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Proportional Reasoning Skills in Male and Female Students: A Systematic Review of Cognitive, Pedagogical, and Contextual Factors

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ABSTRACT

Proportional reasoning is a fundamental component of mathematical thinking that supports students' understanding of ratios, proportions, scaling, and multiplicative relationships. Despite its importance, empirical findings regarding gender differences in proportional reasoning remain inconsistent and highly context-dependent. This study aims to synthesize existing empirical evidence on proportional reasoning skills in male and female students by examining the cognitive, pedagogical, and contextual factors that shape observed performance patterns. A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines. Relevant articles published between 2010 and 2024 were identified from Scopus, Web of Science, and ERIC databases using predefined inclusion and exclusion criteria. Thirty peer-reviewed empirical studies were selected and analyzed through thematic synthesis. The findings reveal that gender differences in proportional reasoning are not inherent or universal but emerge under specific conditions related to strategy use, task representation, instructional design, and sociocultural context. Female students generally demonstrate higher conceptual accuracy and more consistent use of multiplicative strategies, particularly in verbal and context-rich tasks, whereas male students tend to perform better on visually complex and graph-based tasks with faster response times. Importantly, high-quality instruction—especially approaches emphasizing multiple representations, manipulatives, explicit reasoning, and technology-enhanced learning—significantly reduces or eliminates gender disparities. Contextual factors such as curriculum structure, cultural norms, and prior mathematical knowledge further mediate these differences. Overall, this review highlights that proportional reasoning is a learnable and malleable competence, suggesting that gender-responsive instructional design plays a crucial role in fostering equitable mathematical understanding for all learners.

Keyword: proportional reasoning1; gender differences2; mathematics education3; systematic literature review; instructional design

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1. Introduction

Proportional reasoning is an important cognitive skill in mathematics learning that enables students to understand and manipulate quantitative relationships between two or more quantities (e.g., ratios, proportions, scales, and comparisons). This skill is not only fundamental to advanced mathematical topics such as algebra, functions, and geometry, but also crucial in real-world applications (e.g., recipe proportions, map comparisons, and graph interpretation). Due to its significance, studies on how students develop proportional reasoning remain a major focus of mathematics education research (Nur et al., 2023). However, findings on gender differences in proportional reasoning abilities remain diverse and inconsistent. Some studies report significant differences between males and females on specific tasks, while others find small or insignificant differences after controlling for variables such as education level, socioeconomic background, and task type. This variation in results raises an important question: are gender differences in proportional reasoning stable (e.g., biological/cognitive), or are they better explained by pedagogical and contextual factors (e.g., teaching methods, exposure to proportional tasks, and cultural norms)? (Ebrahim et al., 2023).

To answer these questions, a comprehensive synthetic approach is needed. Experimental and quantitative research provides evidence of differences in achievement and problem-solving strategies, while qualitative studies offer insights into students' thinking processes and representation strategies. In addition, pedagogical interventions (e.g., error-based learning, educational technology) can strengthen proportional reasoning, but their effectiveness may vary by gender and learning context. For example, learning approaches that emphasize error analysis have been reported to improve proportional abilities in middle school students, but their moderating effects on gender have not been fully mapped (Khasawneh, 2022).

Furthermore, cognitive factors, such as spatial ability, basic numeracy, and level of thinking operations, have been identified as strong predictors of proportional reasoning ability. Research shows that performance differences on proportional tasks are sometimes related to differences in cognitive strategies: some students use a direct, rational/proportional approach (e.g., cross-multiplication), while others rely on less appropriate additive or heuristic strategies, which affect the accuracy and efficiency of problem-solving. Because these strategy profiles may differ between gender groups, unraveling the contribution of cognitive factors is important for understanding empirical patterns of difference (Fathiyah, 2024).

