Navigating four dimensions – upper secondary students' understanding of movement in spacetime

Magdalena KERSTING

University of Oslo, Department of Physics, Postboks 1048, 0316 Oslo, Norway

Abstract. In contrast to classical physics, general relativity (GR) interprets gravitation as geometry. Objects follow geodesic curves in four-dimensional spacetime and curvature creates the illusion of a gravitational force. Despite the scientific relevance of this theory, educational research in the domain of GR is scarce. This study contributes to a growing body of knowledge concerning secondary students' understanding of GR. Based on a thematic analysis of student discussions of 97 Norwegian physics students(18-19 years), we present results on students' understanding of geodesic movement in spacetime. Our findings can give guidance to improve learning and instruction of GR at upper secondary level.

1 Introduction and Research Questions

In the last years, physics educators have made first attempts of introducing the general theory of relativity (GR) to secondary school curricula (1). Initial efforts have focused on developing appropriate teaching approaches that rely on qualitative understanding (2), geometrical approaches (3), or simplified mathematical treatments (4). However, to make teaching and learning successful, there remains the need to study students' knowledge and conceptual understanding of key features of GR.

One central feature of GR relates to the motion of objects in four-dimensional spacetime. Spacetime provides the dynamic setting in which GR takes place and in which gravity arises. According to Einstein, objects follow geodesic curves through spacetime when no external force acts on them. The phenomenon of gravity arises when the curvature of spacetime makes objects deviate from their geodesic curves. An exploratory study with upper secondary physics students in Norway revealed that their understanding of gravity and curvature is closely linked to movement: While students could draw on the Einsteinian view of gravity to explain planetary movement, they struggled to grasp the gravitational influence on objects at rest (5).

This observation served as the starting point of this study that aims to gain deeper insight into upper secondary students' understanding of movement in spacetime related to gravity and curvature. Two research questions guide our study:

1) What characterizes students' understanding of movement in four-dimensional spacetime?
2) What are difficulties and challenges that students face when conceptualizing movement along geodesic curves?

2 Project Background and Data Collection

This study is part of the larger design-based research project ReleQuant that develops digital learning environments and studies students' learning processes in modern physics (6). The project takes a sociocultural stance towards learning (7) and emphasizes the use of language in physics education. In particular, the learning environments invite students to discuss key topics repeatedly through structured interactions.

This study reports from the second trial of the learning environment in GR that was implemented in five upper secondary physics classes with in total 97 students (18-19 years) in three Norwegian schools in spring 2017. To collect data, we employed a novel approach of fostering collaborative learning: In several built-in activities, students were asked to discuss in pairs or small groups, record their conversations with mobile phones and send the records to the teacher afterwards. Based on results from the first trial that showed that students struggled to relate gravity to movement in spacetime (5), the second version of the learning environment presented students with the following discussion task:

Are you moving in spacetime right now? Do you follow a geodesic curve through spacetime? According to Newton, why do you experience a pull towards the ground? And according to Einstein?

Our data comes from 21 audio-recorded discussions of small groups of 2-4 students. After transcribing the audio files, we used methods of thematic analysis (8) to unpack students' understanding of movement in spacetime. The codes emerged inductively and we grouped them into themes related to spatial and temporal movement as well as Newtonian and Einsteinian conceptions of spacetime.

3 Results and Conclusion

Even though most students were able to explain the difference between Newton's and Einstein's theory of gravity, few understood the subtleties of geodesic movement in spacetime which lies at the heart of GR. Our results show that the awareness for movement in space was more prevailing among students than movement in time. Students found it easier to relate to the spatial movement of the Earth around the Sun when talking about geodesic curves. Only few addressed the time dimension and the fact that no object will ever be at rest because we are moving in time as well. In fact, only one of the 21 groups was able to explain correctly that they were not following a geodesic curve in spacetime because they were not in free fall.

While our study can improve learning and instruction of GR by shedding light onto challenges that students face when working with concepts of gravity and geodesic movement, our results have influenced the final design of the learning environment as well[1]:The final unit on curved spacetime addresses geodesic movement along the time-dimension now explicitly.

4 References

1. Kersting M, Stannard W, Moschilla J, Kraus U, Zadnik M. Symposium: Research into the teaching and learning of Einsteinian physics in international contexts. GIREP-ICPE-EPEC Dublin. Dublin; 2017.
2. Kersting M, Henriksen EK, Bøe MV, Angell C. Teaching General Relativity in Upper Secondary Schools: an Educational Reconstruction. Manuscr under Rev.
3. Zahn C, Kraus U. Sector Models-A Toolkit for Teaching General Relativity. Part 1: Curved Spaces and Spacetimes. Eur J Phys. 2014;35:55020.
4. Stannard W, Blair D, Zadnik M, Kaur T. Why did the apple fall? A new model to explain Einstein's gravity. Eur J Phys. IOP Publishing; 2017;38(1):15603.
5. Steier R, Kersting M. Metaimagining and embodied conceptions of spacetime. Manuscr under Rev.
6. Bungum B, Henriksen EK, Angell C, Tellefsen CW, Bøe MV. ReleQuant - Improving teaching and learning in quantum physics through educational design research. Nord Nord Stud Sci Educ. 2015;11(2):153–68.
7. Vygotsky L. Thought and language. Cambridge: M.I.T. Press; 1962. 168 p.
8. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3:77–101.

[1] The learning environment can be accessed under www.viten.no/relativity.