

From Newton to Einstein: Conceptual gains and gender equity in teaching gravity at the primary level

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ABSTRACT

The general theory of relativity, developed by Albert Einstein, represents the most precise scientific framework for elucidating gravity. Despite its fundamental importance in modern physics and its ability to elucidate cosmic events, it is predominantly excluded from educational curricula, especially at the primary level. This study examines sixth-grade pupils' introductory, model-based conceptual representations of Einsteinian gravity in Greek primary schools and assesses the impact of gender on learning outcomes. A pedagogical intervention utilizing guided inquiry and a spacetime simulator (rubber sheet analogy) was executed in six educational institutions. Students administered a written multiple-choice questionnaire prior to and after the intervention. The results demonstrated a notable enhancement in students' comprehension of gravitational events in accordance with the Einsteinian paradigm. Statistical study (Wilcoxon signed-rank test) revealed no significant disparity in performance improvements between males and girls. The results indicate that young learners may comprehend non-Newtonian gravity models when adequately supported, and that gender does not serve as a significant determinant in conceptual understanding. The discussion encompasses implications for curricular reform and gender-inclusive pedagogies.

Keywords: Einsteinian gravity, primary education, conceptual understanding, gender equity, modern physics curriculum

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INTRODUCTION

Albert Einstein's creation of the general theory of relativity in the early 20th century was a groundbreaking shift from classical Newtonian physics. Einstein's theory reconceptualized gravity not as a force, but as a manifestation of the curvature of spacetime induced by mass and energy. This theoretical advancement provided significant insights into cosmic mechanisms, clarifying phenomena such as the precession of mercury's orbit, black holes, and universal expansion, while also stimulating progress in various fields, including astrophysics, GPS technology, and quantum field theory (Cherepashchuk & Chernin, 2008; Ehlers, 2007; Günther & Müller, 2020). Notwithstanding these contributions, the incorporation of Einsteinian physics into educational curriculum has been remarkably constrained, particularly at the primary level.

This exclusion is notable, considering the increasing focus in science education research on equipping scientifically literate citizens who are knowledgeable about classical physics and acquainted with the fundamental models that characterize modern science (Foppoli et al., 2019; Greca & Freire, 2014). In recent decades, there has been a trend toward incorporating modern physics concepts at earlier educational stages, not primarily to master mathematical formalism, but to foster qualitative understanding and engagement with fundamental ideas that

influence contemporary scientific thought (Olsen, 2002; Velentzas & Halkia, 2013). Research increasingly indicates that young learners possess the cognitive ability to comprehend the conceptual underpinnings of Einsteinian gravity, especially when suitable analogies and visual representations are utilized (Dua et al., 2020; Kamphorst et al., 2023; Kaur et al., 2017a).

A promising educational method entails utilizing physical models, exemplified by the "rubber sheet" simulator of spacetime curvature. This model enables students to witness the deformation of an elastic surface by varying masses, providing a concrete counterpart for gravitational interaction as articulated by general relativity. Although these parallels require clear delineation of their limitations (e.g., spatial constraints and Newtonian bias), they have demonstrated efficacy in enhancing conceptual change of abstract processes (Kaur et al., 2017b; Postiglione & Angelis, 2021). This study employed a model-based, guided inquiry framework to familiarize sixth-grade pupils with introductory Einsteinian-inspired representations of gravity.

The mental framework of gravity presents significant obstacles for learners. Research at various educational levels has shown numerous enduring misconceptions, including the idea that gravity solely operates downward, exclusively affects heavy things, or is nonexistent in space (Gönen, 2008; Kassetas, 2004; Pablico, 2010; Syuhendri, 2019). These concepts are frequently reinforced by quotidian language and

experiences and may be exacerbated by early exposure to oversimplified or inaccurately described scientific models. Newtonian formulations, though historically important and still applicable for numerous practical computations, may unintentionally reinforce mechanistic and geocentric interpretations of gravity, thereby obstructing students' comprehension of more comprehensive relativistic viewpoints (Baldy, 2007; Kavanagh & Sneider, 2006; Williamson & Willoughby, 2012).

The lack of gender-inclusive approaches in physics education remains a significant challenge. Conventional narratives and educational methodologies frequently do not captivate girls with the same intensity or regularity as boys, notwithstanding research indicating that gender disparities in scientific aptitude are minimal or nonexistent (Kaur et al., 2020). Discrepancies are often observed in students' attitudes, confidence, and perceived self-efficacy toward science-related courses. These characteristics lead to disproportionate participation in STEM disciplines and may become evident early in education. There is an urgent necessity for instructional methodologies that deliver demanding scientific information while simultaneously promoting fairness and inclusivity from the beginning.

This study operates under a twin framework:

- (1) The necessity of integrating Einsteinian concepts into primary education to foster enhanced scientific comprehension and
- (2) The obligation to assess whether such interventions yield gender-equitable learning outcomes.

This research underscores the advantages of early exposure to contemporary physics concepts for students, particularly when interventions are succinct, conceptually targeted, and reinforced by physical models (Choudhary et al., 2018; Kaur et al., 2020; Kersting et al., 2020; Ruggiero et al., 2021).

The research specifically examines two questions:

1. To what degree can sixth-grade students enhance their comprehension of gravity from an Einsteinian viewpoint after a brief instructional intervention?
2. Does gender affect the efficacy of this intervention for quantifiable performance?

This study examines these problems within the framework of Greek primary education, so contributing to the global dialogue over the viability and effects of curriculum reform that incorporates modern physics at the foundational stage.

A preliminary version of this study was presented at the 2024 National Greek Conference on Science Education, when initial findings and methodological insights were disseminated to the educational research community.

