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Stories of physics teachers teaching special relativity concepts in senior high school

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Abstract

Teaching Special Relativity in senior high school presents significant challenges due to its abstract and counterintuitive concepts, which often contradict students' everyday experiences. This study employs a narrative research approach to explore the experiences of three physics teachers in teaching Special Relativity. The findings reveal that teachers struggle with explaining relativistic effects such as time dilation, length contraction, and simultaneity, as students frequently hold persistent misconceptions influenced by classical mechanics and popular media. Furthermore, curriculum constraints and the lack of appropriate instructional resources hinder effective teaching. The study identifies key pedagogical strategies, including the use of interactive simulations, thought experiments, and historical contexts, to make relativity more accessible. Teachers emphasize the need for conceptual scaffolding before introducing mathematical derivations to ensure students grasp the fundamental principles. Despite the challenges, teachers express passion and excitement when students experience conceptual breakthroughs, highlighting the transformative power of physics education. This study underscores the importance of professional development programs and curriculum adjustments to better support teachers in delivering relativity concepts effectively. Future research should explore additional instructional interventions to enhance relativity education in high schools.

Keywords: Special Relativity, Physics Education, Teaching Strategies

1. Introduction

Teaching special relativity in senior high schools is a formidable challenge due to its abstract nature and counterintuitive concepts. Students must grapple with ideas like time dilation and length contraction, which contradict their everyday experiences and Newtonian mechanics. The mathematical demands, including advanced algebra and calculus, further complicate understanding, as students may not have the required proficiency. Teachers face the task of simplifying complex equations without losing the essence of the theory. Moreover, real-world examples of special relativity, such as high-speed particles and theoretical space travel, are often distant from students' daily lives, making the material seem esoteric. Additionally, the historical context, dating back to Einstein's early 20th-century work, can feel irrelevant to modern students. Addressing diverse learning styles in a single classroom compounds the difficulty, requiring teachers to employ a variety of teaching strategies, including multimedia resources, hands-on experiments, and interactive simulations. These efforts aim to make the abstract principles of special relativity more accessible and engaging, but the inherent complexity of the subject continues to pose significant educational challenges.

The aim of this research is to delve into the narratives of physics teachers as they navigate the complexities of teaching special relativity in senior high schools. By investigating their experiences, the study seeks to uncover the challenges and strategies employed by educators to convey such abstract and counterintuitive concepts. This exploration will highlight how teachers address the intricate mathematical underpinnings, like Lorentz transformations, and make them accessible to students who may not yet have advanced mathematical skills. Additionally, the research aims to identify the pedagogical approaches that successfully bridge the gap between theoretical physics and students' everyday experiences, thereby enhancing engagement and comprehension. Understanding these stories will shed light on the creative and practical solutions teachers develop to simplify and contextualize special relativity, including the use of multimedia resources and hands-on activities. Furthermore, the research aspires to reveal the broader implications of these teaching practices on students' scientific literacy and critical thinking skills. Ultimately, this study aims to provide valuable insights and recommendations for improving physics education, ensuring that complex scientific theories like special relativity can be effectively taught and appreciated at the high school level.

2. Literature Framework

2.1 Emotional geographies

Andy Hargreaves' studies on emotional geographies in education explore how teachers' emotions are deeply intertwined with their professional interactions and environments. His concept of emotional geographies describes the patterns of closeness and distance in human interactions that shape the emotions experienced in relationships. In the context of teaching, these emotional geographies influence how teachers connect with students, colleagues, administrators, and families. For instance, a teacher's sense of moral purpose and commitment to fostering student growth can create a supportive and nurturing classroom atmosphere, while feelings of isolation or lack of support can lead to emotional distance and disengagement. Hargreaves also emphasizes the importance of understanding the emotional landscapes of teachers to build stronger relationships among educational stakeholders (Hargreaves 2001). By recognizing the emotional dimensions of teaching, educators can develop strategies to enhance their emotional well-being and create more empathetic and effective learning environments. This approach encourages teachers to reflect on their own emotional experiences and consider how these emotions impact their teaching practices and interactions with students (Hargreaves 2004).

1. Physical Geography: This aspect focuses on the spatial and temporal dimensions of teaching, such as the physical proximity between teachers and students, and how this affects emotional interactions. For example, in a physics classroom, the arrangement of desks and the teacher's movement around the room can influence students' emotional engagement and comfort levels.
2. Moral Geography: This dimension considers the emotional impact of teachers' sense of purpose and accomplishment. In physics teaching, this could involve the teacher's commitment to fostering scientific curiosity and understanding, and how this sense of purpose influences their emotional connection with students.
3. Sociocultural Geography: This aspect explores how social and cultural factors, such as gender, race, and cultural background, shape emotional experiences in the classroom. In physics, addressing diverse perspectives and ensuring inclusive teaching practices can help create a supportive emotional environment for all students.

