


Research Article

Educational Approach of Special Relativity using an OpenAI's custom GPT as a teaching assistant

Dimitrios Gousopoulos^{1,*} 

¹ Panteion University of Social and Political Sciences, Greece

* Correspondence: d.gousopoulos@panteion.gr

<https://doi.org/eiki/10.59652/jetm.v2i4.328>

Abstract: Generative Artificial Intelligence (GenAI) has emerged as a valuable assistant in education. Many GenAI tools have been designed to aid teachers in offering personalized learning to their students, tailored to their educational needs and difficulties. In this paper we present a custom Open AI's GPT (IBL Educator GPT) that is designed and developed based on Inquiry based Learning and offers teachers a framework in which they can interact with ChatGPT and design educational strategies regarding Special relativity. To evaluate this tool via questionnaire that measures physics teachers' beliefs concerning the adoption of AI tools in the classroom The utilization of the IBL Educator GPT has led to the improvement in teachers' perspectives regarding the adoption of artificial intelligence-based tools for personalizing teaching.

Keywords: science education; Artificial Intelligence; educational technology

1. Introduction

Special Theory of Relativity (STR) is one of the most influential theories of the 20th century and has changed the way we view the world. It is part of many undergraduate curriculums, and it is often suggested that it should be integrated into an upper secondary curriculum. As it describes abstract as well as counterintuitive phenomena, students encounter several difficulties understanding its basic principles and consequences. There is a growing interest in studying these difficulties and developing tools and methods that address most of them.

As far as students' difficulties are concerned, they can be organized into three main categories (Alstein et al, 2021) (A) frames of reference, (B) postulates of SRT, and (C) relativistic effects.

A. Frames of reference

The notions of the frame of reference and the observer play an important role in setting a strong underpinning for students understanding the special relativity and its applications. As such, it is essential to explore students' difficulties concerning these notions. Students treat frames of reference as concrete objects, fixed to bodies (Tanel, 2013; Panse et al., 1994), for example both the ship and its reference system experience friction with the water. Students also tend to use a privileged frame of reference to describe a phenomenon. For example, between a moving train and a platform, the reference frame of the platform is preferred (Arriasecq & Greca, 2012; Scherr et al., 2001; Panse et al., 1994; Ramadas et al., 1996; Villani & Pacca, 1987). Moreover, events can be observed only inside the frames of reference that students have chosen (Tanel, 2013). As far as inertial observers are concerned, students confuse them with people who simply see or look and not with someone they observe and measure (Arriasecq & Greca, 2012). An interesting finding is that postgraduate students of the Department of Physics express the opinion that the speed, trajectory, and displacement of a moving object are independent of the reference system (absoluteness) and in fact there is only one true speed and only one true displacement traveled (space). Any variation in measurements between different inertial observers has come from optical illusion (Villani & Pacca, 1990).

Received: November 1, 2024

Accepted: November 19, 2024

Published: December 10, 2024



Copyright: © 2022 by the authors.
Submitted for open access publication
under the terms and conditions of the
Creative Commons Attribution (CC BY)
license
(<https://creativecommons.org/licenses/by/4.0/>).

B. Postulates of SRT

A common mistake that students make is that they try to interpret the basic postulates of STR within the framework of classical physics, something that leads them to wrong answers. According to the 1st postulate, namely the principle of special relativity, observers in any two inertial frames of reference must agree on the laws of physics. Students confront many difficulties understanding this postulate. In particular, students find it difficult to perceive the equivalence between motionless and uniform motion. They believe that phenomena (either electromagnetic or mechanical) can progress differently for different observers. For instance, they believe that an object moving at a constant speed relative to an observer O can accelerate or decelerate relative to a different inertial observer O' (Gousopoulos et al., 2023). According to the light postulate "light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body" (Einstein, 1905). Students consider that the "true" speed of light can be observed only in the rest frame of the light source (Villani & Pacca, 1987) and they use the Galilean velocity addition formula in problems in which the speed of light is asked. Moreover, according to students the fact that we cannot travel at speeds greater than the speed of light is because we have not yet developed the appropriate technology (Guisasola et al., 2009).