THEORETICAL BACKGROUND

Conceptual Change of Gravity and Student Misconceptions

Gravity is a deeply abstract and sometimes misconstrued notion in educational science, especially during the shift from common experiences to formal scientific frameworks. Newtonian gravity is typically presented first as a force exerted at a distance; however, Einstein's general theory of relativity redefines gravity as the curvature of spacetime caused by mass and energy (Cherepashchuk & Chernin, 2008; Günther & Müller, 2020). This paradigm shift presents ontological and epistemological issues, especially in higher education. It

is now widely recognized that simpler yet precise representations of Einsteinian concepts can be effectively introduced even at the primary level (Dua et al., 2020; Foppoli et al., 2019).

Children's comprehension of gravity is frequently influenced by intuitive, sensory experiences that result in the development of alternate ideas. Prevalent fallacies encompass the notion that gravity needs air for its operation, that it exclusively influences massive objects, or that it is nonexistent in outer space. These concepts are not simply "errors" but embody coherent cognitive frameworks based on previous experiences and language indicators (Baldy, 2007; Gönen, 2008; Kavanagh & Sneider, 2006; Nik Daud et al., 2015; Syuhendri, 2019). Such alternative ideas are not confined to primary education; research has shown that even freshman university students may retain significant misconceptions about core mechanical concepts (Stylos et al., 2008) while similar reasoning difficulties are observed among primary preservice teachers in thermal contexts (Stefanou et al., 2023). Alternative ideas are considered a timelessly valuable tool for physics education, as they provide educators with critical insights into students' cognitive processes and learning needs (Kotsis, 2023). Pablico (2010) and Williamson and Willoughby (2012) assert that these misunderstandings are profoundly ingrained and frequently endure until adulthood unless expressly addressed through educational intervention.

Kassetas (2004) observes that in the Greek educational context, traditional instruction centered exclusively on Newtonian mechanics may inadvertently reinforce mechanistic and terrestrial interpretations of gravity, thereby constraining students' cognitive adaptability to embrace more abstract, general relativistic perspectives. Baldy (2007) contends that instructional methods that arbitrarily divide gravitational events into "terrestrial" and "space" categories perpetuate errors instead of fostering a unified and cosmologically coherent understanding of gravity.

Teaching Modern Physics in School Settings

The incorporation of modern physics, particularly Einsteinian theories, into school science curricula has historically been postponed until upper secondary or post-secondary education, mostly due to the perceived complexity of the mathematics involved. A burgeoning corpus of research contends that the conceptual underpinnings of relativity and quantum physics can and need to be introduced earlier through age-appropriate, non-mathematical methodologies (Greca & Freire, 2014; Olsen, 2002; Velentzas & Halkia, 2013). This has resulted in the development of Einsteinian physics education as a subdiscipline within physics education research (PER).

Global research indicates that brief educational interventions, when focused on model-based reasoning and visual metaphors, can significantly enhance students' conceptual comprehension (Choudhary et al., 2018; Ruggiero et al., 2021). Employing analogies like the rubber sheet simulator, which depicts spacetime as a malleable fabric distorted by mass, provides learners with an approachable means to comprehend the geometric essence of gravity (Kaur et al., 2017b; Postiglione & Angelis, 2021). However, researchers warn that these models should be contextualized to prevent the reinforcement of Newtonian interpretations of gravity as a downward force operating in two dimensions (Kersting et al., 2020).

The objective of basic education is not to impart the complete mathematical intricacies of general relativity, but to cultivate scientific

thinking and literacy by familiarizing children with the conceptual framework of modern physics. Foppoli et al. (2019) highlight the favorable reactions of teachers and students to curriculum materials including Einsteinian viewpoints, indicating both the practicality and appeal for extensive curricular transformation.

It is important to distinguish between canonical scientific formulations of general relativity and the introductory, representational forms of "Einsteinian gravity" employed in school contexts. In the present study, students' understanding of curved spacetime is necessarily metaphorical and grounded in physical analogies and visual models, rather than in the formal geometrical and mathematical structure of the theory. The aim is not conceptual mastery of general relativity, but the development of age-appropriate representations that challenge Newtonian intuitions and support early epistemic engagement with modern physics.

Gender and Engagement in Physics Education

The underrepresentation of women in physics and engineering is a continuous global challenge, frequently stemming from gendered socialization processes that commence in early infancy. Although the historical narrative of girls' underachievement in physics is increasingly contested, gender discrepancies endure, especially in students' views, confidence, and sense of belonging in the scientific field (Kaur et al., 2020). Research indicates that these discrepancies do not consistently correlate with actual performance outcomes; instead, they are evident in self-perception and engagement behaviors.

Presenting current physics concepts through inclusive, collaborative, and experiential methods provides a chance to transform gendered pathways in science education. Kaur et al. (2020) executed extensive interventions at educational institutions and revealed that girls had a notable affinity for Einsteinian physics content, frequently surpassing boys in post-intervention evaluations. The involvement of girls significantly rose when teaching focused on conceptual comprehension rather than memorization and incorporated interactive models and narrative techniques.

These findings indicate that Einsteinian gravity, when presented in a gender-neutral and pedagogically effective way, could facilitate equity in science education. Furthermore, the originality and creativity embedded in relativity-based explanations can engage the interest and curiosity of learners from many backgrounds, challenging assumptions regarding who is deemed suitable for physics.

METHODOLOGY

This study utilized a quasi-experimental, one-group pre-/post-test design to explore changes in sixth-grade students' comprehension of gravity following a brief instructional intervention grounded in Einsteinian concepts. While this design is appropriate for exploratory classroom-based research, it does not permit strong causal inferences. Therefore, any observed learning gains should be interpreted as being associated with, rather than caused exclusively by, the intervention. This strategy was chosen for its appropriateness in interventions carried out in authentic classroom settings where random assignments are impractical. The absence of a control group constrains the ability to draw causal inferences; yet the approach offers significant insights into educational feasibility and impact inside genuine teaching environments.

A prior iteration of this research, derived from the pilot application of the educational intervention, was presented at the 2024 National Greek Conference on Science Education. The feedback from this presentation guided the enhancement of the questionnaire items and the instructional materials included in the current study (**Appendix A**).

