Linear Correlations between Misconception of Special Relativity Concepts in High School

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Abstract

In an increasingly technologically demanding world, knowledge and skills within natural sciences, technology and engineering are crucial for development of competitiveness of individuals and societies. Thus, recent decades many countries are emphasizing and planning to introduce the STEM fields in education systems as early as possible, including basic concepts of modern physics. By learning basic concepts of modern physics (quantum physics, special relativity, elementary particle physics, etc.), youths acquire knowledge and skills relevant to solve complex problems, understanding data and information, which makes them competent for validating evidence for responsible decision-making. Basic concepts of special relativity can be extremely interesting for youth and thus, for research in physics education. Philosophically, concepts in special relativity are very demanding, while the mathematical formalism is simple enough to introduce them in secondary high schools. Research-based assessment resources at the PhysPort portal are very useful tools in physics education research of misconception (physport.org/assessments/).

Here, we report difficulties in understanding the basic special relativity concepts in high school, which are less analysed comparing to concepts in classical mechanics. By using selected and adapted questions on basic concepts in special relativity, which are developed by J.S. Aslanides and C.M. Savage in 2013, we have analysed linear correlations between misconception of basic special relativity concepts.

Keywords: *Linear correlations, special relativity concepts, misconception*

1. Introduction

In an increasingly complex and technologically demanding world, it is important to prepare young people to acquire knowledge, skills and competences that will help to solve complex problems, understand data and information and be competent in collecting and evaluating evidence for responsible decision-making. It is not possible to participate in the development and relevant use of modern technologies without the relevant knowledge and skills in modern physics.

In this paper we chose the basic concepts of the special relativity because they are very interesting for research in the education of physics. The philosophical elements of the special theory of relativity are very attractive and deeply challenging, but the mathematics is simple enough to be taught in high schools. The complexity of mathematical forms in special relativity are comparable to the understanding and application of Pythagorean theorem, which is a part of curricula even in primary schools.

The relativity of motion is one of central concepts in both, classical and relativistic physics. Thus, by considering relativity it is easier to monitor the cognitive development of students and the achievement of those concepts. Similar case we can expect with the concept of inertial reference frames, which is also central concept for both, classical and relativistic physics.

The motivation for the research of concepts in modern physics comes also from the fact that these subjects have been less analysed comparing to other parts of physics. We have analysed the difficulties in understanding the basic concepts of the special relativity by high school students. We selected and adapted questions about fundamental concepts in relativistic physics, developed and researched by J.S. Aslanides and C.M. Savage in 2013 [1]. Further, we have analysed the linear correlations between misconception of key concepts in special relativity by high school students and discussed more comprehensive theoretical approach for finding principal correlations in a multi-dimensional system of correlated knowledge, skills and competences.

2. Learning outcomes

Some of learning outcomes in high schools in physics are related to understanding of special relativity concepts and their application to simple physical problems. Those learning outcomes integrate the following concepts:

- First postulate of the special relativity (the laws of physics are the same in all inertial reference frames),
- Second postulate of the special relativity (the speed of light in vacuum is the same in all reference frames),
- Time dilation,
- Length contraction,
- Relativity of simultaneity,
- Inertial reference frame,
- Velocity addition,
- Causality, and
- Mass-energy equivalence.

Any task, question or a problem in special relativity can be created by using one or a combination of more above-listed concepts.

3. Assessment of achievement of learning outcomes

We have conducted the assessment on two groups of students from the High School in Rijeka, Croatia (Andrija Mohorovičić Gymnasium), which attend high school programme in science and mathematics. The first group consisted of second and third grade students, 46 of them, who have not taught the concepts of the special relativity in their schooling, and thus, were selected to be the control group for this research. The second group consisted of fourth grade students, 51 of them, who attended classes related to the special relativity, and thus selected as the central group for this research.

For the assessment of achieved learning outcomes, we selected and adapted 24 closed-ended questions from the inventory [1]. Students had 30 minutes to answer the questions. In addition to each answer, they were asked to rate on a scale between 1 and 5 how confident they were in their answers. For example, if they guessed one question then the scale should be 1, and if they were sure to their answers, they should scale them to 5. Each concept from the special relativity, which was assessed by the exam, are linked to one, or up to four questions. For example, four questions (questions: 16, 18, 19, 20) were related to the concept of first postulate of the special relativity, while only one question to the concept of mass-energy equivalence (question: 24).

From the Fig. 1 it is evident that the central group of students in most of questions had better results comparing to the control group. The control group answered better only to 6 questions, but those

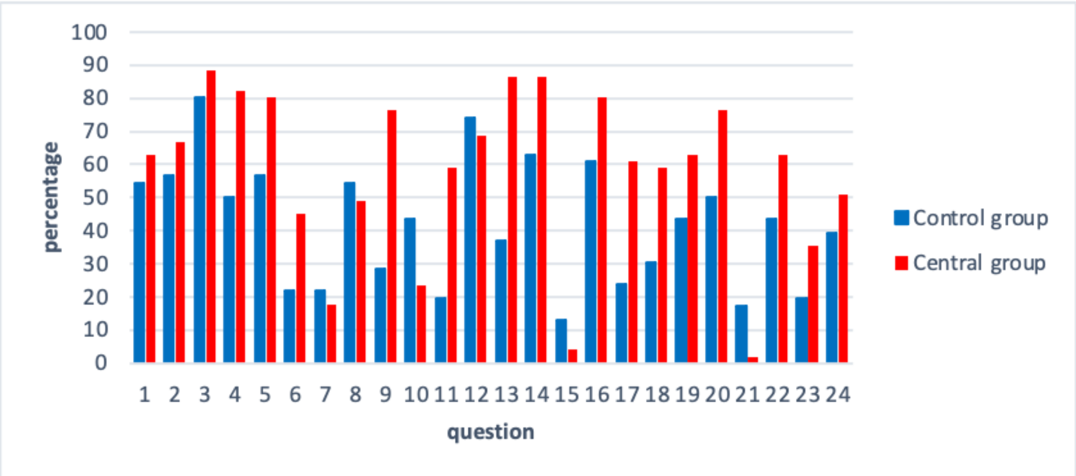

Fig.1. Rate of correct answers in percentage for both groups, central and control.

questions were very poorly answered by both groups of students. Although the controlled group achieved better results for those answers, the certainty in their own response was very low. Thus, we can conclude that they guessed the answers to those questions, and by accident have better results (about 20 % correct answers comparing to about 5 % of the central group).