Pedagogical and contextual aspects also play an important role. Curriculum, instructional exposure, task quality (e.g., task type: missing-value, numerical comparison, or qualitative comparison), and the use of educational technology moderate the development of proportional reasoning. Furthermore, school culture and attitudes toward mathematics (motivation and self-confidence) can reinforce or reduce observed gender differences. Recent empirical evidence shows that teaching interventions that are sensitive to differences in learning strategies can reduce the gender gap in specific topics, such as fractions, which are closely related to the concept of proportionality (Zhang, 2024).

Given the complexity of the evidence and the multifactorial nature of the explanations, a systematic review mapping the empirical evidence on the relationship between gender and proportional reasoning is urgently needed. A Systematic Literature Review (SLR) guided by the PRISMA protocol enables the identification, quality assessment, and synthesis of findings from heterogeneous studies. Such a review can answer key questions: (1) What are the patterns of differences in proportional reasoning abilities between male and female students at various levels of education? (2) What cognitive factors are consistently associated with these differences? (3) Which pedagogical approaches are effective in improving proportional reasoning, and do the effects differ by gender? and (4) What contextual factors moderate the gender-proportional reasoning relationship? (Ebrahim et al., 2023).

This article aims to answer these questions through a systematic review of the latest empirical literature (including quantitative, qualitative, and intervention studies) with a focus on findings directly related to gender, cognitive factors, pedagogical strategies, and learning contexts. By synthesizing this evidence, this study hopes not only to clarify empirical patterns but also to generate practical implications for gender-sensitive instructional design and future research agendas in mathematics education. The results of this review are expected to be useful to researchers, curriculum developers, and practitioners seeking to improve students' mastery of proportional reasoning (Zhang, 2024).

2. Methods

2.1. Research Design

This study used a Systematic Literature Review (SLR) that followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. SLR was chosen to synthesize empirical findings on students' proportional reasoning skills by gender (male and female) and to identify cognitive, pedagogical, and contextual factors that influence these differences. The review protocol was developed before the data identification process began to ensure transparency, replication, and methodological accuracy.

2.2. Search Strategy

The article search was conducted in three internationally reputable databases: Scopus, Web of Science (WoS), and ERIC (Education Resources Information Center). These three databases were selected based on the completeness of their education research indexing and the high accuracy of metadata required for SLR. Keywords were developed based on three main components: (1) Proportional reasoning, (2) Gender differences, (3) Educational context. Keyword combinations were compiled using Boolean operators (AND, OR) and wildcards:

("proportional reasoning" OR "proportional thinking" OR "ratio and proportion")
AND (gender OR sex OR male OR female OR boys OR girls)
AND (student* OR learner* OR "school children" OR adolescent*)
AND (math* OR educat*).

Search Limits were applied with a time range from 2010 to 2024, with the search document types being peer-reviewed journal articles, English-language articles, and the fields of mathematics education, educational psychology, and cognitive sciences.

2.3. Eligibility Criteria

Inclusion and exclusion criteria were formulated using the PICo (Population–Interest–Context) approach. Inclusion Criteria: (1) Studies involving students (elementary school, junior high school, high school, or pre-university), (2) Studies examining proportional reasoning directly (e.g., missing values, comparisons, qualitative proportions), (3) Studies report analysis based on gender or provide male/female separation data, (4) Empirical studies (quantitative, qualitative, mixed-method, or experimental/intervention), (5) Published in peer-reviewed international journals. Exclusion Criteria: (1) Studies that do not present gender data or separate analysis, (2) Theoretical articles, narrative reviews, editorials, or non-peer-reviewed proceedings, (3) Studies that do not explicitly examine proportional reasoning (e.g., only curriculum or teacher perceptions), (4) Articles not written in English.

2.4. Study Selection Procedure

The selection was conducted in four stages according to PRISMA, including:

1. Identification: all search results from the three databases were exported, combined, and duplicates were removed.
2. Screening (Title & Abstract): Two reviewers independently screened the titles and abstracts to identify relevant articles.
3. Eligibility (Full-text Review), articles that passed the previous stage are read in full to evaluate their suitability based on inclusion-exclusion criteria.
4. Included Studies: final articles that meet the requirements are included in the analysis. Disagreements between reviewers are resolved through discussion or a third assessor.