The study was conducted in six public primary schools situated in the Ioannina region of Greece. The sample comprised 166 sixth-grade pupils, aged 11 to 12 years (76 girls and 90 boys). Classes were selected through convenience sampling based on school accessibility and the willingness of teachers and administrators to participate. The same instructional materials, lesson structure, and teaching procedures were used in all participating schools in order to ensure consistency of implementation. All interventions were delivered by the same physics educator and followed an identical lesson plan in each school (**Appendix B**). This sample strategy lacks generalizability to the wider population, although it is often utilized in exploratory educational research when logistical and ethical factors are critical. Participation was voluntary and executed with the complete approval of school authorities, educators, and the legal guardians of pupils. All ethical protocols concerning anonymity, secrecy, and low risk were rigorously adhered to.

The primary instructional intervention was one hour and utilized a guided inquiry learning methodology. The lesson sought to introduce students to an Einsteinian-inspired representation of gravity, not as a force exerted at a distance, as traditionally presented through Newtonian physics, but as the effect of curved spacetime. This representation was necessarily qualitative and model-based, relying on analogies and visualizations rather than on formal mathematical or theoretical treatment of general relativity. Instruction commenced with the elicitation of past knowledge and students' intuitive concepts regarding gravity, then introducing the rubber sheet model, a prevalent pedagogical analogy in Einsteinian physics education. This model features an elastic fabric symbolizing spacetime, upon which numerous spherical objects of differing masses are positioned. The distortion of the sheet surrounding huge entities enables pupils to comprehend how curvature influences the trajectory of smaller items nearby.

The intervention was conducted by a physics educator proficient in Einsteinian teaching methods and encompassed multimedia presentations, brief talks, and practical observation of model demonstrations. Emphasis was placed on prompting students to formulate predictions, explain reasons, and address their original misconceptions through reflective inquiry. The analogy employs Newtonian principles to illustrate Einsteinian phenomena (e.g., gravity's downward force on a rubber sheet), and its pedagogical value resides in rendering abstract relativistic ideas comprehensible to students without the requisite advanced mathematical knowledge for formal analysis. The limitations of the analogy were explicitly discussed with the students, including its representation of a four-dimensional phenomenon in two spatial dimensions and its inability to illustrate all facets of gravitational interaction (Kaur et al., 2017b; Kersting et al., 2020).

A written questionnaire was presented to all participants immediately before and after the class to assess the impact of the educational intervention. The instrument consisted of seven multiple-choice questions designed to probe students' conceptual understanding of gravitational phenomena on earth and in extraterrestrial contexts, as well as their introductory understanding of spacetime. The items were

adapted from previously published and validated sources (Pablico, 2010; Postiglione & Angelis, 2021) and were reviewed for content relevance, conceptual alignment, linguistic clarity, and developmental suitability for primary school students. The questionnaire was intended as a diagnostic conceptual probe rather than a comprehensive psychometric scale. Each item had a single correct answer, and total scores ranged from 0 to 7. Content validity was supported through alignment of the items with the targeted conceptual constructs (gravity beyond earth, spacetime, and curvature by mass) and by their grounding in established research instruments. Given the exploratory nature of the study and the age of the participants, the emphasis was placed on conceptual coverage and clarity rather than on scale development. Due to the small number of items, estimation of internal consistency reliability was not considered meaningful, and the instrument should be interpreted as a focused conceptual probe rather than as a high-reliability measurement scale. A preliminary version of the questionnaire was implemented during an earlier pilot phase of the study, which was presented at the 2024 National Greek Conference on Science Education. Feedback from this pilot application informed minor revisions to item wording and distractor plausibility in order to improve clarity and age-appropriateness. No items were removed or added at this stage; refinements focused on linguistic precision and reduction of ambiguity. Item difficulty varied substantially across the seven questions, with some items (e.g., gravity on earth) showing high pre-intervention success rates and others (e.g., spacetime distortion) showing very low initial success rates. This pattern is consistent with the conceptual progression targeted by the instrument and supports its sensitivity to instructional change. Given the small number of items and their intentional coverage of distinct conceptual domains, internal consistency indices such as Cronbach's alpha were not considered appropriate indicators of quality. Instead, the instrument is intended to function as a set of conceptually focused probes capturing shifts in specific ideas rather than as a unidimensional scale. The identical instrument was employed for both the pretest and posttest, facilitating a direct comparison of student comprehension prior to and following the intervention. All questions were anonymous, and no identifying information was gathered, adhering to ethical research standards.

The gathered data were examined utilizing IBM SPSS statistics. Descriptive statistics, encompassing means, standard deviations, and response frequencies, were calculated to summarize student performance on each topic. The Wilcoxon signed-rank test was employed to evaluate the statistically significant effect of the intervention on students' comprehension of Einsteinian gravity. This non-parametric test was chosen because of the limited sample size and the non-normal distribution of the test scores, as verified by the Kolmogorov-Smirnov test ($p < .05$). Additionally, the data were analyzed by gender to examine potential differences in pretest and posttest scores between males and females. Because the gender groups constitute independent samples, the Mann-Whitney U test was employed for between-group comparisons. Effect sizes (r) were also calculated to estimate the magnitude of the observed differences. A p -value threshold of 0.05 was employed to ascertain statistical significance.

The study aimed to evaluate both the conceptual advancements attained by students after a single educational session and the equitable distribution of these gains across gender groups. The research seeks to enhance physics teaching and foster inclusive learning environments in

science classrooms by integrating pedagogical innovation with empirical analysis.

RESULTS

This study's findings are structured around two primary themes:

- (1) students' overall performance prior to and following the Einsteinian gravity intervention and
- (2) possible disparities in learning outcomes based on gender.

