event in a lift which goes up close to the speed of light as if it took place in a longer time than the observer in the lift. Some of the answers given to this question by the students in an application performed before the course was studied were given below:

- "Gamze measures it in 2t time."
- "When the lift goes up, a downward gravitational force acts on the nail. If Merve measures it in t time, Gamze will measure it more than t time."
- "According to Merve, if X=V·t, V will be regarded the same for both Merve and the nail. However, because V will be close to the speed of light for Gamze, t time will be much shorter".

The students who answered the question before the lesson relied their explanations on the concepts or the formulae in classical physics. Most of the students could not answer this question. Some of the answers given by the students to this question in the practice performed after the course was studied were given below:

- "She measures more than t time. Because Merve travelled in the speed of light, she experienced time dilation."
- "t is the same for both of the observers. Because both of them are in their own systems, their observations will be the same."
- "Because Gamze is a steady observer, she will see that the nail falls on the ground in more time."
- "The time measured by Merve, who travels close to the speed of light, will be less than the time measured by Gamze because concept of time is relativistic. Time slows down near the speed of light".

When the answers given after the lesson were examined, some of the students stated that time concept is relativistic. But very few students were able to make the correct explanations. Frequency analysis for question 5 was given in Table 6.

Table 6. Analysis for Question 5

	Statement of the student	Frequency
BEFORE	Blank	12
	Measures less than t.	3
	Gamze measures 2t time.	1
	Due to the effect of gravity, Gamze measures greater than t.	1
	Becomes $t=t_o \cdot \gamma$	1
AFTER	Blank	7
	Because time dilates, this duration is more according to Gamze	4
	Merve sees that it falls in lesser time than t seconds.	3
	Because Gamze is a steady observer, she sees that it falls in more time.	3
	Both of them measure t time.	1

Before the lesson, most of the students could not interpret the question and left the question blank. The students who tried to interpret the question made wrong interpretations or could not explain it. Although one student wrote the correct formula for the result, he/she could make its explanation. After the course, there were only seven students who stated correctly that "it falls in more time". While seven students could not answer it, four students answered it incorrectly.

3.6. Findings for Question 6

The sixth question used in the study is:

“If an object with m mass is exposed to a constant F force for infinite time in a frictionless environment, what is its speed:
a) according to Newton ?
b) according to Einstein ?
c) If the answer is different according to both of them, which one is incorrect?”

This question is about the predictions of modern physics which do not agree with the predictions in classical physics of Newton which says that the speed of an object, when force acts upon, will increase infinitely. According to modern physic, a particle that has mass needs infinite energy to accelerate to the speed of light. That’s why it cannot reach the speed of light. Frequency analysis for question 6 was given in Table 7.

Table 7. Analysis for Question 6

		Statement of the student	Frequency
BEFORE	Option a	Blank	12
		The object moves with a constant speed.	2
		The object maintains its motion in a frictionless environment forever.	2
		It accelerates forever.	2
	Option b	Blank	14
		It moves with the changing speed.	2
		It accelerates to the speed of light.	2
	Option c	Blank	14
		It moves by accelerating with F force.	2
		Einstein is right.	2
AFTER	Option a	Blank	8
		It has infinite speed.	4
		$F=m \cdot a$ and $V=a \cdot t$	3
		It goes with a constant speed forever.	2
		Its velocity increases.	1
	Option b	Blank	11
		It changes according to the reference system.	2
		It cannot go over the speed of light.	3
		According to $m=m_o \cdot \gamma$ formula, because its mass changes, its speed will change too.	2
	Option c	Blank	11
		True for both of them.	5
		Einstein is right.	2

It was revealed in the application performed before the lesson that the students misinterpreted Newton physics incorrectly. Because this subject was not explained in the lesson, this misinterpretation was also observed in the application performed after the lesson. There were only three students who emphasised that the speed of light was the speed limit depending on the predictions of the modern physics. It is attention getting that most of the students could not answer this question.It is also remarkable that the students were not able to answer the option “a” of the question within the scope of the classical physics lesson they studied in previous years.

