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Conceptual Instruction in Physics and Gender Equity: Experiences from Swedish Upper Secondary Schools

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Abstract

This study examines how sustained conceptual instruction influences gender disparities in physics understanding among Swedish upper secondary students. Drawing on Ausubel's Meaningful Learning Theory and Vergnaud's Conceptual Field Theory, the research explores how instructional design interacts with students' cognitive development, prior knowledge, and sociocultural context. Using a quasi-experimental design, 852 students from 38 classes were assessed using a gender-balanced version of the Force Concept Inventory (G-FCI). Normalized change was applied to measure conceptual gains across instructional methods and genders. Findings confirm persistent gender gaps under traditional instruction, favoring male students. However, in cohorts with sustained conceptual teaching across Physics 1 and 2, female students outperformed male peers—a statistically significant shift not observed under traditional methods. While conceptual instruction improved learning for all, its equity potential was most evident when implemented consistently. These results highlight the importance of pedagogical continuity for promoting gender equity in physics education. Nevertheless, instructional change alone is insufficient; broader interventions addressing classroom climate, stereotype threat, and identity development are needed. The study contributes empirical evidence to the international discourse on gender and science education and underscores the value of conceptually grounded pedagogy as part of a systemic strategy for equitable physics learning.

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Introduction

Persistent gender disparities in physics education have long been a concern for researchers, educators, and policymakers. These differences remain evident despite years of concerted efforts to promote equality in the field (Madsen, McKagan & Sayre, 2013). Although physics is often perceived as a neutral or universal domain of knowledge, decades of research have shown that students' conceptual understanding of physics is shaped not only by cognitive development but also by sociocultural and psychological factors – including gender.

A significant insight into students' difficulties with physics is given by a video documentary, *A Private Universe* by Schneps and Sadler (1987) which showed that even high-achieving students often hold deep-seated misconceptions about physics concepts. Their work helped launch the Alternative Conceptions Movement (Konicek-Moran & Keeley, 2015) leading to a growing body of research focused on helping students replace intuitive but incorrect ideas with scientifically more accurate conceptual models (Treagust, 1988; Wandersee, Mintzes & Novak, 1994; Ruiz-Primo & Shavelson, 1996).

In response, many educators and researchers have advocated for a shift from procedural instruction to more conceptual teaching approaches, which emphasize reasoning, real-world application, and interactive engagement. Studies show that such approaches can improve learning outcomes in physics (Hake, 1998; Pollock, 2008) and are generally beneficial for all students. However, their impact on gender disparities remains somewhat vague. Some studies report that conceptual instruction narrows gender gaps (Lorenzo, Crouch & Mazur, 2006), while others show limited or mixed effects (Kost, Pollock & Finkelstein, 2009; Madsen et al., 2013). A possible explanation is that instructional change alone may not be sufficient, but it is necessary to address also classroom climate, self-efficacy, and stereotype threats (Miyake et al., 2010).

Sweden presents a compelling context in which to study these issues. Sweden is frequently ranked among the top nations globally for gender equality. Swedish educational policies explicitly promote gender equality and inclusion across all levels of schooling and these efforts have yielded measurable results. For instance, the most recent Swedish results in PISA and TIMSS indicate that the gender gap in science learning outcomes is quite small. Nonetheless, there remains a significant difference between boys' and girls' attitudes towards learning science. This suggests that there is a need to invest more efforts also in the gender equity in science education.

This study also aims to contribute to the international discussion on gender equity in science by investigating whether a conceptual approach to physics teaching can reduce or eliminate the gender gaps in conceptual understanding among Swedish upper secondary students. Building on both theoretical and empirical foundations, the study is grounded in a quasi-experimental design comparing learning outcomes between traditional and conceptually oriented instruction across multiple cohorts.

Research Question

This study unfolds in three phases. First, it establishes baseline gender differences in students' understanding of

Newtonian mechanics under traditional instruction. Second, it examines the impact of a conceptual teaching approach on both learning outcomes and gender disparities. Third, it analyses how these effects evolve over time across successive physics courses, comparing students who experienced conceptual instruction with those who did not. Our research questions are:

1. How large gender gap in Newtonian mechanics do we observe among students who have received traditional instruction in upper secondary physics?

2, How do different instructional approaches influence the development of students' conceptual understanding of physics?

3. What impact do different instructional approaches have on the gender gap in physics understanding?

In the following sections, we review relevant literature, introduce the theoretical framework, outline the methodology, and present the results of the study. Finally, we discuss the implications of the findings for teaching practice, curriculum design, and the pursuit of gender equity in physics education.

Literature Review

Research into gender disparities in science education gained momentum in the 1970s, spurred by growing concern over equity and representation in STEM fields (Kelly, 1981; Harding, 1986). Early investigations often framed gender gaps in terms of innate differences in ability or interest. However, by the 1980s and 1990s, scholars increasingly emphasized the role of cultural, structural, and societal factors – including teacher expectations, stereotype threat, and institutional norms – in shaping participation and performance in physics (Eccles, 1986; Seymour & Hewitt, 1997). This paradigmatic shift redefined gender disparities as emergent from educational environments rather than individual deficiencies. Despite policy reforms, large-scale international assessments such as PISA and TIMSS continue to reveal persistent gender gaps in physics achievement (Baye & Monseur, 2016; Meinck & Brese, 2019), reinforcing the need for pedagogical innovation that promotes not only access but also engagement, identity development, and epistemic agency.

Within physics education, a longstanding emphasis on *conceptual understanding* over rote memorization has informed the development of diagnostic tools like the Force Concept Inventory (Hestenes et al., 1992), which revealed that many students can solve problems algorithmically without grasping underlying principles. This finding catalyzed a shift toward *interactive engagement* and *student-centered instruction*, including peer instruction, guided inquiry, and real-world applications (Hake, 1998; Crouch & Mazur, 2001; Pollock, 2008). These methods aim to challenge misconceptions, deepen understanding, and foster transferable knowledge. The effectiveness of conceptual instruction in improving learning outcomes is well documented (Mazur, 1997; McCaskey et al., 2004). However, its role in addressing *gender inequities* remains contested.