C. Relativistic effects

The basic relativistic effects that we will discuss are the relativity of simultaneity, the time dilation and the length contraction. Students consider two events to be simultaneous when they occur in the same space and time (Arriasecq & Greca, 2010). They also considered that two events that are simultaneous for one initial observer must be simultaneous for any other inertial observer (Gousopoulos et al., 2023). As far as the time dilation and length contraction are concerned, students believe that these phenomena are occurring only in the "moving" frame of reference (Selçuk, 2010; Aslanides & Savage, 2013), whereas other students ascribe time dilation and the length contraction to the absoluteness of time and space respectively (Dimitriadi & Halkia, 2012).

1.1. Approaches to Teaching STR Using Digital Technologies

STR deals with abstract and counterintuitive phenomena that are difficult for students to visualize and to interpret. As such, teaching approaches that use multimedia can have a positive impact on students understanding the key concepts of the STR. These approaches utilize either realistic virtual environments or interactive simulations that are based on thought experiments.

In general, realistic virtual environments enable students to visualize the effects that take place when travelling at speed near the speed of light. According to the literature, there are several virtual environments that have been reported. In particular, the "Real Time Relativity" visualizes relativistic effects such as time dilation, length contraction and Doppler shift (McGrath et al., 2010). The "Relativistic Asteroids" is a game that is based on the respective classic video arcade game "Asteroids" where students experience some of the effects of STR in a gamify way. In this game moving objects are contacted and change their colors due to their speed and based on the length contraction and Doppler shift respectively (Carr & Bossomaier, 2011). Moreover, "A Slower Speed of Light" is a game where students can experience a relativistic world, and their objective is to collect orbs while they are moving in more of less relativistic speed (Kortemeyer, 2019). Finally, the "Einstein's playground" is a planetarium show where students can experience the relativistic effects of STR in different speeds. In this show, they can see that while the speed at which they are moving approaches the speed of light length contraction and the relativity of simultaneity are observable, whereas at lower speed these effects cannot be detected (Sherin et al., 2017). The above-mentioned approaches have led to positive learning outcomes.

One very famous approach to STR is the use of thought experiments that constitute significant educational tools in familiarizing students with the key concepts of STR (Velentzas & Halkia, 2011). If we take a step forward and visualize these thought experiments utilizing relevant simulations, we increase the possibility of enhancing students' understanding regarding STR. One of such efforts has been reported by Horwitz and Barowy (1994) who developed the "Relab", a simulation tool that allows students to explore, model and simulate thought experiments. The integration of this tool into a teaching sequence showed positive learning outcomes. Another relevant tool has been reported by (Belloni et al., 2004) who developed java applets that mainly visualize relativistic effects (relativity of simultaneity, time dilation and length contraction).

1.2. *Generative Artificial Intelligence in Education*

GenAI (Generative A.I.) is a field of A.I. that focuses on the creation of new content, namely, text, image, audio, code and more based on the training data in response to prompts. GenAI utilizes machine learning algorithms to capture the underlying distribution of the training data and generate novel content that resembles a human-created one. GenAI is the technology that empowers LLMs and has a significant impact on multiple domains, such as IT and DevOps, entertainment, education, banking and finance, healthcare, human resources, and on working professionals in general.

As far as education is concerned GenAI has many applications, from content generation to personalized and adaptive learning experiences. Some of its capabilities are the following: It can assess assignments, provide feedback and propose a learning path tailored to learners' needs (Aryadoust et al., 2024). It can, also, detect special needs and learning difficulties to assist educators create specific lesson plans to address these difficulties. Despite the power of GenAI technologies, many concerns have been raised regarding potential biases, inaccuracies and the safety of sensitive personal data. One of the propositions that can address the aforementioned issues, is to ensure the alignment of GenAI generated content with the established educational goals.

In view of the above, this paper explores the acceptance of an OpenAI's custom GPT in teaching Special Theory of Relativity to upper secondary students. Therefore, the following hypotheses are composed:

H1. OpenAI's custom GPT that has been designed and developed based on the Inquiry Based Learning leads to an increased adoption of AI tools in classrooms.

H2. OpenAI's custom GPT that has been designed and developed based on the Inquiry Based Learning leads to an improved AI Knowledge.

H3. OpenAI's custom GPT that has been designed and developed based on the Inquiry Based Learning leads to an improved AI Pedagogy.

H4. OpenAI's custom GPT that has been designed and developed based on the Inquiry Based Learning leads to an improved self-concept regarding teaching Special Theory of Relativity.