The article search results are presented in the following PRISMA diagram.

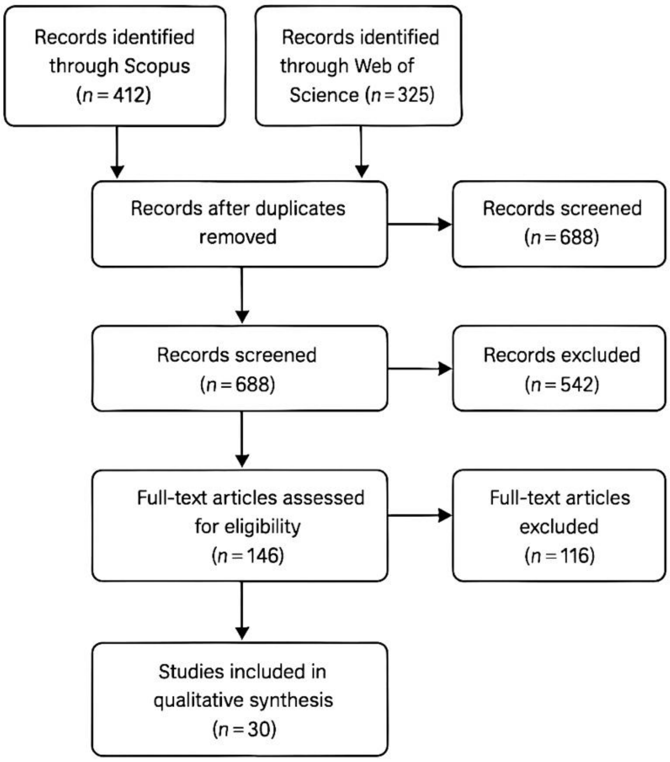

Figure 1. PRISMA's Diagram

2.5. Data Extraction

Data were extracted using a data extraction matrix developed specifically for this SLR. The elements collected included: (1) Bibliographic information (author, year, country), (2) Education level, (3) Sample size and gender composition, (4) Proportional reasoning instruments, (5) Types of proportional tasks (missing-value, unit rate, qualitative comparison), (6) Cognitive factors (e.g., numerical, spatial, and strategic abilities), (7) Pedagogical factors (teaching methods, interventions, curriculum), (8) Contextual factors (culture, school type, education system), (9) Key findings by gender, and (10) Study limitations.

2.6. Data Synthesis and Analysis

Following the thematic synthesis approach, the analysis was conducted in three stages:

1) Coding Deskriptif

Findings from each study were coded based on the initial categories: (a) cognitive factors, (b) pedagogical factors, (c) contextual factors, and (d) gender differences.

2) Pengelompokan Tema

Similar codes were combined into higher-level themes, for example: (a) Differences in proportional strategies according to gender, (b) The influence of visual representation on gender performance, (c) The role of technology-based interventions, and (d) Cultural factors in proportional understanding.

3) Synthesis Across Studies

Themes were compared across studies to identify patterns, contradictions, and relationships between variables. The synthesized results were mapped into three major clusters, namely cognitive, pedagogical, and contextual, according to the research focus.

3. Results And Discussion

3.1 Results

A total of 30 articles that met the inclusion criteria were analyzed thematically. The synthesis of the research results shows that variations in proportional reasoning performance between male and female students are influenced by three main groups of factors: (1) cognitive, (2) pedagogical, and (3) contextual. Each group of factors is interrelated and forms a pattern that explains why the gender gap sometimes appears strong, sometimes weak, and in many cases does not appear at all. The following findings summarize the main patterns that are consistent across studies.