While some studies report that conceptual instruction reduces gender disparities – particularly by creating more inclusive, collaborative environments (Lorenzo et al., 2006) – others caution that its impact is not automatic. Without deliberate attention to classroom norms, task design, and representational diversity, gender gaps may persist or even widen (Kost et al., 2009; Madsen et al., 2013). Assessment tools themselves can contribute to inequities: many physics items feature male-oriented contexts such as sports or mechanics, potentially privileging male students' prior informal experiences (McCullough & Meltzer, 2001; McCullough, 2004). In response, gender-balanced instruments like the Gender-FCI have been developed to offer more equitable measures of conceptual understanding.

Cognitive theories also highlight that boys and girls often enter physics education with differing conceptual schemas, shaped by varied informal experiences and access to spatial reasoning tasks (Docktor & Heller, 2008; Nygren, 2021). According to Vergnaud's Conceptual Field Theory (1982), these disparities may reflect differential opportunities to engage with domain-specific representations. A didactic implication is that *gender-sensitive instruction* should provide multiple representational modes – visual, symbolic, relational – to support a broader range of learners. Moreover, the *learning environment* plays a decisive role: studies show that girls tend to thrive in classrooms that emphasize collaboration, dialogue, and contextual relevance, rather than competition or formalism (Abraham & Barker, 2023; Kost et al., 2009; Radulović et al., 2022).

The gender gap – and strategies for addressing it – has also been explored in the context of mathematics education. A relevant example is provided by Tossavainen et al. (2020), who examined the performance of first-year engineering students on mathematical tasks in relation to their motivation and epistemological beliefs about the nature of mathematics. The study found that students who emphasized conceptual understanding tended to perform better on a set of secondary-level mathematics tasks. Notably, female students achieved a slightly higher mean score overall and outperformed male students on some individual tasks.

One possible explanation is that female students were more likely to set demanding learning goals, particularly those related to conceptual knowledge of mathematics. In contrast, male students more frequently associated mathematics with real-world applications and phenomena. These findings suggest that motivational and epistemological orientations may help explain gender differences in mathematical performance and underscore the value of conceptual instruction for all student groups. From a critical didactic standpoint, the above findings suggest that also physics education must address not only conceptual development but also the *cultural meanings* students assign to science. As physics continues to be socially constructed as a masculine domain (Francis et al., 2017), instructional innovations must be accompanied by teacher awareness and professional development to avoid reproducing implicit biases (Pollock et al., 2007; Kreutzer & Boudreaux, 2012). Finally, fostering *science identity and self-efficacy* is vital for long-term participation. Longitudinal studies show that early interventions – especially those highlighting female role models and emphasizing inquiry-based learning – can shift students' attitudes and identity trajectories, but only if sustained across courses and contexts (Lynch et al., 2024; Hofer, 2015). The convergence of conceptual pedagogy with inclusive and identity-supportive practices thus offers the most promising path toward gender equity in physics education.

Theoretical Perspectives

This study builds on two theoretical frameworks that offer a robust foundation for examining both the effectiveness of teaching strategies and the nuances of gender differences in physics learning. First, *Ausubel's*

Meaningful Learning Theory (2012), rooted in the cognitivist tradition, emphasizes the integration of new knowledge with existing cognitive structures. This aligns closely with the study's objective to assess how different teaching methods affect students' understanding of the central concepts in physics. The theory underscores the importance of meaningfully linking new information to prior knowledge, which is particularly relevant in addressing students' misconceptions in physics, such as intuitive but incorrect notions of force or motion. Ausubel distinguishes between rote and meaningful learning, arguing that conceptual understanding is fostered when learners actively relate new content to established cognitive frameworks. This is an essential perspective when examining how students process physics concepts differently, and how these differences may be influenced by gender-related variation in prior experiences or learning strategies.

Second, *Vergnaud's Conceptual Field Theory* (1982) offers another useful perspective for analyzing gender-based differences in learning. CFT is based on the idea that learning involves more than the acquisition of isolated concepts: it entails the mastery of a network of interrelated ideas, representations, and meaningful situations within a particular domain. In the context of physics, this includes the ability to apply conceptual knowledge across varied problem types, representations (e.g., symbolic, graphical, verbal), and real-world contexts. The theory emphasizes that learners may engage differently depending on their familiarity with specific situations or forms of representation. This makes CFT particularly relevant for investigating gender dynamics, as prior research suggests that male and female students may differ in their exposure to or comfort with certain physics contexts or symbolic tools. Importantly, the theory advocates pedagogical diversification – i.e., the use of varied representations and contexts – to enhance equitable access to learning opportunities across diverse student groups. By adopting this theoretical lens, researchers can explore not only what students learn, but also how they learn and under what conditions gender-related differences in learning arise and persist.

Methods and Design

This study was conducted in Northern Sweden over three academic years and included 38 classes, comprising a total of 852 students from grades 10 to 12 as well as a university preparatory program (see Table 1). According to the Swedish curriculum, the upper secondary school physics program includes two compulsory courses: *Physics 1* and *Physics 2*. The university preparatory course, *Physics G1*, is essentially a recapitulation of *Physics 1* and *Physics 2*.

Table 1. Participating Classes and the Given Instruction

Classes	Course	Teaching design	Number of		Period
			female	male	
1	Physics G1	Traditional	33	59	Autumn 21
2–11	Physics 1	Traditional	88	96	
12–18	Physics 2	Traditional	56	52	
19–26	Physics 1	Conceptual	19	43	Autumn 22

Classes	Course	Teaching design	Number of		Period
			female	male	
		Traditional	78	54	
27–32	Physics 2	Conceptual	9	17	
		Traditional	50	54	
33–35	Physics 1	Conceptual	23	59	Autumn 23
36–37	Physics 2	Conceptual	9	32	
38		Traditional	9	12	
Total			374	478	

The core instructional contrast in this study lies between *traditional instruction* – a teacher-centered, calculation-intensive approach focused on formulas and procedural problem-solving – and *conceptual instruction*, which emphasizes a deep understanding of physical principles, real-life applications, multiple representations, and student-led discussion. The conceptual approach was collaboratively developed by four participating upper secondary physics teachers and the research team during a learning study. To ensure effective implementation, the teachers and the first researcher met biweekly to plan and analyze instructional design. For more details, see François et al. (2025).