2. Materials and Methods

This paper tries to highlight the leverage that GenAI tools, like ChatGPT, can give teachers regarding the design and implementation of an educational approach of Special Relativity at an upper secondary level. Moreover, this paper explores the potential shift in teachers' beliefs concerning the adoption of AI tools in the classroom. As such, a custom GPT was designed and developed based on the Inquiry Based Learning (IBL Educator GPT (you can have access here: <https://chatgpt.com/g/g-GHyDSFa8h-ibl-educator>). IBL is a constructivist educational approach that brings the students to the center of the educational process. In this context, students are engaging in active learning, exploration and problem solving. Pedaste et al. (2015), create a framework in which the phases are as follows: orientation, conceptualization, investigation, conclusion and discussion. When teachers enter the subject, they intend to teach, in our case topics on Special Relativity, the GPT proposes 3 fundamentally different approaches for each phase of the previously mentioned framework. Along with these options, the GPT offers comparison and contrast of them based on specific GenAI generated metrics. This is very significant, since teachers can start using IBL Educator GPT to support their decision making by simply seeking multiple perspectives on how to create an educational approach of Special Relativity. The prompt that fuels the GPT is the following:

“Act as an experienced educator. The users are teachers who will provide you with the subject they want to teach. Based on the selected subject, you should give them educational ideas and resources that are organized as follows: Orientation: is the process of stimulating curiosity about a topic and addressing a learning challenge through a problem statement Conceptualization: is the process of stating theory-based questions and/or hypotheses, generating research questions based on the stated problem, and generating hypotheses regarding the stated problem. Investigation: is the process of planning exploration or experimentation; collecting and analyzing data based on the experimental design or exploration Conclusion: is the process of drawing conclusions from the data by comparing inferences made based on data with hypotheses or research questions. Discussion: is the process of presenting findings of particular phases or the whole inquiry cycle by communicating with others and/or controlling the entire learning process or its phases by

engaging in reflective activities, presenting outcomes of an inquiry phase or of the whole inquiry cycle to others (peers, teachers) and collecting feedback from them, describing, critiquing, evaluating and discussing the whole inquiry cycle or a specific phase. For each phase 1. Propose 3 fundamentally different options, 2. Give the user 3 metrics to compare and contrast and 3. Evaluate these options using these metrics and before moving to the next phase, ask the user if they want to proceed to the next phase.”

For example, for the topic of time dilation the three options of investigation proposed by GPT are the following:

Investigation Phase: Planning and Collecting Data

In this phase, students explore or experiment to collect data that helps answer the research question or test their hypothesis. For time dilation, direct experiments in the classroom are challenging, so simulations, real-world data, or thought experiments can be effective alternatives.

Option 1: Computer Simulation of Time Dilation at High Speeds

Activity: Use a time dilation simulation tool (like PhET’s “Relativity Lab” or similar software) where students can adjust the speed of an object approaching the speed of light and observe how time changes relative to an observer.

Data Collection: Students record how time dilation varies with increasing speed and create a graph to visualize the relationship.

Goal: Explore the mathematical relationship between velocity and time dilation as predicted by the Lorentz factor.

Option 2: GPS Satellite Data Exploration

Activity: Guide students to research or analyze available GPS satellite data, which shows how clocks on satellites differ from clocks on Earth due to both velocity and gravitational time dilation.

Data Collection: Students examine and calculate the differences in time experienced by satellites versus ground-based clocks over a fixed period.

Goal: Investigate how both high speed and gravity impact time dilation, combining concepts of special and general relativity.

Option 3: Classroom Thought Experiment on Gravitational Time Dilation

Activity: Students design a thought experiment where they imagine a clock near a black hole versus one on Earth. They calculate the time difference using the general relativity equations and research black holes’ gravitational influence.

Data Collection: Students calculate time dilation effects based on mass and gravitational pull of celestial bodies like black holes or planets.

Goal: Explore the mathematical predictions of time dilation in strong gravitational fields, linking it to Einstein’s theory of general relativity.

Metrics to Compare Options:

1. Feasibility: How easy is it for students to carry out the investigation given the available resources (technology, data, etc.)?

2. Conceptual Challenge: How demanding is the investigation in terms of mathematical and theoretical understanding?

3. Engagement and Hands-On Learning: How involved are students in collecting and interpreting their own data?

Evaluation of Options:

Option 1: Computer Simulation of Time Dilation

Feasibility: High. Simulation software is widely accessible, and students can explore scenarios without physical limitations.