4. Professional Geography: This dimension examines the emotional aspects of professional norms and practices. For physics teachers, this might involve navigating the expectations of scientific rigor while also being empathetic and supportive to students' learning needs.
5. Political Geography: This aspect looks at the power dynamics and emotional implications of educational policies and practices. In the context of physics teaching, this could involve understanding how curriculum standards and assessment pressures impact teachers' emotional well-being and their ability to connect with students.

2.2 Prior studies of special relativity concepts from teachers' and students' perspectives

Previous studies on teaching special relativity have highlighted significant challenges from both physics-teachers' and students' perspectives. For teachers, the primary difficulty lies in conveying concepts that are fundamentally abstract and counterintuitive. Studies show that teachers often struggle with finding effective pedagogical strategies to explain time dilation, length contraction, and the equivalence of mass and energy in ways that are accessible to high school students. Many teachers express the need for more professional development opportunities and resources to improve their understanding and teaching methods of these complex ideas. Additionally, integrating these concepts into the curriculum without overwhelming students or detracting from other essential physics topics remains a persistent concern for educators (Dimitriadi and Halkia 2012).

Teachers often find special relativity difficult to teach due to its abstract nature and counterintuitive concepts (e.g., time dilation, length contraction, and the relativity of simultaneity). We could imagine how students in senior high school should imagine about time dilation which it is difficult to be understood. The time would be slow at the motion reference when compared to rest reference is not easy understanding for students. Moreover, twin paradox that is fundamental event in the special relativity is challenging to be existed in the classroom even students should imagine it. Moreover, not only students but also physics teachers lack confidence to teach because they also have limited understanding about special relativity. Consequently, they sometimes did not choose to teach the topics of special relativity and they were skip to choose easy topics to be learned by students. In addition, many physics teachers have a lack of understanding in mathematical formalism (Kamphorst et al. 2023). Because to teach the concepts of special relativity, the need of mathematical formalism is required in order to create simple mode of explanation. Teachers could explain the association of different variable supported by mathematical derivation.

From the students' perspective, previous research indicates that special relativity is often perceived as one of the most challenging topics in the high school physics curriculum. Students report difficulty in grasping the mathematical and conceptual foundations of the theory, which can lead to frustration and disengagement. Studies also reveal that students struggle with reconciling the principles of special relativity with their everyday experiences and prior knowledge of classical physics. This cognitive dissonance can hinder their ability to fully comprehend and appreciate the significance of relativistic effects. Effective teaching strategies, such as using visual aids, interactive simulations, and real-world analogies, have been found to help bridge these gaps, making the abstract concepts of special relativity more tangible and engaging for students (Scherr, Shaffer, and Vokos 2001).

Interestingly, in fact, students were interesting to listen the historical context of the emergence of special relativity concepts. The stories of the Einstein's thought experiment look amazed events for students and how the theory itself develops overtime. The emergence of technology to enhance teaching mostly help to visualize model of visualization of special relativity concepts (Fan 2015). For instance, how light travels for the observer in the rest reference and how it would be appeared for constant velocity of references. Interactive simulations and visualizations (e.g., spacetime diagrams, animations of moving clocks) are highly effective in helping students understand relativistic phenomena. Further, students often express interest in the philosophical implications of relativity, such as the nature of time and reality.

3. Research Method

3.1 Research design and participants

This study employs a narrative research design to explore the experiences, perspectives, and reflections of three senior high school physics teachers regarding their teaching practices, challenges, and professional development (Clandinin 2006). The narrative approach is chosen because it allows for an in-depth understanding of teachers' lived experiences through their personal stories, providing rich qualitative insights into the teaching and learning of physics. In addition, the study involves three senior high school physics teachers in Indonesia (i.e. West Java Province) selected through purposive sampling. These teachers, who have varying levels of experience and backgrounds, are actively engaged in physics instruction in different school settings. The study focuses on their journey in teaching physics, incorporating their instructional strategies, challenges, and the impact of external factors such as curriculum changes and technological advancements.

3.2 Instrument and data analysis

The primary data collection method in this study is in-depth interviews, conducted individually with each of the three senior high school physics teachers. Each interview session will last approximately one hour and will follow a semi-structured format, allowing flexibility while ensuring that key themes related to teaching Special Relativity are explored in depth. The interview will be recorded with the participant's consent and later transcribed for analysis. The interview will be divided into three main phases: the opening interview, core interview, and closing phase. The questions in each interview can be seen in Table 1.