The study design comprised three main phases, aligned with the progression of the national physics curriculum (Physics 1 and Physics 2):

1. *Baseline Comparison.* Establishing gender differences in conceptual understanding among students taught using predominantly traditional instruction methods. This phase included 18 classes (n = 384 students) across Physics G1, Physics 1, and Physics 2 courses.
2. *Instructional Intervention.* Implementing a conceptual teaching approach in a selected group of classes, while maintaining traditional instruction in others. This allowed for between-group comparisons of conceptual gains and gender gaps following different instructional methods. A total of 20 classes (n = 468 students) participated in this phase.
3. *Longitudinal Comparison.* Comparing outcomes among students who experienced sustained conceptual instruction across both Physics 1 and 2 with those who received traditional instruction or a mixed instructional sequence. This design enabled an exploration of cumulative effects on both learning gains and gender disparities.

To evaluate students' conceptual understanding, all participants completed the Gender- Force Concept Inventory (G-FCI) as both a pre-test and a post-test. The G-FCI is a context-balanced version of the traditional Force Concept Inventory (FCI) designed to reduce gender-related assessment bias (McCullough & Meltzer, 2001). The tests were administered at the beginning and end of each course, allowing for the calculation of gain scores and comparisons across cohorts, instructional types, and gender. The data were analyzed using SPSS Statistics Software version 29. A baseline analysis was conducted using data from classes 1-18 to examine the gender gap in students' understanding of Newtonian mechanics under traditional instruction. The effect of instructional approach on the gender gap was assessed using data from classes 19-38, with changes in conceptual understanding measured through normalized change (e.g., Marx & Cummings, 2007). This measure is defined via

$$c = \begin{cases} \dfrac{\text{Post-test score (\%)} - \text{Pre-test score(\%)}}{100 - \text{Pre-test score (\%)}} & \text{for} \qquad \text{post} \geq \text{pre} \\ \text{drop} & \text{for} \qquad \begin{cases} \text{pre} = 100 \text{ or } 0 \\ \text{post} = 100 \text{ or } 0 \end{cases} \\ \dfrac{\text{Post-test score (\%)} - \text{Pre-test score(\%)}}{\text{Pre-test score (\%)}} & \text{for} \qquad \text{post} < \text{pre} \end{cases}$$

Normalized change measures both improvements and declines in learning outcomes relative to students' pre-test scores, providing a more equitable evaluation than the traditional normalized gain, which is sensitive to ceiling effects and less suitable for students with high initial scores. Unlike normalized gain, normalized change accounts for both gains and losses and applies symmetrically across all levels of prior achievement. This metric is especially useful when comparing heterogeneous groups – such as male and female students – with varying baseline performance levels. The analysis also includes the calculation of Cohen's *d* for the effect sizes and independent samples *t*-tests to further assess the significance and magnitude of observed differences.

Students in classes 19-21, 27 and 33-35 had no prior exposure to conceptual instruction whereas those in classes 36 and 37 were enrolled in their second physics course using the conceptual approach. This distinction enabled a more detailed examination of the cumulative impact of a fully conceptual physics education at the secondary level on the gender gap. Furthermore, it allowed for a comparative analysis of how the gender gap evolved among students exposed to conceptual instruction versus those who continued under traditional teaching methods. This comparison yielded valuable insights into the long-term effects of instructional design on gender disparities in physics learning outcomes.

An important methodological consideration in this type of educational research is the potential for the *Hawthorne effect* – the phenomenon in which participants improve their performance simply because they are aware they are being observed (Brown, 1992; Merrett, 2006). To distinguish the true effects of the instructional intervention from those arising merely from researcher presence or increased attention, it is common practice to include control groups that receive some form of attention or "treatment" without exposure to the specific instructional method being tested (Bauernfeind & Olson, 1973).

In this study, we have partially mitigated this risk by ensuring that both experimental and comparison groups experienced similar testing environments. Furthermore, no feedback was provided during the study period; students received only a summary score after the study's conclusion. Furthermore, students had no access to the test items outside the testing sessions. This approach helps reduce the possibility that observed performance gains are attributable to test familiarity rather than genuine conceptual growth.

Also, the use of repeated measures and comparison groups should enhance the internal validity of the design of this study, allowing for meaningful inferences about the impact of instructional design on students' conceptual understanding and the dynamics of gender differences in physics learning. The study adhered to the guidelines outlined in the Swedish Ethical Review Act (Ministry of Education and Cultural Affairs, 2003:460). To protect the integrity and privacy of the participants, all collected data were treated with strict confidentiality. Participation was fully voluntary, and participants were thoroughly informed of their right to withdraw from the study at any stage, without facing any repercussions. This ensured an ethical research process that respected the autonomy and rights of all involved.

Results

To address the first research question, we present the quartile distributions of the percentage of correct responses on the G-FCI test in Figure 1. As already said, data for this analysis consist of the results of the G-FCI test from the traditionally instructed classes (1–18).