The analysis utilizes the pre- and post-test scores derived from a constructed questionnaire of seven multiple-choice questions that evaluate comprehension of gravity and spacetime within the framework of general relativity.

Descriptive Analysis of Conceptual Gains

Overall descriptive analysis of total test scores indicated clear improvement following the instructional intervention. Pretest scores were generally low, reflecting limited initial understanding of Einsteinian gravity concepts, whereas posttest scores showed a marked upward shift across the sample. This pattern consists of substantial overall gains in conceptual understanding following the lesson. These improvements suggest that the intervention was associated with positive learning outcomes, although causal attribution cannot be established due to the absence of a control group. Elevated rates of incorrect responses were noted on almost all items, with the exception of the initial question regarding the existence of gravity while standing on earth, a concept already known to students due to their familiarity with Newtonian mechanics. Correct responses for this topic were 84.2% among girls and 80.0% among boys prior to instruction, demonstrating a common basic understanding rooted in conventional school science.

Conversely, more intricate questions addressing gravity in extraterrestrial settings or the essence of spacetime, such as the existence of gravity on the moon (Q3), the presence of gravity near a satellite (Q4), or the concept of spacetime (Q6), exhibited markedly lower rates of right responses. For example, before the intervention, merely 13.2% of girls and 26.7% of boys answered Q3 accurately, whereas only 7.9% of girls and 8.9% of boys recognized the right definition of spacetime. Item Q7, the most difficult question regarding what could distort spacetime, received a 0.0% correct response rate from girls and a mere 2.2% from boys.

Subsequent to the intervention, performance significantly enhanced across all items. Significant improvements were noted in conceptual inquiries pertaining to spacetime and gravitational effects in non-earth scenarios. For instance, the percentage of right responses to Q6 (What is spacetime?) increased from 7.9% to 78.9% for girls and from 8.9% to 66.7% for boys. The proportion of students who accurately recognized that gravity persists underwater (Q5) rose to 78.9% for girls and 64.4% for boys, in contrast to 26.3% and 22.2%, respectively, before the lecture.

Despite significant post-intervention enhancements in most questions, one item, Q4, which inquired about the sense of gravity near a satellite orbiting earth, exhibited persistently low accuracy: merely 44.7% of girls and 37.8% of boys answered correctly. This outcome indicates that the prevalent fallacy that "gravity is nonexistent in space" remained widespread among a considerable segment of the sample,

Table 1. Percentage of students providing correct responses before and after the intervention

Questions	Girls (Pre)	Boys (Pre)	Girls (Post)	Boys (Post)
Q1: Gravity on Earth	84.2%	80.0%	100.0%	97.8%
Q2: Gravity falling from a plane	15.8%	20.0%	71.1%	40.0%
Q3: Gravity on the Moon	13.2%	26.7%	76.3%	62.2%
Q4: Gravity near a satellite	15.8%	26.7%	44.7%	37.8%
Q5: Gravity under water	26.3%	22.2%	78.9%	64.4%
Q6: What is spacetime?	7.9%	8.9%	78.9%	66.7%
Q7: What distorts spacetime?	0.0%	2.2%	76.3%	55.6%

despite the conceptual intervention. **Table 1** summarizes item-level performance, displaying the percentage of correct responses by question, gender, and time of administration, while overall score patterns are described in the text above.

Inferential Analysis: Gender-Based Differences

A descriptive examination of overall scores indicated similar performance patterns for boys and girls at both the pretest and posttest. To explore the statistical significance of learning gains and any gender-related differences, inferential analyses were performed utilizing IBM SPSS. Initially, the distribution of pre- and post-test scores was assessed. Histograms demonstrated non-normality, corroborated by the Kolmogorov-Smirnov test ($p < .05$), thereby validating the application of non-parametric methods for hypothesis testing.

The Wilcoxon signed-rank test was utilized to examine pre-/post-test changes in students' overall test scores. The results indicated statistically significant improvements for both boys and girls after the lesson ($p < .01$). The associated effect sizes were in the negligible-to-small range, indicating that while the gains were statistically significant, gender-related differences in improvement were minimal.

To examine gender as a potential factor influencing learning outcomes, Mann-Whitney U tests were conducted to compare boys' and girls' scores on both the pretest and posttest. The analysis revealed no statistically significant differences between boys and girls prior to the intervention ($p = 1.00$) or after the intervention ($p = 1.00$). The corresponding effect sizes were negligible, indicating that gender-related differences in performance were minimal.

The $p = 1.00$ values reflect identical or near-identical rank distributions between the two gender groups, a situation that can occur in non-parametric testing when score patterns are highly similar. Descriptive statistics indicated that females somewhat surpassed boys on most post-test items, especially in conceptual questions (e.g., Q6 and Q7); however, these differences lacked statistical significance. This corresponds with international research indicating that, when provided with equal chances and stimulating instructional environments, females achieve comparable performance to boys in science (Kaur et al., 2020). It further substantiates the capacity of Einsteinian physics education to serve as a gender-equitable instructional method.

DISCUSSION

This study aims to investigate two primary questions: first, whether a brief instructional intervention centered on Einsteinian gravity can improve primary school students' conceptual understanding; and second, whether gender influences the effectiveness of this intervention. The results provide strong evidence consistent with the first research hypothesis and present a nuanced view of the second.

The results reveal that students initially possessed a limited and fragmented comprehension of gravitational phenomena as defined by the general theory of relativity. Before the intervention, most participants primarily linked gravity to terrestrial experiences and lacked familiarity with its functioning in alien environments. Their comprehension of spacetime and its distortion by mass, a fundamental principle of Einsteinian gravity, was notably inadequate, as seen by the nearly nonexistent success rates on questions evaluating this understanding (Q6 and Q7). The results align with previous studies indicating prevalent misconceptions among students, including the notions that gravity is exclusive to Earth, that it necessitates air for operation, or that it is nonexistent in space (Gönen, 2008; Syuhendri, 2019; Williamson & Willoughby, 2012).