3.3 Data analysis

The data analysis in this study follows a thematic narrative approach, focusing on understanding and interpreting the personal experiences of three senior high school physics teachers in teaching Special Relativity. The process begins with data preparation, where all interview recordings are transcribed verbatim, reviewed for accuracy, and anonymized to protect participants' identities.

Next, the analysis follows thematic coding, starting with open coding, where key phrases related to teaching strategies, challenges, and student misconceptions are identified. These initial codes are then grouped into broader themes through axial coding, which helps establish connections between different experiences. Expected themes include teachers' first encounters with Special Relativity, difficulties in explaining abstract concepts, the use of Einstein's thought experiments, and strategies to address student misconceptions. In the selective coding phase, the most significant themes are integrated into a structured narrative, ensuring that each teacher's personal voice and perspective are preserved. The analysis highlights key turning points, such as changes in pedagogical methods, adaptations to curriculum constraints, and impactful classroom experiences. Direct quotes from participants are included to enhance authenticity.

To ensure trustworthiness, the study incorporates member checking, where participants review their narratives for accuracy, and peer debriefing, where other researchers validate the thematic interpretations. Triangulation is also applied by comparing interview data with classroom observations and teacher reflections. Finally, the findings are interpreted in the broader context of physics education, providing insights into effective teaching practices, challenges in Special Relativity instruction, and implications for teacher training and curriculum development in modern physics education. We

4. Result of the research

4.1 Challenges Faced by Teacher in Teaching Special Relativity

Teaching Special Relativity in senior high school presents significant challenges for physics teachers due to the abstract nature of the subject and students' difficulty in conceptualizing relativistic effects.

Table 1. The indicators of interview questions

Phase	Indicators of Questions
Opening	Brief introduction to the study's purpose and ethical considerations (e.g., confidentiality, voluntary participation).
	Informal conversation to build rapport and ease the participant into sharing their experiences.
	Background information about the participant: Teaching experience (years in service, grade levels taught), educational background and professional qualifications, and experience in teaching modern physics topics, particularly Special Relativity
Core	When and how did you first learn about Special Relativity?
	How did your initial understanding of Special Relativity shape your approach to teaching it?
	What challenges did you face in grasping Special Relativity as a student, and do you see similar difficulties in your students?
	How do you typically introduce Special Relativity to your students?
	Can you describe a memorable experience or lesson when teaching Special Relativity?
	What instructional strategies do you find most effective in explaining time dilation, length contraction, and simultaneity?
	How do students typically react when first learning about Special Relativity?
	Do you use simulations, thought experiments, or historical narratives to enhance understanding?
	How do you typically introduce Special Relativity to your students?
	Can you describe a memorable experience or lesson when teaching Special Relativity?
	What instructional strategies do you find most effective in explaining time dilation, length contraction, and simultaneity?
	How do students typically react when first learning about Special Relativity?
	Do you use simulations, thought experiments, or historical narratives to enhance understanding?
	What are the biggest difficulties students face in learning Special Relativity?
	How do you help students overcome misconceptions about relativistic concepts?
	How do you assess students' understanding of Special Relativity?
	Have you encountered any curriculum constraints in teaching this topic?
	What role does mathematical rigor play in your approach to teaching Special Relativity?
Closing	What do you enjoy most about teaching Special Relativity?
	If you could improve the way Special Relativity is taught in high school, what would you change?
	Any final thoughts or additional experiences you would like to share?
	Expression of appreciation for their participation and explanation of the next steps (e.g., transcript review, potential follow-ups).

One major issue highlighted by the teachers is that Special Relativity contradicts students' everyday experiences and classical mechanics intuition. Unlike Newtonian physics, where time, space, and velocity are perceived as absolute, Special Relativity introduces concepts such as time dilation, length contraction, and the relativity of simultaneity, which defy common sense. Teachers reported that students often struggle with understanding how time can slow down for a moving observer or how two simultaneous events in one frame may not be simultaneous in another. Additionally, the mathematical framework, including the Lorentz transformation equations, requires a solid foundation in algebra and functions, which not all students have mastered. Furthermore, teachers face curriculum constraints, as Special Relativity is often introduced briefly within modern physics topics, leaving limited time for in-depth discussions. Some teachers also noted the lack of appropriate instructional resources, such as interactive simulations or visual demonstrations, which could help students better grasp relativistic concepts. As a result, many physics educators rely on thought experiments and analogies, but these are not always effective in overcoming deeply ingrained misconceptions.