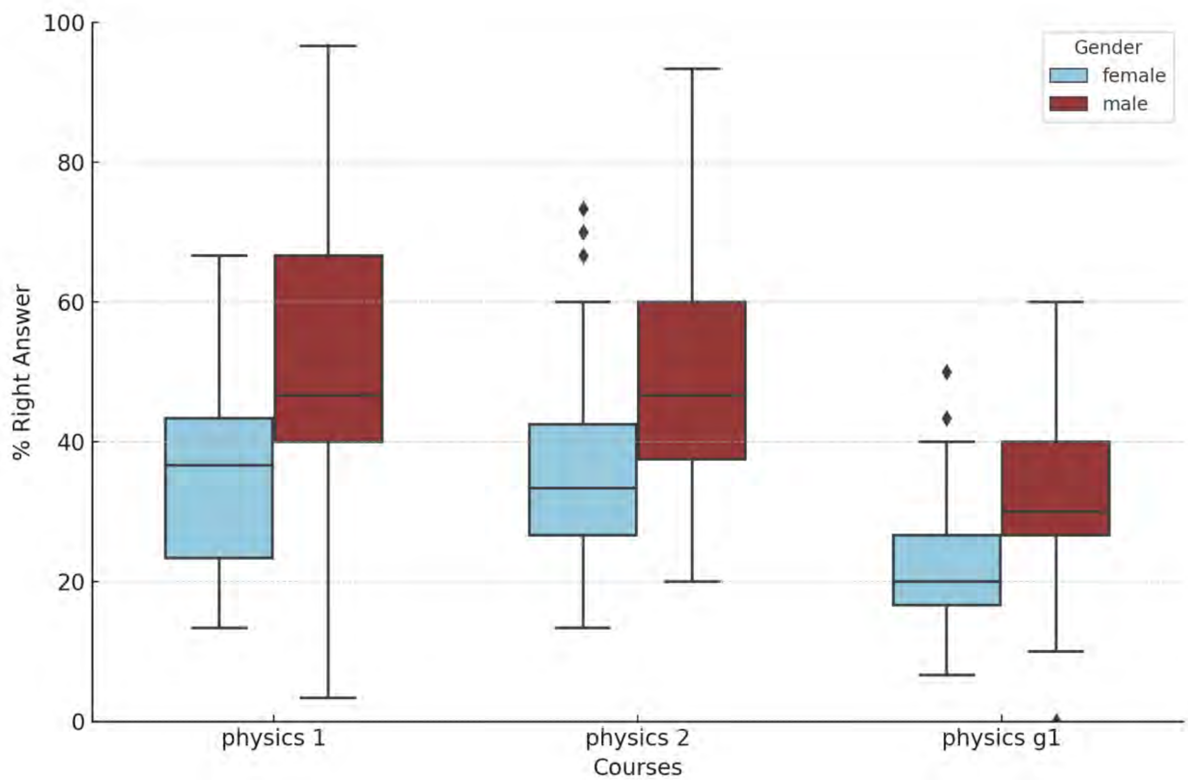

Figure 1. Gender Conceptual Physics understanding under a Traditional Learning

Figure 1 shows that male students outperformed female students across all three courses. The mean differences between the groups range from 11 to 17 percentage points, while median differences fall between 10 and 13 percentage points. Another notable distinction is the greater heterogeneity observed within the male groups, particularly among the highest-performing students. This is evident in the quartile distributions: the top-performing female quartile overlaps substantially with the second-highest male quartile.

To address the second research question – the impact of instructional design on gender differences in physics understanding – we analyzed data from classes 19-38. Of these, eleven classes received traditional instruction, while nine were taught using a reinforced conceptual approach. A total of 468 students participated in this part of the study, comprising 197 female and 271 male students. Summaries of the analysis results are presented in Figures 2-4.

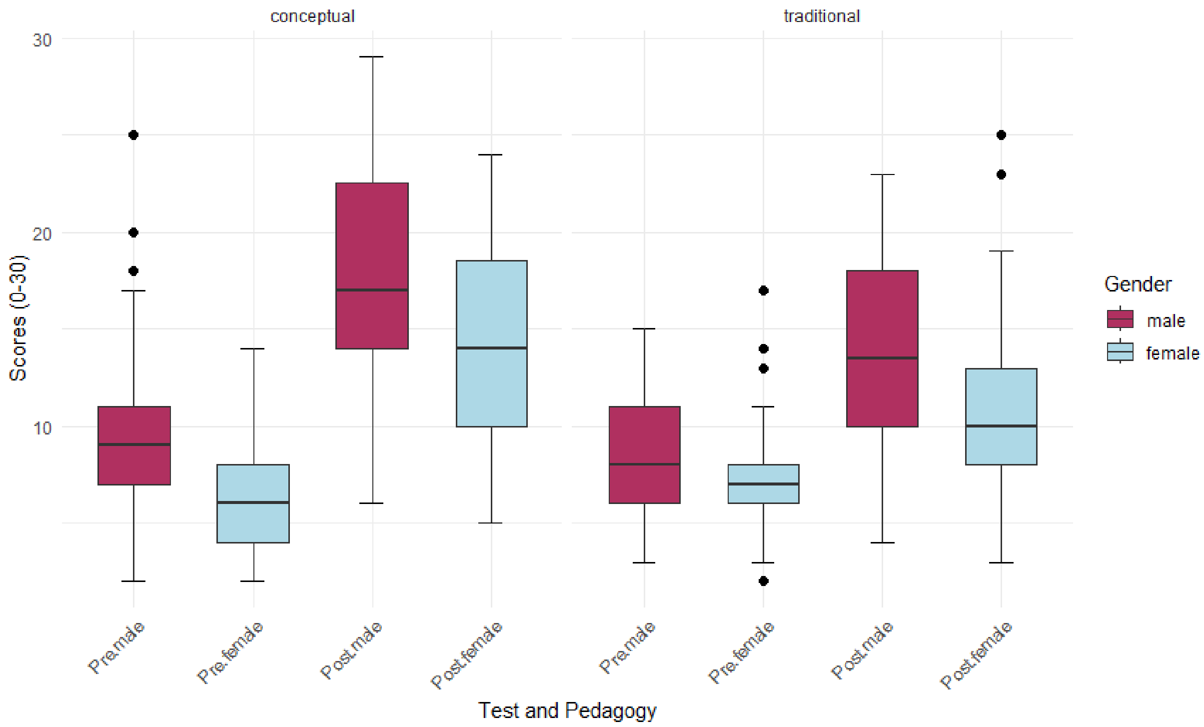

Figure 2: Gender and Instruction Comparison, Physics 1

Figure 2 reinforces the trends observed in Figure 1, now disaggregated by instructional design. The data reveal that, regardless of approach, a gender gap in favor of male students persists and even widens from pre- to post-test, albeit to varying degrees across pedagogies. Under traditional instruction, the gender gap in mean scores increases from approximately five percentage points at pre-test to 9.3 percentage points at post-test. In contrast, for students receiving conceptual instruction, the corresponding increase is slightly more moderate – from 9.8 to 11.7 percentage points. A similar trend is seen in the median values, where the conceptual group maintains a constant gender difference of 10 percentage points across both test occasions, whereas the traditional group exhibits a widening gap from 3.3 to 11.7 percentage points.

This divergence is further reflected in the interquartile range (IQR) distributions. In the traditional pre-test, the female IQR overlaps with the male Q2, suggesting a partial alignment in performance. However, by the post-test, this alignment diminishes: female Q2 overlaps only with male Q1, while female Q3 overlaps with male Q2, indicating a shift in relative distribution. In contrast, the conceptual instruction group exhibits a parallel broadening of score distributions for both genders from the pre- to the post-test. Importantly, the symmetry in this widening suggests a more balanced developmental trajectory under conceptual pedagogy, as opposed to the more gender-divergent pattern seen under traditional instruction.