Subsequent to the educational intervention, student performance significantly enhanced across all items. The advances in conceptual knowledge of gravity beyond Earth (Q3) and the distortion of spacetime (Q7) were particularly significant, with post-intervention correct response rates above 70% for girls and nearing or exceeding 60% for boys. The results indicate that students not only absorbed new information but also began to restructure their existing knowledge within a more advanced theoretical framework. However, due to the study design, these changes cannot be attributed solely to the intervention and may also reflect testing effects, novelty effects, or contextual classroom factors. The results indicate that students not only absorbed new information but also began to reorganize elements of their existing knowledge in ways consistent with a more advanced theoretical framework. However, due to the one-group pre-/post-test design, these changes cannot be attributed solely to the intervention. Alternative explanations, such as testing effects, novelty effects, or contextual classroom influences, cannot be excluded. The observed gains are therefore interpreted as being consistent with the pedagogical value of the lesson rather than as definitive evidence of causal impact. These findings align with previous research suggesting that even brief, well-scaffolded interventions can support students' engagement with Einsteinian concepts (Choudhary et al., 2018; Kaur et al., 2020).

The application of the rubber sheet paradigm was important in enabling this change. Although constrained in its spatial depiction and at times reinforcing Newtonian intuitions (e.g., "falling into" a well), the model functioned as an effective heuristic instrument that assisted students in visualizing the curvature of spacetime and its implications for motion. Kaur et al. (2017b) and Kersting et al. (2020) have highlighted that analogies, when accompanied by a clear delineation of their limitations, can connect abstract theory with experience learning. In this study, students were not only passive consumers of information; they were encouraged to observe, hypothesize, and communicate their thinking. This corresponds with current demands in PER for more active, inquiry-based teaching methods that include learners in the process of constructing scientific understanding.

An anomaly in the overall trend of enhancement was noted in question Q4, which inquired if gravity influences an individual traversing near a satellite in Earth's orbit. Despite the intervention, less than fifty percent of the pupils answered properly, and the misunderstanding that "there is no gravity in space" persisted significantly. These findings resonate with those of Baldy (2007) and Kavanagh and Sneider (2006), who observed the entrenched nature of this specific misconception. A potential explanation is that colloquial terminology (e.g., "zero gravity" or "weightlessness") and visual representations in mainstream media bolster these concepts. This indicates the necessity for continuous instructional emphasis and potentially diverse modalities of representation when confronting this misperception.

The result that gender did not have a statistically significant impact on student performance, both before and during the intervention, is equally important. Although girls excelled over boys in most of the items post-lesson, the disparities were not statistically significant ($p = 1.000$), as verified by Wilcoxon signed-rank tests. This outcome contests enduring narratives regarding gender disparities in science learning results and aligns with recent international research suggesting that gender differences in science achievement are frequently exaggerated, particularly when interventions are crafted to be inclusive and participatory (Kaur et al., 2020). Furthermore, the enhanced performance of girls on conceptual questions (Q6 and Q7) underscores the capacity of Einsteinian physics to function as an equal gateway to scientific reasoning, providing novel cognitive and creative realms that appeal to a wider array of learners.

This study's findings enhance the existing research supporting the early incorporation of contemporary physics into school curricula. Traditional arguments have highlighted the mathematical complexity necessary to understand relativity or quantum mechanics, but current approaches underscore the accessibility of conceptual frameworks when suitably modified (Greca & Freire, 2014; Olsen, 2002; Velentzas & Halkia, 2013). This research substantiates the premise that students, even at the elementary level, may effectively engage with the fundamental concepts of general relativity without the necessity of formal calculus or tensor analysis. Moreover, such involvement can confront established beliefs and foster epistemic flexibility, a crucial aspect of scientific literacy in the 21st century (Foppoli et al., 2019).

However, the study has certain shortcomings. The reliance on convenience sampling and the limited number of participating schools restricts the generalizability of the results. The one-hour intervention, while significant, does not permit a thorough examination of concept development over time. Future research may utilize longitudinal designs to examine knowledge retention and transfer, or to compare various teaching techniques (e.g., storytelling, simulations, and immersive settings). Furthermore, the impact of additional variables, such as educators' opinions, classroom environment, or previous familiarity with cosmological concepts, requires further examination.

Notwithstanding these limitations, the work provides encouraging evidence that Einsteinian physics can be integrated into primary education in a theoretically robust and gender-inclusive fashion. It emphasizes the significance of curricular innovation and pedagogical creativity in addressing scientific progress and societal demands for equity and inclusion in science education.

EDUCATIONAL IMPLICATIONS

This study's findings have significant implications for elementary scientific education, especially considering ongoing global initiatives to modernize curricula and tackle enduring equity challenges in STEM learning contexts. The effective presentation of Einsteinian gravity in a one-hour instructional session indicates that primary school students can comprehend complex scientific concepts and highlights the practicality of integrating such material into current curricula. The lack of statistically significant gender disparities in student performance after the intervention suggests that Einsteinian physics may serve as a gender-inclusive pedagogical gateway to the physical sciences.

This study advocates for the prompt incorporation of current physics topics into basic and lower secondary science curriculum. Current curricular models in numerous nations, including Greece, are rooted in classical Newtonian mechanics, which, although basic, no longer aligns with the present scientific comprehension of the cosmos. The incorporation of Einsteinian principles, including spacetime curvature, gravitational waves, and cosmic occurrences, can enhance students' conceptual frameworks and adequately equip them for future learning. This transition does not need a complete rejection of classical physics, but instead a recalibration of content to present a more precise and motivating depiction of scientific understanding.