4.2 Students' Most Impressive Misconceptions About Special Relativity

One of the most striking findings in this research is the range of misconceptions students hold regarding Special Relativity. Teachers shared several notable examples that illustrate how students attempt to reconcile relativistic principles with their existing understanding of physics. A common misconception is the belief that time dilation means a moving clock is "broken" rather than experiencing time differently relative to an observer. Some students also assume that length contraction is a physical compression rather than an observer-dependent effect. Another widespread misunderstanding is the assumption that an object moving close to the speed of light will "experience" a different time rate, failing to grasp that time dilation is a relative phenomenon dependent on the observer's frame of reference. Some students incorrectly interpret Einstein's postulates, believing that only light experiences the effects of Special Relativity, while ordinary objects moving at high speeds should still follow classical mechanics. Others believe that an observer moving close to the speed of light would perceive their surroundings as slowing down rather than experiencing the opposite effect due to time dilation. Teachers emphasized that these misconceptions often stem from students' prior exposure to non-scientific interpretations of relativity in science fiction movies, which depict time travel and relativistic effects in ways inconsistent with actual physics. While such media representations can sometimes spark interest in relativity, they also contribute to confusion and require careful conceptual correction during instruction.

4.3 What Physics Teachers Need to Address When Teaching Special Relativity

To effectively teach Special Relativity in high schools, physics teachers must address both conceptual and instructional challenges. One of the first steps is establishing a strong conceptual foundation by reinforcing Einstein's two postulates— the constancy of the speed of light and the principle of relativity—before introducing mathematical derivations. Teachers emphasized that visualization tools, such as interactive simulations and animations, can help students better understand relativistic effects. Thought experiments, such as the famous twin paradox or the light clock experiment, must be carefully structured to ensure students grasp the relativity of time and space rather than interpreting these effects as absolute distortions. Teachers also need to connect relativity to real-world applications, such as GPS satellites, particle accelerators, and cosmic ray interactions, to make the topic more relevant to students. Additionally, introducing historical perspectives on the development of relativity, including the limitations of Newtonian mechanics and the Michelson-Morley experiment, can help students appreciate the necessity of Einstein's theory. Another key aspect is scaffolding mathematical reasoning, ensuring that students understand the Lorentz transformation equations step by step rather than memorizing formulas without conceptual understanding. Moreover, teachers highlighted the importance of addressing misconceptions explicitly, using diagnostic assessments and discussions to uncover and correct false beliefs. Given the constraints of the high school curriculum, some teachers suggested integrating Special Relativity within broader discussions of modern physics and technological advancements, rather than presenting it as an isolated topic.

4.4 Teachers' Emotions About Teaching Special Relativity

The emotional experiences of physics teachers when teaching Special Relativity range from frustration and challenge to excitement and intellectual satisfaction. Many teachers described feeling frustrated when students struggle to grasp fundamental concepts, especially when deeply rooted misconceptions persist despite multiple explanations. The abstract nature of the topic, combined with students' reliance on classical physics intuition, often makes it difficult to achieve immediate conceptual breakthroughs. However, teachers also expressed a strong sense of accomplishment and excitement when students finally understand key relativistic principles. One teacher described the "aha" moments in the classroom when students successfully apply relativistic reasoning to thought experiments, calling them some of the most rewarding experiences in teaching physics. Another teacher shared that despite the challenges, teaching relativity provides an opportunity to ignite curiosity and philosophical discussions about the nature of time, space, and reality, making it one of the most intellectually stimulating topics in high school physics. Some teachers also reflected on how their own understanding of relativity deepened over time, as they continuously sought new ways to explain complex ideas more effectively. Despite curriculum constraints, many teachers remain passionate about teaching Special Relativity, viewing it as a way to introduce students to the beauty and elegance of modern physics. While challenges persist, their emotional connection to the subject often drives them to refine their teaching approaches, ensuring that future students gain a deeper appreciation of Einstein's groundbreaking contributions to physics.