Figure 3 illustrates the development of the gender gap at the Physics 2 for students who received traditional instruction in Physics 1. In comparison with Physics 1 outcomes, the gender gap under traditional instruction in Physics 2 widens significantly: the mean difference increases to between 22.4 and 24.7 percentage points, reflecting a substantial disparity in favor of male students. By contrast, the conceptual instruction group shows more moderate gender differences, with mean gaps ranging from 3.7% at pre-test to 11% at post-test, values that are generally comparable or slightly lower than the gap observed in Physics 1 (10 - 12%).

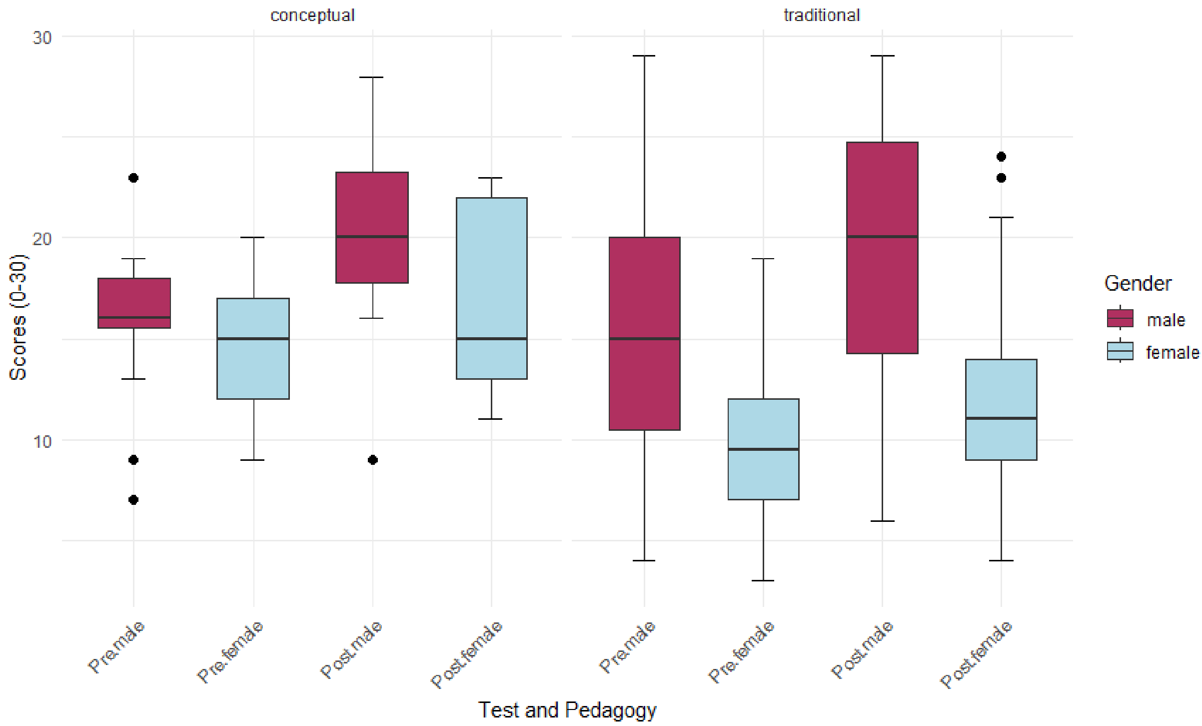

Figure 3. Gender and Instruction Comparison, Physics 2, Part 1

Interestingly, the evolution of the gender gap in mean scores exhibits a somewhat counterintuitive trend. While absolute differences remain smaller in the conceptual group, the relative increase in the gap – from 3.7 to 11 percentage points – is larger than the increase observed in the traditional group (from 22.4 to 24.7 percentage points). This finding suggests that prior instructional experience may exert a cumulative effect, particularly in the traditional group, where exposure to procedural and formal problem-solving strategies might contribute to both performance and conceptual development over time.

The median scores follow a similar but subtler pattern: in the conceptual group, the gender gap increases from 3 to 18 percentage points, whereas in the traditional group it expands from 18 to 30 percentage points. This indicates that gender disparities become more pronounced across instructional levels, but that the relative escalation is steeper in the conceptual group, despite its more favorable starting point. The interquartile range (IQR) analysis provides further nuance. In the conceptual group, post-test results show substantial overlap between the female and male distributions: the second-highest female quartile overlaps nearly the entire male interquartile range. In contrast, the equivalent quartile in the traditional group fails to reach even the second-lowest male quartile, signaling a much greater divergence in performance distributions. These patterns reinforce the interpretation that conceptual instruction promotes a more inclusive distribution of learning gains, particularly for female students, even if the overall gender gap persists or modestly increases. However, these results, derived from a limited sample corresponding for the conceptual case of only one class, warrant further investigation. Longitudinal and mixed-method studies are needed to unpack the interplay between instructional method, gender dynamics, and cognitive development across domains in physics education.