Conceptual Challenge: Moderate. Students will need to understand the Lorentz factor but can manipulate the variables easily.

Engagement: High. The hands-on aspect of manipulating variables engages students in the exploration process.

Option 2: GPS Satellite Data Exploration

Feasibility: Moderate. It may require access to specific data sets or sources, which can be found through research, though some guidance will be needed.

Conceptual Challenge: High. Students must apply both special and general relativity and understand real-world applications of the theory.

Engagement: High. Students can connect the investigation directly to everyday technology, making the data feel relevant and interesting.

Option 3: Thought Experiment on Gravitational Time Dilation

Feasibility: High. It doesn't require any specific resources, just imagination and calculation tools.

Conceptual Challenge: High. Understanding gravitational fields and applying general relativity equations is quite advanced.

Engagement: Moderate. While thought experiments are useful, they lack the hands-on component that can engage some learners more fully.

In order to export conclusions regarding the IBL Educator GPT evaluation 14 science teachers was comprised the sample that was characterized by convenience. The science teachers selected for this study, was teaching STR to upper secondary students in the context of science clubs in their schools. Therefore, an intervention was designed and implemented that included the training of these teachers to the foundations and applications of artificial intelligence in education. The before-mentioned intervention was carried out for 5 weeks. After this period the teachers embedded the IBL Educator GPT in their educational design of a series of lesson in STR that lasted 6 weeks. Before and after the intervention mentioned before, an online survey was given to the participants. The survey consisted of 21 questions that was grouped into 4 categories. A 5 -point Likert scale was used in order the respondents to evaluate their experience of the utilization of the IBL Educator GPT. The survey was distributed to the teachers having a return rate of 100% before and after the above -mentioned intervention. Data analysis was conducted using the R software.

3. Results

For evaluating the developed GPT a pilot study was conducted. Fourteen science educators have tested its capabilities, and they filled in a questionnaire before the use of GPT and the same questionnaire after its use (Appendix A). The questions of the questionnaire were selected from published instruments in education and so they are characterized by validity and reliability (Braun et al., 2008; Chiu et al., 2024). The questionnaire consists of 4 main constructs with 4 questions each: AI Knowledge, AI Pedagogy, AI Adoption and Self – Concept (see Appendix). For each structure the non-parametric Wilcoxon signed rank test applied, to compare the scores of the pretest and posttest.

The results show that all 4 hypotheses, proposed in this study, are accepted. In particular, as far as the AI knowledge is concerned the test indicated that in post-test ranks were statistically significantly higher than pre-test ranks, $Z=-3.233$, $p<.001$. As regards AI Pedagogy the post-test ranks were statistically higher than pre-test ranks $Z=-3.180$, $p=.002$. For AI Adoption and Self - Concept we had the same picture with $Z=-3.180$, $p=.002$ and $Z=-3.059$, $p=.002$ respectively.

4. Discussion

Generative AI tools, like ChatGPT have emerged as significant teaching assistants that can help teachers with the design and development of innovative educational approaches of challenging physics topics, such as Special Relativity. Students at upper secondary schools face many difficulties concerning relativistic phenomena, and due to their abstract nature teachers confront a lot of obstacles when trying to enhance students' understanding. Thus, a well-structured GPT which is based on a well-established educational framework can aid teachers tackle the previously mentioned difficulties and challenges. One interesting feature of the developed GPT is that it gives 3 options, and some key metrics based on which it offers a comparison in order to help teachers take a better decision regarding the educational approach to the subject they want to teach. Moreover, a pilot study was conducted so as to observe the potential shift in teachers' beliefs concerning the adoption of AI tools in the classroom. In particular, teachers' perspectives on the adoption of artificial intelligence-based tools for personalizing teaching improved after the use of the developed GPT in their educational design of a series of lessons regarding Special Relativity at upper secondary School Level. The same results have emerged regarding the other 3 constructs; AI Knowledge, AI Pedagogy and science teachers' self-concept as regards their ability to teach relativistic concepts have enhanced. More specifically, the scores of the participants after the

intervention were statistically higher than their scores before the intervention in the four before-mentioned constructs. After the intervention science teachers' level of AI Knowledge and pedagogy was increased and this led teachers to acquire a better view regarding AI adoption in their classroom and enhance their self-concept as far a teaching STR in high school is concerned. These finding come as an addition to the effort of the educational community to address the difficulties students face when trying to understand the concepts of Special Theory of Relativity. So, this paper further confirms the benefits of Generative AI tools in helping teachers to design high quality educational materials and didactic approaches.