5. Discussion and conclusion

The findings of this study highlight the significant challenges physics teachers face when teaching Special Relativity, largely due to the abstract and counterintuitive nature of its concepts. The difficulty in explaining relativistic effects, such as time dilation and length contraction, stems from students' deep-rooted reliance on classical mechanics and their struggle to reconcile relativistic principles with everyday experiences (Villani and Arruda 1998; Duit and Treagust 2003). The presence of persistent misconceptions, such as the belief that time dilation is a mechanical failure rather than a relativistic effect, further complicates the learning process. These findings are consistent with previous research in physics education, which suggests that students often misinterpret relativity due to prior exposure to non-scientific explanations in media and popular culture (Fan 2015). To address these challenges, teachers must employ effective instructional strategies, including the use of visual simulations, thought experiments, and real-world applications to enhance conceptual understanding (Candido et al. 2022). The study also emphasizes the need for a curriculum revision that allows more time for Special Relativity discussions, rather than treating it as a supplementary topic within modern physics (Scherr, Shaffer, and Vokos 2001). Moreover, the emotional experiences of teachers—ranging from frustration over student misunderstandings to excitement when students experience conceptual breakthroughs—demonstrate the complexity of teaching Special Relativity at the high school level. While teachers acknowledge the subject's difficulty, they also recognize its potential to inspire curiosity and deeper engagement with physics. Moving forward, professional development programs should focus on equipping teachers with effective pedagogical tools and strategies to tackle Special Relativity more effectively (Arriassecq and Greca 2012). This study reinforces the importance of explicitly addressing misconceptions and integrating relativity into a broader scientific context, ensuring that students develop a more accurate and meaningful understanding of one of the most revolutionary theories in modern physics. This study provides valuable insights into the challenges, misconceptions, instructional strategies, and emotional experiences of senior high school physics teachers in teaching Special Relativity. The findings reveal that the abstract and counterintuitive nature of relativistic concepts, such as time dilation, length contraction, and simultaneity, makes it difficult for students to grasp. Teachers struggle to correct deeply ingrained misconceptions, often influenced by everyday experiences and popular media. Additionally, curriculum constraints and the lack of appropriate instructional resources further hinder effective teaching (Dimitriadi and Halkia 2012).

To address these issues, teachers must implement interactive simulations, thought experiments, and real-world applications to facilitate students' understanding. Emphasizing conceptual reasoning over rote memorization and explicitly tackling misconceptions can improve learning outcomes. Furthermore, teacher professional development and curriculum adjustments are necessary to allow for a more comprehensive exploration of Special Relativity (Candido et al. 2022; Fan 2015). Despite the challenges, teachers express passion and excitement when students experience conceptual breakthroughs, demonstrating the transformative power of physics education. By refining pedagogical approaches and integrating relativity within broader scientific contexts, teachers can inspire students to appreciate one of the most revolutionary theories in modern physics. Future research should explore additional instructional interventions and assessment methods to enhance relativity education in high schools (Souza, Serrano, and Treagust 2024).

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References

Arriassecq, Irene, and Ileana María Greca. 2012. A teaching–learning sequence for the special relativity theory at high school level historically and epistemologically contextualized. *Science & Education* 21:827–851.

Candido, Keneth John O, King Christian C Gillesania, Justine C Mercado, and Joy Mae B Reales. 2022. Interactive simulation on modern physics: a systematic review. *International Journal of Multidisciplinary: Applied Business and Education Research* 3 (8): 1452–1462.

Clandinin, D Jean. 2006. Narrative inquiry: a methodology for studying lived experience. *Research studies in music education* 27 (1): 44–54.

Dimitriadi, Kyriaki, and Krystallia Halkia. 2012. Secondary students' understanding of basic ideas of special relativity. *International Journal of Science Education* 34 (16): 2565–2582.

Duit, Reinders, and David F Treagust. 2003. Conceptual change: a powerful framework for improving science teaching and learning. *International journal of science education* 25 (6): 671–688.

Fan, Xinxin. 2015. Effectiveness of an inquiry-based learning using interactive simulations for enhancing students' conceptual understanding in physics.

Hargreaves, Andy. 2001. Emotional geographies of teaching. *Teachers college record* 103 (6): 1056–1080.

———. 2004. Teaching in a box: emotional geographies of teaching. In *Developing teachers and teaching practice,* 27–49. Routledge.

Kamphorst, Floor, MJ Vollebregt, ER Savelsbergh, and WR Van Joolingen. 2023. An educational reconstruction of special relativity theory for secondary education. *Science & Education* 32 (1): 57–100.

Scherr, Rachel E, Peter S Shaffer, and Stamatis Vokos. 2001. Student understanding of time in special relativity: simultaneity and reference frames. *American Journal of Physics* 69 (S1): S24–S35.

Souza, Maira Giovana de, Agostinho Serrano, and David Treagust. 2024. Exploring the relationship between mental representations and conceptual understanding of special relativity by high school students. *Research in Science & Technological Education,* 1–26.

Villani, Alberto, and Sergio M Arruda. 1998. Special theory of relativity, conceptual change and history of science. *Science & Education* 7:85–100.