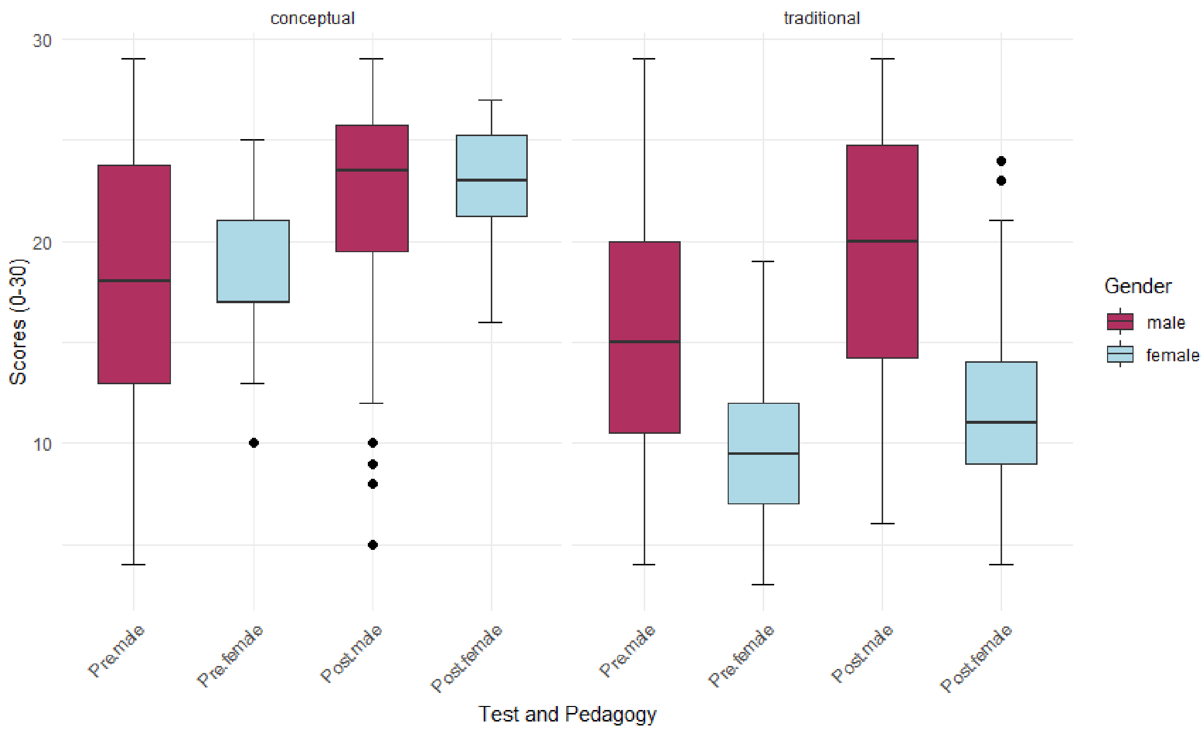

Figure 4. Gender and Instruction Comparison, Physics 2, Part 2

Figure 4 presents a focused comparison of the gender gap in Physics 2, for students who experienced a consistent instructional approach – either traditional or conceptual – across both Physics 1 and 2. The analysis of this matched subgroup offers crucial insight into the sustained effects of pedagogical design on gendered learning outcomes. Already at the pre-test stage, students with a conceptual background demonstrated not only higher overall performance but also a dramatically reduced gender gap. The mean difference between female and male students was nearly eliminated – 0.7 percentage points in favor of boys – compared to a persisting 22.4 percentage points in the traditional cohort. This suggests that conceptual instruction may help equalize foundational understanding before formal teaching begins in Physics 2.

The post-test results offer the most compelling evidence. For the first time in this investigation, female students in the conceptual group outperformed their male peers, with a mean difference of five percentage points in favor of girls. In contrast, the traditional group maintained and slightly widened its original gap, increasing from 22.4 to 24.7 percentage points in favor of boys. Median difference values follow this same trajectory, decreasing from 3 to 1.5 percentage points for the conceptual group, while increasing from 18 to 30 percentage points for the traditional group.

The quartile distributions further emphasize this contrast. Under conceptual instruction, there is now complete overlap between the female and male interquartile ranges, indicating comparable learning distributions. By contrast, the traditional group reveals accentuated separation, with minimal overlap and a distinctly skewed performance distribution favoring boys. These findings provide compelling evidence that a sustained application of conceptually oriented instruction throughout the full physics curriculum in Swedish upper secondary education can effectively eliminate – and even reverse – the gender gap in performance. This supports the hypothesis that the cumulative impact of conceptual instruction fosters a more equitable learning environment, particularly for female students. Since the two conceptual classes had a significant underrepresentation of girls, these results cannot be generalized and demand further investigation.

Figure 5 provides an initial response to the third research question. It illustrates that both female and male students tend to achieve higher normalized gains under conceptual instruction compared to traditional instruction. Notably, female students taught using conceptual approaches exhibit a broad and often substantial improvement, with several of them displaying high individual gains. However, despite this overall positive trend, the variation in normalized change remains slightly greater in favor of male students within the conceptual instruction group. This suggests that, at the Physics 1 level – where students typically lack prior experience with conceptual learning – male students may benefit somewhat more from this instructional design than their female peers.

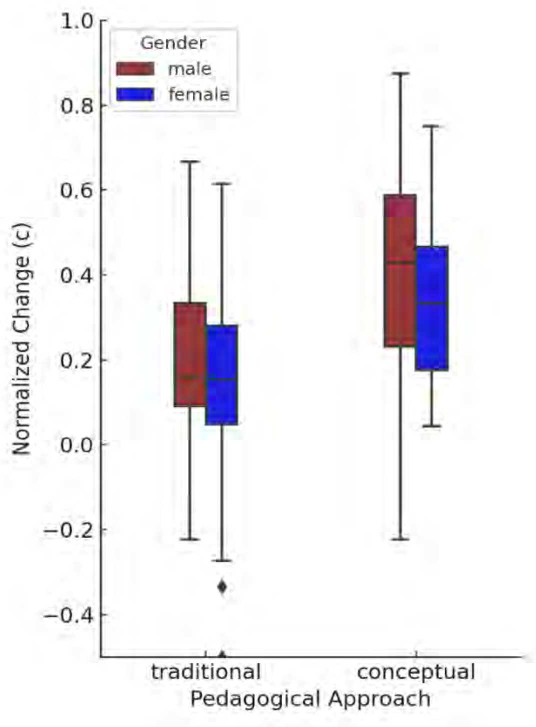

Figure 5. Normalized Change by Pedagogy and Gender, Physic 1

Two key findings from the statistical analyses concerning Physics 1 are as follows. First students who received conceptual instruction had significantly higher normalized changes than those who received traditional instruction. This effect was statistically significant for both male ($t(124) = 5.04$, $p < 0.001$, $d = 0.92$) and female students ($t(77) = 3.80$, $p < 0.001$, $d = 0.85$), indicating a large effect size in both cases. Secondly under conceptual instruction, male students showed significantly higher normalized changes than female students ($t(61) = 2.18$, p

= 0.032, d = 0.38), representing a small to medium effect size while under traditional instruction, the gender difference was not statistically significant (p = 0.23, d = 0.27), and the effect size was small.

Figure 6 illustrates the same comparison for students who received traditional instruction in Physics 1.