The findings underscore the pedagogical significance of model-based learning and guided inquiry in the instruction of abstract concepts like gravity. The application of the rubber sheet model of spacetime offered students a visual and tactile sense of how mass distorts spacetime, enhancing comprehension through embodied cognition and analogical reasoning. Despite its shortcomings, the model demonstrated effectiveness in enhancing engagement and comprehension, as evidenced by the performance improvements observed post-intervention. Educators ought to be motivated to include such parallels, accompanied by explicit disclosures of their limitations, as a component of a comprehensive approach to render abstract physics concepts comprehensible to young students. Furthermore, identifying and working with students' alternative ideas is a timelessly valuable strategy for physics education, as it provides teachers with diagnostic tools for tailoring instruction to students' cognitive starting points (Kotsis, 2023).

The findings underscore the necessity for specialized professional development for scientific educators, particularly those in primary education. Numerous educators may exhibit a deficiency in confidence or acquaintance with Einsteinian principles, having predominantly received their education within Newtonian paradigms. Teacher training programs should incorporate modules on contemporary physics, pedagogical techniques for elucidating intricate topics without sophisticated mathematics, and the application of analogical and experiential teaching methods. Providing educators with topic understanding and pedagogical strategies is crucial for the effective implementation of Einsteinian physics in the classroom.

The gender-equitable results identified in this study indicate that Einsteinian physics education could function as an effective mechanism for fostering inclusion and engagement among underrepresented demographics in STEM, especially girls. By transitioning from mechanical computation to creative, conceptual inquiry, such interventions may help dismantle prejudices regarding who "belongs" in physics and cultivate a feeling of scientific agency among all students.

Future educational designs may increasingly incorporate storytelling, interdisciplinary linkages (such as with philosophy or art), and student-led research to accommodate a variety of learning styles and identities.

The study ultimately encourages contemplation over the necessary policy-level modifications to foster innovation in science education. Education ministries and curriculum authorities could contemplate piloting and assessing modules on Einsteinian physics in designated schools, using them as experimental grounds for broader reforms. Collaboration with research institutions, scientific centers, and worldwide networks can furnish essential resources, training opportunities, and comparative data to facilitate evidence-based policy formulation.

In conclusion, the findings of this study offer a compelling justification for rethinking possibilities in primary science education. Introducing Einsteinian gravity at this preliminary stage not only elucidates contemporary scientific concepts but also has the potential to revolutionize students' engagement with science as inquisitive, competent, and innovative thinkers. Educational systems that adopt this perspective will not only nurture future scientists but also enable all students to comprehend the intricate and evolving world in which they reside.

CONCLUSION

This study aimed to investigate the feasibility and educational significance of teaching Einsteinian gravity to primary school kids, specifically examining whether a brief, model-based instructional intervention could improve conceptual knowledge equitably among genders. Based on international research and contextualized within Greek primary education, the study suggests that young learners can engage meaningfully with fundamental concepts of modern physics when such material is presented in a developmentally suitable and conceptually robust manner.

The findings indicate that students' comprehension of gravity, particularly in non-terrestrial contexts and in relation to the concept of spacetime curvature, improved following a single one-hour instructional session; however, these improvements should be interpreted as indicative rather than conclusive due to the exploratory nature of the study design. These advancements validate the pedagogical efficacy of tactile models like the spacetime simulator and endorse the wider transition in scientific education towards inquiry-driven and analogical instructional approaches. Furthermore, the results contest enduring fallacies regarding the intricacy of Einsteinian physics, demonstrating that such concepts can be proficiently conveyed without the necessity of formal mathematical instruments.

The finding that gender did not appear to influence learning outcomes is equally relevant within the context of this intervention. This outcome advances current dialogues around fairness in STEM education and underscores the capacity of Einsteinian physics to serve not just as a content innovation but also as a stimulus for inclusive pedagogy. Girls exhibited performance comparable to boys across most metrics, indicating that when contemporary science is conveyed through captivating and unconventional media, enduring participation disparities can be reduced or entirely eradicated.

Although the study's breadth is inherently constrained by sample size and contextual specificity, its implications are extensive. It

advocates that curriculum reform in science education should not be limited by historical order or assumed complexity but should instead be directed by current scientific knowledge and educational research. Introducing Einsteinian gravity at the elementary level fulfills both epistemic and social objectives: it links educational science with contemporary knowledge and enables all learners to perceive themselves as capable of comprehending, and contributing to, modern scientific discourse.

Subsequent study should seek to reproduce these results in many educational settings and examine long-term memory, transferability, and the impact of incorporating current physics into comprehensive curricular structures. Through deliberate implementation and ongoing support for educators, the instruction of Einsteinian gravity in primary schools can transition from an innovation to a standard practice, drawing kids nearer to the frontiers of science and fostering their curiosity, imagination, and sense of wonder. Given the absence of a control group and the short duration of the intervention, further research using controlled and longitudinal designs is required before firm causal conclusions can be drawn.

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Ethics declaration: This study was conducted in accordance with established ethical standards for research involving human participants. Approval for the implementation of the study was obtained from the relevant school authorities, and participation was voluntary for all students involved. Informed consent was secured from the legal guardians of the pupils prior to data collection. All participants were assured of anonymity and confidentiality. No personally identifiable information was collected, and all data were recorded and analyzed in aggregated form exclusively for research purposes. Students were informed that their participation, as well as their responses, would not affect their academic evaluation. The instructional intervention posed no physical or psychological risk to participants, as it was fully aligned with regular educational practices and designed to support learning in an inclusive and non-discriminatory environment. The study adhered to the principles of respect, beneficence, and justice throughout all stages of the research process.

AI statement: Artificial intelligence (AI) tools were used in a supportive capacity during the preparation of this manuscript. Specifically, AI-assisted language tools were employed to improve clarity, grammar, and overall readability of the text. These tools were not used to generate original research content, analyze data, or produce scientific conclusions. All conceptual development, research design, data collection, analysis, and interpretation were conducted solely by the authors. The authors take full responsibility for the content, accuracy, and integrity of the manuscript.