4.CONCLUSION AND SUGGESTIONS

In the research, the viewpoints of physics teacher candidates at undergraduate level towards the concepts in special theory of relativity and the interpretations they made about these concepts were investigated. The approaches of the students to the concepts of relativity were examined by using the length contraction, time dilation, relativistic mass and postulates of special relativity of Einstein’s theory of relativity within the content of modern physics. The approaches of the teacher candidates to the concepts of special relativity subject were discovered with six open ended questions prepared by the writers who are the physics teachers in university. The research is a qualitative research and eighteen teacher candidates took part in the study.

It can be stated that the teacher candidates did not experience difficulty about length contraction as a result of the research. On the other hand, because they had difficulty in dimension concept geometrically, only six candidates could answer the first question of the research in full. The candidates usually concentrated either on length contraction or on mass increase in the second question about relativistic mass and they could not think that both of them could change. With the third question about relativistic mass, the candidates before the lesson argued that the mass would not change relying on their classical physics knowledge but they got the correct answer after the lesson both with formulae and verbally. When the findings of the fourth and the fifth question about the relativity of time were examined, it can be stated that the candidates acquired the basic knowledge about time dilation after the lesson. However, most of the candidates could not get the correct answer with the fifth question which is about the relativity of time and reference framework. It could be stated that the candidates had difficulty in the relativity of time and reference framework. In parallel with this finding, Sezgin Selcuk (2011) found in his study that the teacher candidates experienced special and important difficulties with the concepts of real time, time dilation, relativistic density. Similarly, as a result of the research by Scherr, Shaffer and Vokos (2002) they found that the definitions of basic concepts such as reference system, time, and simultaneity were lacking with most of the students. In the sixth question which is about the postulates of special theory of relativity, most of the candidates could not make the interpretation that the speed of light is the maximum speed and no object will be able to reach this speed. An important finding about this question is that the candidates could not interpret Newton's second law which they learned in basic physics courses.

When the findings of the application performed before the lesson is examined, it can be stated that the candidates tried to answer the events and the concepts within the rationale of classical physics. Similarly, Sen (2002) concluded in his study conducted that the students had the tendency to explain the concepts of modern physics with the similes used in classical physics. This result is normal, but it can be expected from the teacher candidates who took physics for three years to discuss space with time and determine that time is relativistic.

The approaches of the students about time, mass, volume in special relativity principle and the postulates of special theory of relativity and the mathematical difficulties about these concepts are important obstacles of learning. Moreover, the students' not being able to get rid of the classical predictions which are known as Newton's predictions cannot form the desired constructs about the concepts of relativity in the students' mind. According to the results of the research, it was found that most of the students had never been introduced to the special theory of relativity and the concepts related to it. The answers given by some students to the questions were not only at a desired level but also the answers given by some of them could not go beyond the answers inspired with their previous physics knowledge. Some of the students can't help themselves giving "fantastic" answers. All these findings mean that the students lack problem solving strategies due to lack of relativity concepts in terms of their ways to use the concepts and mathematical reasoning. According to another result obtained from the research, the students' not being introduced to the concepts of relativity before resulted in their being not able to do qualitative analysis, determine the variable and display the problem on a graphic or figure. This condition leads to the result that although most of the participants become acquainted with the concepts of relativity later, their problem solving approaches are not scientific and strategic solution. Particularly, this case is the best observed with the answers given to the questions about length contraction and time dilation.

Of course, we cannot generalize the results obtained from this study for the whole universe. However, the results obtained from the study reveal that the students had to be introduced to special relativity, modern physics and the concepts related to them much earlier (at secondary education level). Naturally, the students will not suffer the difficulties of being unfamiliar about these concepts at university level. The results of the study also revealed that it would be most beneficial to give opportunities to the students to get acquainted with the concepts before, create learning environment supported with visual elements, and to make the students comprehend that modern physics and its disciplines would contribute to the process of physics and the development of physicists in order to simplify the approaches of the students with modern physics and the concepts belonging to it.

The completely abstract special relativity subject must be told via simulations and similar visuals in the lessons so as to enhance the interest and the knowledge and skills of the teacher candidates about the subject. Most of the students stated that computer simulations enhanced their interest in special relativity (McGrath, Savage, Williamson, Wegener, McIntyre, 2008). While explaining time dilation in the lesson, more practises must be done about its reference frameworks. Likewise, predictions of special theory of relativity must be emphasized more and its results must be interpreted.

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