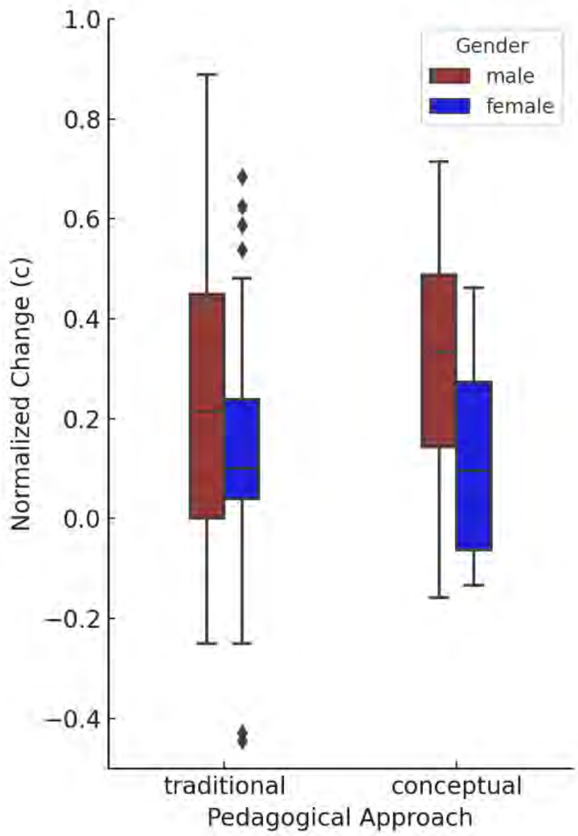

Figure 6. Normalized Change, Physic 2, Part 1

The summary of normalized change (*c*) in G-FCI scores from the Physics 2 course without previous experience with conceptual instruction, disaggregated by gender and instructional method, reveals overall higher gains for male students across both pedagogical conditions. Male students under conceptual instruction demonstrated the highest mean normalized change (M = 0.307), while female students in the same condition exhibited a lower mean gain (M = 0.122). Under traditional instruction, male students again showed higher gains (M = 0.245) compared to female peers (M = 0.135). These results mirror earlier findings in Physics 1 data, but the absolute values of normalized gain are lower in Physics 2, suggesting a reduced instructional impact or ceiling effects for students who have already completed a prior physics course with traditional learning.

The accompanying statistical analyses indicate that none of the comparisons reached statistical significance at the conventional $\alpha = 0.05$ level. However, the comparison between male and female students within the conceptually instructed group approached significance (p = 0.06, d = 0.82), suggesting a potentially meaningful gender-based disparity in response to conceptual instruction. All other comparisons, including those between pedagogy types for each gender, yielded non-significant p-values and small-to-negligible effect sizes (Cohen's d < 0.4). These findings contrast with earlier Physics 1 data, where conceptual instruction had a statistically robust effect. This suggests that instructional gains in Physics 2 are smaller and less differentiated by gender or pedagogy, potentially due to ceiling effects or content and/or instructional familiarity after the previous course.

Figure 7 summarizes comparisons for students who received matched instruction, i.e., they were instructed following the same design both Physics 1 and Physics 2. This enables a clearer assessment of the impact of continued pedagogy.

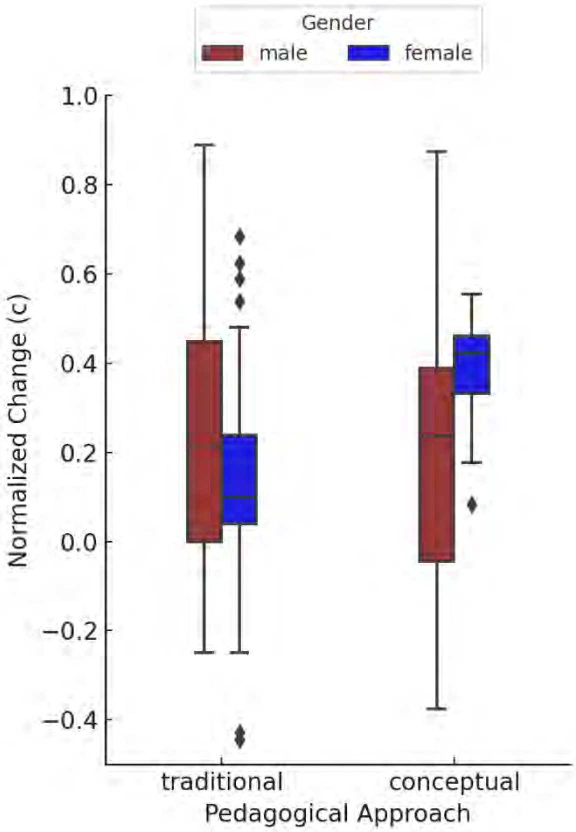

Figure 7. Normalized Change, Physic 2, Part 2

Figure 7 reveals for the first time a gender gap favoring female students within the context of conceptual physics instruction. This finding suggests that when such an instructional model is implemented consistently across the secondary school physics curriculum, it may be particularly effective in supporting conceptual understanding among female learners. In contrast, the traditional instructional design continues to exhibit a slight gender advantage for male students, thereby reinforcing previously observed patterns.

The statistical analyses show now a significant difference between male and female students within the conceptually instructed group, with female students showing greater normalized gains ($t = -2.30$, $p = 0.031$, $d = -0.66$). In contrast, gender differences in the traditionally instructed group were not statistically significant ($p = 0.084$), though the effect size was small to moderate ($d = 0.40$).When comparing students across pedagogies, female students benefited substantially more from conceptual instruction than traditional ($t = 3.22$, $p = 0.005$, $d = 0.93$), representing a large effect size. For male students, the difference between pedagogies was not statistically significant ($p = 0.41$, $d = -0.20$).These results suggest that conceptual physics instruction, when sustained across multiple courses, has a disproportionately positive impact on female students. While male students showed consistent gains across both instructional approaches, female students exhibited significantly higher improvement under conceptual instruction, indicating that this pedagogical approach may be particularly effective in addressing gender disparities in physics learning outcomes. The smaller sample size for the conceptually instructed female group also suggests caution in generalizing this result.

Discussion

The results in Figure 1 reveal a clear and systematic gender gap favoring male students in conceptual understanding of physics across all courses. The consistency between the mean and median scores indicates that the data is not significantly skewed, suggesting that the performance gap is systemic rather than due to outliers. This gap is comparable between Physics 1 and Physics 2, with the mean percentage of correct answers differing by 16.81% and 14.16%, respectively. The gap for the preparatory course, Physics G1, is slightly smaller but still significant at 11.10%. The narrower performance gap in Physics G1 might be attributed to differences in age, study level, and life experience between students in the preparatory course and secondary school students. Additionally, the direct comparison of the percentage improvement in correct answers between Physics 1 and Physics 2 highlights the limited benefit of traditional teaching methods in enhancing conceptual understanding. Female students improved by only 1.12%, while male students' performance declined by 1.53%. Furthermore, students in the preparatory course performed significantly worse than those in secondary school, suggesting that life experience alone cannot substitute for formal education regarding understanding physics concepts.