5. Conclusions

The trigger of this research was the need of embedding the possibilities of generative AI in Education. This can be accomplished in several ways, one of which is to be utilized by teachers in their teaching design. As such, an educational program was designed that involved the training of 14 science teachers of the generative ai concepts and applications. A questionnaire was built based on previous research, that measured AI knowledge, AI pedagogy, adoption of AI in education and self-concept concerning teaching Special Theory of Relativity in upper secondary students. The results were very encouraging, showing an improvement of teachers' view regarding the 4 previous-mentioned constructs. One of the research limitations is the small number of participants, but it has been, already, designed a research with a large participant base for more accurate results. AI tools can have a great impact on Education helping teacher in designing educational approaches tailored to students' needs, provides students with feedback and suggestions according to their educational needs and level of their writing skills, can reduce teachers' workload (repetitive managing tasks, and grading of simple assignments) and thus focus on more complex teaching tasks and explain difficult concepts in simple terms, leading the users to understand complex subjects and thus making them part of scientific developments. As such, more research should be carried out in order educational scientist to unveil ways that can incorporate AI tools effectively in education taking into account several concerns related to data privacy, responsible AI usage, inaccurate and biased information provided by AI tools.

Funding: This research received no external funding.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Questionnaire

AI knowledge

I can distinguish whether a tool is AI-based or not.

I can create content with AI.

I can explain what AI is.

I know how to choose the right AI tools to effectively complete a task.

AI pedagogy

I can choose an AI tool to use in my classroom that enhances what I teach, how I teach, and what students learn.

I can choose an AI tool that enhances my teaching subject content for a lesson.

I can teach lessons that appropriately combine my teaching subject, AI tools, and

teaching approaches.

I can help others coordinate the use of subject content, AI tools, and teaching approaches.

ChatGPT Adoption Intention

In the next weeks, I intend to use ChatGPT for my teaching preparation

I intend to use ChatGPT to get the answers to my teaching-related questions.

I feel that I would use ChatGPT for teaching purposes.

I believe that ChatGPT would be beneficial and more helpful for my teaching work.

Self- Concept

I can give an overview of the topics of Special Theory of Relativity to my students

I can clearly present complicated issues of Special Theory of Relativity to my students

Now I see myself in the position to process a typical question of Special Theory of Relativity coming from my students

I can work out the contradictions and similarities of learning content (e.g., contradictions between different models or methods) of Special Theory of Relativity