4. Analysis of results

If we analyse an example of one group of questions, which is related to one of listed concepts, then the correlation between students' answers could give us a better view to understanding the particular concept and a rationale for possible misconception.
As an illustration for analysis of correlations between answers to questions related to the same concept, here as an example we use the concept of time dilation. That concept of time dilation has been assessed by four questions (5, 6, 7 and 8) with different view to the concept. The question 7 is related to quite unrealistic personal situation,"*travel through galaxies at high speed*", while other three questions are formulated in terms of general observations. As it is seen from the Fig. 1, the question 7 has very low rate of correct answers comparing to questions 5, 6 and 8. This leads us to the conclusion that students show more difficulties in accepting the concept of time dilation if it is far from normal life and everyday experiences. Answers to questions 5 and 6 can be directly compared because they compare the same events as seen from two different inertial reference frames. Each observer measures that the other's clock goes slower. The question 5 has been correctly answered by 80.39 % by the central group, while for the control group there were 56.5 % correct answers. The question 6 has a rate of 45.1 % correct answers for the central group, while the students of the control group answered correctly only 41,3 %. The linear correlation between answers for those two questions is relatively high compared to correlations between other questions. Still the obtained correlations are not high as it would be expected. From the analysis of correlations between answers of those two questions, we could conclude that there are difficulties in understanding the asymmetry in which: "X measures that the Y clock goes slower" implies that "Y measures that the X clock goes faster".
Strong correlation we have found between questions related to the concept of inertial reference frame and first postulate. There are relatively high correlations between some questions that belongs to different concepts, which gives relationship between different concepts (for example, first postulate, length contraction and time dilation).

4. Theoretical approach to the analysis of linear correlations

In statistics, the linear correlations between two sets of data we usually measure by covariance of two variables divided by the product of their standard deviations (called Pearson's correlation coefficient) [4]. The Pearson's correlation coefficient is a normalised covariance, which has a value between 1 and -1. The covariance can only reflect a linear correlation of two variables, ignoring any other independent correlations. If the value of correlation coefficient is close to 1, the correlation between two sets of data is very strong. Zero value would be in case when there is no linear correlation between two variables at all.
In case when there is a need to analyse correlations between large number of sets of data, such as for correlations of answers to 24 questions, a more comprehensive theoretical approach should be used. It is very complex to analyse correlations between any two pairs of answers in this paper (in our case there are 276 different pairs). The frequency of correlation coefficient is shown in the Fig. 2.

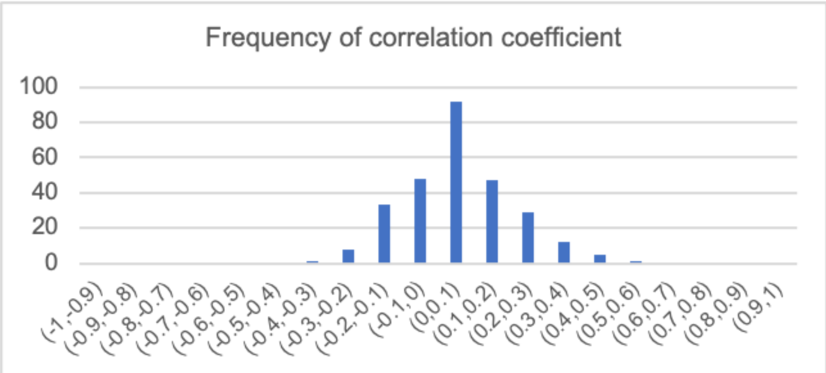

Fig.2. Frequency of correlation coefficient answers to all different pairs of questions.

The base for the key understanding of such complex system of correlations it is possible to find in the linear algebra which is fully used and developed in various fields of science, such as in quantum physics. The approach to find the principal correlations includes determination of eigenvectors and eigenvalues for the related system operator of correlations. This approach provides unique solution, which means that all original data on specific correlations of any pair of data can be reconstructed and uniquely represented as linear representations of eigenvectors. The mathematical formalism for determination of principal eigenvectors and eigenvalues can be find in various literature in physics and mathematics, for example in any book on quantum physics.

5. Discussion and Conclusion

In this paper, we have conducted a survey on two groups of high school students: 1) Control group of students who were not taught on the special relativity, and 2) the Central group of students who learned basic concepts in special relativity according to regular curricula in high school. The survey included 24 selected and adapted questions that were developed by J.S. Aslanides and C.M. Savage [1]. The selected questions covered the following concepts in special relativity: the first and the second postulates of the special relativity (the laws of physics are the same in all inertial reference frames; the speed of light in vacuum is the same in all reference frames), time dilation, length contraction, relativity of simultaneity, inertial reference frames, velocity addition, causality, and mass-energy equivalence. As an example, we have discussed correlations between answers on questions that are related to the same concept.

For further actions we suggest to conduct a comprehensive analysis of the linear correlations by using diagonalisation of the corresponding correlation matrix. The elements of matrix describe the form of multidimensional relation between introduced concepts.

6. Acknowledgement

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