Addressing this gender gap may require adopting more inclusive teaching strategies, such as collaborative learning or context-based instruction, designed to engage diverse learners. The second part of this project investigates such approaches, and the results are discussed in the following section. The overarching finding is that conceptual and active-learning approaches benefit all students and can contribute to reducing gender gaps in physics. By emphasizing understanding, this approach often helps female students catch up in areas where they lacked prior experience, resulting in smaller performance differentials. It also creates more opportunities for engagement – through discussions, experiments, and real-life connections – which can improve girls' attitudes and willingness to continue with physics. Importantly, these gains do not come at the expense of male students; instead, boys and girls alike tend to learn more and enjoy physics more in a well-implemented conceptual classroom.

While a substantial body of research has documented a persistent gender gap in physics performance—often resistant to variation in instructional design (e.g., Hazari et al., 2007; Kost et al., 2009)—these studies also suggest that no single pedagogical intervention is likely to resolve the disparity in isolation. Conceptual instruction has frequently been identified as beneficial for enhancing overall understanding (Mazur, 1997; Hake, 1998), yet its impact on gender equity has often been described as limited or inconsistent (Lorenzo et al., 2006).In contrast, the present study contributes novel evidence indicating that when conceptually oriented pedagogy is applied coherently and consistently across the full sequence of upper secondary physics education, its cumulative effect may be sufficient to eliminate, and even reverse, the gender gap in achievement. These findings suggest that conceptual instruction, when treated not as an isolated intervention but as a sustained curricular foundation, holds significant promise for promoting gender-equitable outcomes in physics education. Consequently, even if gender gaps in physics have deep roots, including societal stereotypes, confidence gaps, and educational contexts that often inadvertently favor boys, conceptual pedagogy addresses some academic barriers and shows promise in making physics more inclusive.

Also this study showed the positive impact of a conceptual instructional design in closing the gender gap, we have to keep in mind that to properly close this gap, it likely needs to be coupled with other measures: encouraging female role models and mentors, fostering a supportive classroom climate, using assessments that reduce stereotype threat, and ensuring that both relevance and rigor are present in the curriculum. Data and analysis indicate that grade (knowledge level) and previous study are two key influencing factors; consequently, it is reasonable to discuss the analysis in relation to these factors. In Physics 1, both male and female students benefited from conceptual instruction, achieving greater normalized gains than those taught using traditional methods. Although the gender gap in normalized change was numerically smaller in the traditional group, overall performance was lower. Statistical analysis revealed no significant effect of gender and no interaction between pedagogy and gender, indicating that conceptual teaching improved learning outcomes for all students equally. However, additional support may be needed to ensure that female students benefit as fully from conceptual instruction at the introductory level.

In Physics 2, where students had previously received traditional instruction, normalized gains were lower than in Physics 1 and the gender gap in learning outcomes became more pronounced. This suggests that the benefits of conceptual instruction may be constrained when preceded by traditional teaching models. Nonetheless, gender differences remained statistically non-significant. Interestingly, male students appeared to derive greater benefit from conceptual instruction when it followed traditional learning. Perhaps this reflects increased sensitivity to pedagogical contrast. The most significant findings emerged in Physics 2, where students received consistent conceptual instruction in both Physics 1 and 2. In this matched group, female students outperformed male students in normalized change ($M = 0.37$ vs. 0.19; $t = –2.30$, $p = 0.031$, $d = – 0.66$), marking a statistically significant and substantial effect in favor of girls. Compared to their peers in the traditional pathway, girls in the conceptual track showed even stronger gains ($t = 3.22$, $p = 0.005$, $d = 0.93$), while no significant differences were found among male students across pedagogies. These results highlight a pedagogical continuity effect: sustained conceptual instruction not only improves learning overall but may also foster greater equity by enabling female students to close – and in some cases, reverse – the gender gap in physics achievement.

While this study has demonstrated that instructional design – particularly when applied consistently – can significantly affect gendered learning outcomes in physics, it is also clear that pedagogy alone cannot fully account for the persistence or resolution of the gender gap. A broad body of research underscores that gender disparities in physics are the result of a constellation of interrelated cognitive, sociocultural, and psychological factors (Madsen et al., 2013; Miyake et al., 2010).We acknowledge that assessment format also plays a pivotal role in sustaining or mitigating gender gaps. Traditional assessments that emphasize speed and accuracy under timed conditions may increase test anxiety and stereotype threat, both of which are documented to negatively affect female performance in physics (Burkholder & Salehi, 2022). Our methodology does not enable us to estimate the extent to which this phenomenon influenced the observed gender gaps in this study. Nevertheless, our data show that conceptual instruction can help female students to overcome this kind of hindrance. In sum, although the gender gap in physics cannot be addressed solely through instructional change, conceptual teaching has the potential to serve as a foundation for the broader equity agenda.

Conclusion

The key conclusions of this study are as follows.

1. Conceptual instruction enhances learning for all students and promotes equity, particularly when applied systematically and consistently across instructional contexts.
2. Gender gaps persist under traditional instruction and may widen over time, especially to the disadvantage of female students.
3. Instructional design alone is unlikely to entirely eliminate gender disparities in physics; however, the continuity and coherence of conceptual pedagogy across course levels are essential for realizing its full potential to support equity.

We justify the above conclusions through the following key findings and interpretations. First, we found compelling evidence that instructional design—particularly the sustained application of conceptual physics instruction—has a meaningful impact on both student learning outcomes and gender equity in upper secondary physics education. Second, results from Physics 1 confirm earlier research which demonstrates that conceptual instruction improves learning across genders. While the gender gap in normalized gains at this level was not statistically significant, students of all genders benefited from the approach.

In Physics 2, where students had consistent exposure to conceptual instruction, the effects became more pronounced. Notably, female students not only closed the performance gap but exceeded their male peers in normalized learning gains – a statistically significant shift. Crucially, these improvements were not at the expense of male students, who also experienced positive gains. The pronounced benefits among female students underscore the capacity of inclusive, meaning-centered pedagogy to foster more equitable learning conditions. Lastly, the observed differences in normalized change highlight the importance of employing robust analytic methods – such as matched data and longitudinal designs – to explore the nuanced interplay between pedagogy, gender, and conceptual development. These tools enable researchers and educators to move beyond surface-level comparisons and gain a deeper understanding of how and under what conditions instructional approaches support or hinder equitable outcomes.

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