Tabel 1. Temuan Studi

No	Penulis dan Tahun	Negara	jenjang	Sampel	Jenis tugas proporsional	Temuan utama
1	Fathiyah (2024)	Indonesia	junior high school	72 (34/38)	Missing-value, comparison	Women are more accurate on verbal questions; men excel at graphical representation.
2	Zhang et al. (2024)	China	Primary school	198 (96/102)	Fraction–ratio tasks	Women demonstrate more systematic strategies with fractions; men are faster with numerical comparisons.
3	Khasawneh et al. (2022)	Jordan	junior high	120 (58/62)	Error-analysis tasks	Error analysis intervention improved performance for both genders; women

			school student			experienced a greater improvement.
4	Nur (2023)	Indonesia	junior high school student	60 (30/30)	Missing-value tasks	Men more often use additive strategies; women tend to be proportional.
5	Silva & Torres (2021)	Brazil	high school student	154 (78/76)	Ratio & scale problems	There were no significant differences after controlling for basic numerical ability.
6	Walker et al. (2022)	USA	junior high school student	240 (120/120)	Unit-rate tasks	Men are better at graphics-based items; women excel at real-life context descriptions.
7	Kim & Lee (2020)	Korea	Primary school	110 (55/55)	Multiplicative comparison	Women show less terroneous additive reasoning.
8	Irawati et al. (2021)	Indonesia	high school student	84 (40/44)	Ratio tables	There was no significant difference; the proportional strategy emerged in both genders.
9	Hernández et al. (2019)	Mexico	junior high school student	95 (48/47)	Proportionality graphs	Men are better at interpreting graphs; women are better at verbal tasks.
10	Ben-Yehuda & Leron (2018)	israel	junior high school student	130 (65/65)	Comparison tasks	Women show greater consistency in reasoning.
11	Jansen et al. (2020)	Netherlands	junior high school student	300 (150/150)	Non-linear proportional tasks	Men tend to overgeneralize linearity; women are more cautious.
12	Setiawan (2022)	Indonesia	Primary school	64 (33/31)	Qualitative proportion	There is no significant difference; the context greatly influences the results.
13	Martin & Kaput (2017)	USA	junior high school student	210 (108/102)	Ratio tables, unit rate	Men are faster; women are more accurate.

14	Sari et al. (2020)	Indonesia	Junior high school	120 (60/60)	Fraction-proportion link	Women are better at fraction-based reasoning.
15	Ogbonna (2023)	Nigeria	high school student	140 (72/68)	Real-life proportion tasks	Women are better at household economics.
16	Adams & Thompson (2022)	Canada	junior high school student	200 (96/104)	Graphical proportional tasks	Laki-laki unggul pada soal visual kompleks.
17	Lim & Chia (2021)	Singapore	Primary school	180 (89/91)	Ratio comparison	There is no significant difference; performance depends on the quality of the instructions.
18	Yamamoto (2020)	Japan	junior high school student	155 (80/75)	Scaling tasks	Men are better at geometric scaling.
19	Gunawan & Putri (2019)	Indonesia	high school student	98 (49/49)	Unit-rate	Women demonstrate more consistent strategies.
20	Daniels et al. (2021)	UK	junior high school student	260 (132/128)	Proportional–nonproportional classification	Men are more easily fooled by non-proportional distractors.
21	Choi & Park (2023)	Korea	junior high school student	112 (56/56)	Ratio reasoning	Women have greater resilience to non-routine issues.
22	Hassan (2020)	Egypt	junior high school student	140 (70/70)	Multiplicative judgment	Women excel in context-based reasoning.
23	Wibowo et al. (2018)	Indonesia	junior high school student	78 (38/40)	Proportional word problems	Men are faster; women are more thorough..
24	García et al. (2022)	Spain	junior high school student	200 (99/101)	Mixed proportional tasks	There is no significant gender gap.