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REFERENCES

- Baldy, E. (2007). A new educational perspective for teaching gravity. *International Journal of Science Education*, 29(14), 1767-1788. <https://doi.org/10.1080/09500690601083367>

- Cherepashchuk, A. M., & Chernin, A. D. (2008). Modern cosmology: Facts and ideas. *Moscow University Physics Bulletin*, 63(5), 299-314. <https://doi.org/10.3103/S0027134908050019>
- Choudhary, R., Foppoli, A., Kaur, T., Blair, D., Zadnik, M., & Meagher, R. (2018). Can a short intervention focused on gravitational waves and quantum physics improve students' understanding and attitude? *Physics Education*, 53(6), Article 065020. <https://doi.org/10.1088/1361-6552/aae26a>
- Dua, Y. S., Blair, D. G., Kaur, T., & Choudhary, R. K. (2020). Can Einstein's theory of general relativity be taught to Indonesian high school students? *Jurnal Pendidikan IPA Indonesia*, 9(1), 50-58. <https://doi.org/10.15294/jpii.v9i1.22468>
- Ehlers, J. (2007). General relativity theory. In I. O. Stamatescu, & E. Seiler (Eds.), *Approaches to fundamental physics. Lecture notes in physics, vol. 721* (pp. 91-104). Springer. https://doi.org/10.1007/978-3-540-71117-9_5
- Foppoli, A., Choudhary, R., Blair, D., Kaur, T., Moschilla, J., & Zadnik, M. (2019). Public and teacher response to Einsteinian physics in schools. *Physics Education*, 54(1), Article 015001. <https://doi.org/10.1088/1361-6552/aae4a4>
- Gönen, S. (2008). A study on student teachers' misconceptions and scientifically acceptable conceptions about mass and gravity. *Journal of Science Education and Technology*, 17, 70-81. <https://doi.org/10.1007/s10956-007-9083-1>
- Greca, I. M., & Freire, O. (2014). Meeting the challenge: Quantum physics in introductory physics courses. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 183-209). Springer. https://doi.org/10.1007/978-94-007-7654-8_7
- Günther, H., & Müller, V. (2020). *The special theory of relativity: Einstein's world in new axiomatics*. Springer. <https://doi.org/10.1007/978-981-13-7783-9>
- Kamphorst, F., Vollebregt, M. J., Savelsbergh, E. R., & van Joolingen, W. R. (2023). An educational reconstruction of special relativity theory for secondary education. *Science & Education*, 32, 57-100. <https://doi.org/10.1007/s11191-021-00283-2>
- Kassetas, A. I. (2004). *To milo kai to quark: Didaktiki tis physikis* [The apple and the quark: Physics teaching]. Savalas.
- Kaur, T., Blair, D., Burman, R., Gower, G., Horne, E., Mitchell, D., Moschilla, J., Stannard, W., Treagust, D., Venville, G., & Zadnik, M. (2017a). *Teaching the Einsteinian gravity paradigm*. arXiv. <https://doi.org/10.48550/arXiv.1703.00164>
- Kaur, T., Blair, D., Moschilla, J., Stannard, W., & Zadnik, M. (2017b). Teaching Einsteinian physics at schools: Part 1, models and analogies for relativity. *Physics Education*, 52(6), Article 065012. <https://doi.org/10.1088/1361-6552/aa83e4>
- Kaur, T., Blair, D., Choudhary, R. K., Dua, Y. S., Foppoli, A., Treagust, D., & Zadnik, M. (2020). Gender response to Einsteinian physics interventions in school. *Physics Education*, 55(3), Article 035029. <https://doi.org/10.1088/1361-6552/ab764d>
- Kavanagh, C., & Sneider, C. I. (2006). Learning about gravity II. Trajectories and orbits: A guide for teachers and curriculum developers. *Astronomy Education Review*, 5(2), 53-102. <https://doi.org/10.3847/AER2006019>
- Kersting, M., Toellner, R., Blair, D., & Burman, R. (2020). Gravity and warped time—Clarifying conceptual confusions in general relativity. *Physics Education*, 55(1), Article 015023. <https://doi.org/10.1088/1361-6552/ab56d7>
- Kotsis, K. T. (2023). Alternative ideas about concepts of physics are a timelessly valuable tool for physics education. *Eurasian Journal of Science and Environmental Education*, 3(2), 83-97. <https://doi.org/10.30935/ejsee/13776>
- Nik Daud, N. S., Abd Karim, M. M., Wan Hassan, S. W. N., & Rahman, N. A. (2015). Misconception and difficulties in introductory physics among high school and university students: An overview in mechanics. *EDUCATUM Journal of Science, Mathematics and Technology*, 2(1), 34-47.
- Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: A study in Norway. *International Journal of Science Education*, 24(6), 565-574. <https://doi.org/10.1080/09500690110073982>
- Pablico, J. R. (2010). *Misconceptions on force and gravity among high school students* [Master's thesis, Louisiana State University].
- Postiglione, A., & Angelis, I. D. (2021). Students' understanding of gravity using the rubber sheet analogy: An Italian experience. *Physics Education*, 56(2), Article 025020. <https://doi.org/10.1088/1361-6552/abd1c4>
- Ruggiero, M. L., Mattiello, S., & Leone, M. (2021). Physics for the masses: Teaching Einsteinian gravity in primary school. *Physics Education*, 56(6), Article 065011. <https://doi.org/10.1088/1361-6552/ac1ca3>
- Stefanou, M., Stylos, G., Georgopoulos, K., & Kotsis, K. (2023). Primary preservice teachers' misconceptions and reasoning of thermal concepts in everyday contexts. *The International Journal of Learning in Higher Education*, 31(1), 127-157. <https://doi.org/10.18848/2327-7955/CGP/v31i01/127-157>
- Stylos, G., Evangelakis G. A., & Kotsis, K. T. (2008). Misconceptions on classical mechanics by freshman university students: A case study in a physics department in Greece. *Themes in Science and Technology Education*, 1(2), 157-177. <https://files.eric.ed.gov/fulltext/EJ1131487.pdf>
- Syuhendri, S. (2019). Student teachers' misconceptions about gravity. *Journal of Physics: Conference Series*, 1185, Article 012047. <https://doi.org/10.1088/1742-6596/1185/1/012047>
- Velentzas, A., & Halkia, K. (2013). The use of thought experiments in teaching physics to upper secondary-level students: Two examples from the theory of relativity. *International Journal of Science Education*, 35(18), 3026-3049. <https://doi.org/10.1080/09500693.2012.682182>
- Williamson, K. E., & Willoughby, S. D. (2012). Student understanding of gravity in introductory college astronomy. *Astronomy Education Review*, 11(1). <https://doi.org/10.3847/AER2011025>