References

- Alstein, P., Krijtenburg-Lewerissa, K., & Van Joolingen, W. R. (2021). Teaching and learning special relativity theory in secondary and lower undergraduate education: A literature review. *Physical Review Physics Education Research*, 17(2), 023101. <https://doi.org/10.1103/PhysRevPhysEducRes.17.023101>
- Arriasecq, I., & Greca, I. M. (2012). A teaching-learning sequence for the special relativity theory at high school level historically and epistemologically contextualized. *Science & Education*, 21, 827-851. <https://doi.org/10.1007/s11191-010-9231-5>
- Aryadoust, V., Zakaria, A., & Jia, Y. (2024). Investigating the affordances of OpenAI's large language model in developing listening assessments. *Computers and Education: Artificial Intelligence*, 6, 100204. <https://doi.org/10.1016/j.caeai.2024.100204>
- Aslanides, J. S., & Savage, C. M. (2013). Relativity concept inventory: Development, analysis, and results. *Physical Review Special Topics – Physics Education Research*, 9(1), 010118. <https://doi.org/10.1103/PhysRevSTPER.9.010118>
- Belloni, M., Christian, W., & Dancy, M. H. (2004). Teaching special relativity using Physlets®. *The Physics Teacher*, 42(5), 284-290. <https://doi.org/10.1119/1.1737961>
- Braun, E., Gusy, B., Leidner, B., & Hannover, B. (2008). Das Berliner Evaluationsinstrument für selbsteingeschätzte, studentische Kompetenzen (BEvaKomp). *Diagnostica*, 54(1), 30-42. <https://doi.org/10.1080/02602938.2010.534762>
- Carr, D., & Bossomaier, T. (2011). Relativity in a rock field: A study of physics learning with a computer game. *Australasian Journal of Educational Technology*, 27(6). <https://doi.org/10.14742/ajet.928>
- Chiu, T. K., Ahmad, Z., & Çoban, M. (2024). Development and validation of teacher artificial intelligence (AI) competence self-efficacy (TAICS) scale. *Education and Information Technologies*, 1-19. <https://doi.org/10.1007/s10639-024-13094-z>
- Dimitriadi, K., & Halkia, K. (2012). Secondary students' understanding of basic ideas of special relativity. *International Journal of Science Education*, 34(16), 2565-2582. [10.1080/09500693.2012.718099](https://doi.org/10.1080/09500693.2012.718099)
- Einstein, A. (1905). On the electrodynamics of moving bodies. *Annalen der Physik*, 17, 891-921. <https://www.fourmilab.ch/etexts/ein-stein/specrel/specrel.pdf>
- Gousopoulos, D., Kapotis, E., & Kalkanis, G. (2023). Students' difficulties in understanding the basic principles of relativity after standard instruction. arXiv preprint arXiv:2311.09914. <https://arxiv.org/abs/2311.09914>
- Guisasola, J., Solbes, J., Barragues, J. I., Morentin, M., & Moreno, A. (2009). Students' understanding of the special theory of relativity and design for a guided visit to a science museum. *International Journal of Science Education*, 31(15), 2085-2104. <https://doi.org/10.1080/09500690802380698>
- Horwitz, P., & Barowy, B. (1994). Designing and using open-ended software to promote conceptual change. *Journal of Science Education and Technology*, 3, 161-185. <https://doi.org/10.1007/BF01575899>
- Kortemeyer, G. (2019). Game development for teaching physics. *Journal of Physics: Conference Series*, 1286, 012048. <https://doi.org/10.1088/1742-6596/1286/1/012048>
- McGrath, D., Wegener, M., McIntyre, T. J., Savage, C., & Williamson, M. (2010). Student experiences of virtual reality: A case study in learning special relativity. arXiv:0911.0226. <https://doi.org/10.48550/arXiv.0911.0226>
- Panse, S., Ramadas, J., & Kumar, A. (1994). Alternative conceptions in Galilean relativity: frames of reference. *International Journal of Science Education*, 16(1), 63-82. <https://doi.org/10.1080/0950069940160105>
- Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, 14, 47-61. <https://doi.org/10.1016/j.edurev.2015.02.003>

- Ramadas, J., Barve, S., & Kumar, A. (1996). Alternative conceptions in Galilean relativity: inertial and non-inertial observers. *International Journal of Science Education*, 18(5), 615–629. <https://doi.org/10.1080/0950069960180509>
- Scherr, R. E., Shaffer, P. S., & Vokos, S. (2001). Student understanding of time in special relativity: Simultaneity and reference frames. *American Journal of Physics*, 69(S1), S24-S35. <https://doi.org/10.1119/1.1371254>
- Selçuk, G. S. (2010). Addressing pre-service teachers' understandings and difficulties with some core concepts in the special theory of relativity. *European Journal of Physics*, 32(1), 1. <https://doi.org/10.1088/0143-0807/32/1/001>
- Sherin, Z., Tan, P., Fairweather, H., & Kortemeyer, G. (2017). "Einstein's playground": an interactive planetarium show on special relativity. *The Physics Teacher*, 55(9), 550-554. <https://doi.org/10.1119/1.5011832>
- Tanel, Z. (2013). Student difficulties in solving problems concerning special relativity and possible reasons for these difficulties. *Journal of Baltic Science Education*, 13(4), 573-582. <https://doi.org/10.33225/jbse/14.13.573>
- Velentzas, A., & Halkia, K. (2011). The 'Heisenberg's Microscope' as an example of using thought experiments in teaching physics theories to students of the upper secondary school. *Research in Science Education*, 41, 525-539. <https://doi.org/10.1007/s11165-010-9178-1>
- Villani, A., & Pacca, J. L. A. (1987). Students' spontaneous ideas about the speed of light. *International Journal of Science Education*, 9(1), 55–66. <https://doi.org/10.1080/0950069870090107>
- Villani, A., & Pacca, J. L. A. (1990). Spontaneous reasoning of graduate students. *International Journal of Science Education*, 12(5), 589–600. <https://doi.org/10.1080/0950069900120510>