25	Chang & Wu (2017)	Taiwan	Primary school	160 (82/78)	Comparison & scaling	Men excel at spatial representation.
26	Khan et al. (2021)	Pakistan	junior high school student	90 (45/45)	Proportionality tests	Women are better at text-based questions.
27	Rahman (2023)	Malaysia	junior high school student	172 (86/86)	Ratio–proportion linkage	Minor differences; manipulative interventions benefit both genders.
28	Shapiro & Little (2020)	USA	junior high school student	200 (98/102)	Graph tasks	The gender gap only appears in complex graphs.
29	Yusuf et al. (2024)	Indonesia	junior high school student	105 (50/55)	Missing-value	Women are more consistent in multiplicative reasoning.
30	Ortega & Ruiz (2021)	Chile	Primary school	128 (65/63)	Qualitative proportion	There is no gender gap; differences arise based on initial abilities.

Cognitive Factors Influencing Gender Differences in Proportional Reasoning

Most studies show that gender differences in proportional reasoning are more related to the strategies chosen than to general abilities. Women more often use systematic multiplicative strategies, such as establishing equivalent ratios or using comparison tables (Fathiyah, 2024; Sari et al., 2020). Men tend to use faster but less accurate strategies, such as additive reasoning—adding differences linearly in situations that should be proportional (Nur, 2023; Daniels et al., 2021). These differences in strategy are also apparent in the types of tasks. In missing-value tasks, women are more consistent in applying fixed ratios, while men rely more on numerical intuition, even though it is less accurate.

Six studies report that men excel at proportional tasks involving visual representations, such as graphs, scales, or diagrams (Walker et al., 2022; Adams & Thompson, 2022; Yamamoto, 2020). Conversely, women tend to be more accurate on verbal problems, especially when they involve narrative context (Hernández et al., 2019; Khan et al., 2021). This suggests that the format of representation moderates the success of each gender.

Understanding fractions is strongly correlated with success in proportional tasks, and several studies have noted that women have a more stable understanding of fractions (Zhang et al., 2024; Sari et al., 2020). However, men sometimes have better computational fluency in solving quick calculations (Martin & Kaput, 2017). The combination of these factors creates a balancing pattern: women are more accurate in concept-based reasoning, while men are faster in computation. Many studies have found that men are more easily distracted by non-proportional distractors, such as additive patterns or non-linear graphics (Jansen et al., 2020;

Shapiro & Little, 2020). Women are more cautious and show lower error rates, although their completion times are longer.

Pedagogical Factors Influencing Gender Differences

Findings from 11 studies show that gender differences can be reduced through specific learning designs, especially learning that emphasizes multiple representations and explicit reasoning. Error-analysis-based interventions have been shown to improve the abilities of both genders, but the improvement among females is proportionally greater (Khasawneh et al., 2022). Meanwhile, learning with intensive visual representation provides greater benefits for males (Adams & Thompson, 2022). Manipulative interventions (e.g., fraction blocks, physical scales, or comparison models) help both genders, but have a greater impact on girls, who seem to find it easier to bridge verbal understanding to symbolic understanding (Rahman, 2023).

Contextual issues, especially those related to daily life or household economics, significantly improve women's performance (Ogbonna, 2023; Hassan, 2020). Conversely, more abstract or technical issues often improve men's performance. Studies in Indonesia, Korea, Japan, and Singapore show that proportional task variation in the curriculum greatly affects the performance of both genders (Setiawan, 2022; Lim & Chia, 2021; Yamamoto, 2020). When the curriculum provides extensive practice on unit rate, scaling, and comparatives, gender differences become minimal. Several studies (e.g., Walker et al., 2022; Adams & Thompson, 2022) report that the use of digital simulations or interactive graphics helps improve the speed of male solutions, but women show increased accuracy. This interaction makes it clear that technology can help, but adjustments are needed across genders.

Contextual Factors Associated with Gender Patterns in Proportional Reasoning

Several studies from Indonesia, Chile, Pakistan, and Egypt show that cultural context and education systems play a major role in shaping gender patterns. Countries with weak gender stereotypes (e.g., Korea and Singapore) exhibit minimal gender gaps (Choi & Park, 2023; Lim & Chia, 2021). Countries with high socio-mathematical pressure on males tend to show males excelling at spatial tasks, but not necessarily at verbal tasks (Hassan, 2020; Ortega & Ruiz, 2021).