APPENDIX A: STUDENT QUESTIONNAIRE ON EINSTEINIAN GRAVITY

A questionnaire was presented to sixth-grade students before and during the instructional intervention on Einsteinian gravity. The items were created to evaluate students' mental comprehension of gravitational phenomena and spacetime as articulated by the general theory of relativity. All items consisted of multiple-choice questions with a single correct answer. The subsequent version is rendered in English and organized for clarity.

Instructions: Read each question carefully and choose the answer you believe is correct. There is only one correct answer for each question.

Q1. Is there gravity when a person is standing on the surface of the earth?

- A. No, because the person is not falling.
- B. Yes, because gravity is always present on earth.
- C. Only if the person is moving.
- D. Only during the day.

Correct answer: B

Q2. If someone falls from an airplane, are they under the effect of gravity?

- A. No, they are floating.
- B. Yes, gravity pulls them downward.
- C. Only if the plane is very high.
- D. Only when they reach the ground.

Correct answer: B

Q3. If a person is standing on the moon, do they experience gravity?

- A. No, the moon has no gravity.
- B. Yes, but less than on earth.
- C. Only when the earth is close.
- D. Only if they jump.

Correct answer: B

Q4. Does a person moving near a satellite orbiting earth experience gravity?

- A. No, there is no gravity in space.
- B. Yes, because gravity extends into space.
- C. Only when touching the satellite.
- D. Only if the satellite is stationary.

Correct answer: B

Q5. Is there gravity when a person is swimming underwater?

- A. No, water cancels gravity.
- B. Yes, but gravity is weaker.
- C. Yes, gravity still acts even underwater.
- D. Only if they touch the bottom.

Correct answer: C

Q6. What is spacetime?

- A. The space where time stops.
- B. A mixture of air and light.
- C. A four-dimensional framework that includes time and space.
- D. The space between stars.

Correct answer: C

Q7. What do you think can distort spacetime?

- A. Wind.
- B. Heavy objects like planets and stars.
- C. Light.
- D. Movement of air.

Correct answer: B

APPENDIX B: LESSON PLAN OVERVIEW – INTRODUCING EINSTEINIAN GRAVITY IN PRIMARY EDUCATION

Lesson title: *Gravity according to Einstein: Exploring curved spacetime*

Grade level: 6th grade (age 11-12)

Duration: 1 teaching hour (45-50 minutes)

Learning Objectives

By the end of the lesson, students will be able to:

- Understand that gravity, according to Einstein, is the curvature of spacetime caused by mass.
- Identify that gravity exists in space and is not limited to earth.
- Recognize that gravity affects all objects, regardless of their location or medium (e.g., air, water, space).
- Begin to overcome common misconceptions about gravity.

Instructional Approach

Guided inquiry and model-based learning, incorporating the use of analogies and physical simulation (rubber sheet model).

Materials and Equipment

- Elastic rubber sheet (e.g., stretched fabric fixed on a circular frame)
- Spherical objects of different masses (e.g., metal and plastic balls)
- Multimedia presentation (PowerPoint) with visual representations of gravitational fields, earth-moon system, and spacetime grid
- Markers or small balls to simulate orbiting objects on the rubber sheet

Lesson Flow

1. Introduction (5-7 minutes)

- Brief discussion on what students already know about gravity.
- Elicit intuitive ideas through open-ended questions (e.g., “Why do things fall?” and “Is there gravity on the moon?”).

2. Bridging to Einstein (5 minutes)

- Present the idea that Einstein had a different view of gravity than Newton.
- Introduce the notion of spacetime as a four-dimensional fabric.
- Show simplified diagrams of curved spacetime (2D grid analogy).

3. Demonstration of the rubber sheet model (15-20 minutes)

- Stretch the elastic sheet over a round frame.
- Place a heavy ball in the center to simulate a massive object (e.g., a star or planet).
- Roll smaller balls to demonstrate how mass curves the sheet and affects motion.
- Facilitate discussion: “Why do the smaller balls move in circles?” and “What would happen with more mass?”
- Explicitly clarify limitations of the model:
 - It uses earth’s gravity to simulate Einstein’s concept.
 - Real spacetime is four-dimensional.
 - The model is an analogy, not a literal representation.

4. Guided reflection and concept building (10-12 minutes)

- Discuss examples of gravity in various contexts: space, the moon, underwater, near satellites.
- Connect observations to Einstein’s idea: “Objects follow curves in spacetime.”
- Highlight how gravity is everywhere, even in space, even without air.
- Address misconceptions noted earlier in the lesson.

5. Consolidation (5 minutes)

- Recap key points:
 - Gravity is not a pulling force, it’s the effect of curved spacetime.
 - Mass causes curvature; the more mass, the more curve.
- Prepare students for the post-intervention questionnaire.

Assessment

- Pre- and post-test using a multiple-choice questionnaire to evaluate conceptual understanding.
- Informal formative assessment during discussion through student responses and predictions.

Differentiation and Inclusion

- Visual aids and hands-on materials supported varied learning styles.
- The model allowed tactile and visual learners to engage.
- Gender-neutral language and inclusive participation were emphasized.