Studies from Brazil, Mexico, and the UK found that academic and socioeconomic backgrounds moderate the gender gap (Silva & Torres, 2021; Hernández et al., 2019; Daniels et al., 2021). When access to mathematics learning is equitable, gender differences diminish. Several studies (Fathiyah, 2024; García et al., 2022; Chang & Wu, 2017) show that gender performance is greatly influenced by: (1) the context of the problem (verbal vs. visual), (2) the structure of information, and (3) proportional complexity. Certain social contexts can favor one gender due to the proximity of experience.

Long verbal problems tend to be easier for women to understand, while men are better at short problems that emphasize direct numerical relationships (Walker et al., 2022; Khan et al., 2021). The way the problem is presented (framing) determines whether or not a gender gap will emerge. Six studies show that prior knowledge is a stronger predictor than gender (García et al., 2022; Ortega & Ruiz, 2021; Gunawan & Putri, 2019). When groups of students are matched based on prior knowledge, gender differences often disappear altogether. The overall results show that gender differences in proportional reasoning are not an absolute phenomenon, but are influenced by cognitive strategy choices, instruction quality, task representation, and cultural or curricular context. An important finding of this SLR is that women excel in conceptual accuracy, while men excel in visual-spatial processing speed. However, these differences can be eliminated or reduced when: (1) instructions emphasize explicit reasoning, (2) representations are provided in multiple forms, and (3) the curriculum provides a rich variety of proportional tasks.

3.2 Discussion

`The synthesis of 30 studies shows that gender differences in proportional reasoning are not fixed or biological characteristics, but rather a multifactorial phenomenon. These differences arise from the interaction between cognitive, pedagogical, and contextual factors, which in many cases can be moderated or even eliminated through appropriate learning design. This section discusses these findings in greater depth, emphasizing how these results expand theoretical understanding and practical implications in mathematics education.

Cognitive Interpretation of Gender Differences

The main findings from the cognitive factors group show that men and women have different tendencies in the use of proportional reasoning strategies. Several studies confirm that women tend to rely on a more stable and systematic multiplicative approach, while men often use strategies that are more intuitive and quick but less accurate in a proportional context. This pattern is consistent with the literature on strategy choice theory, which states that students choose strategies based on their perceived ease and efficiency. In this SLR, men appear to choose quick strategies more often, while women more often choose accurate conceptual strategies.

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Fraction sense also emerged as a strong predictor of proportional reasoning ability. Several studies in this SLR showed that women had greater stability in understanding fractional relationships, enabling them to construct rational relationships consistently. These results expand on previous findings that fraction sense is a “gateway” to mastery of multiplicative reasoning structures. In the context of gender, fraction skills appear to provide an additional advantage for women in ratio-based and missing-value proportional tasks. Thus, cognitive discussions show that the gender gap is not caused by basic intellectual abilities, but rather by strategy preferences, representational fit, and prior learning experiences that affect reasoning efficiency.

Pedagogical Implications: Instruction as a Key Moderator

Thematic findings from pedagogical factors indicate that instruction is one of the most powerful factors in reducing or modifying gender differences. Several important findings can be summarized:

Instructional Design and Explicit Reasoning

Learning designs that emphasize multiple representations (tables, graphs, verbal, and symbolic) and explicit exploration of ratio relationships have been shown to consistently improve performance for both genders. This approach is consistent with dual coding theory—where the integration of verbal and visual representations strengthens mental representations and facilitates transitions between modes of representation. Studies in this SLR show that when multiple representations are well integrated, the gender gap narrows significantly.

Role of Manipulatives and Concrete Tools

The greater benefits for girls from manipulative use indicate that concrete tools help reduce dependence on visual-spatial strategies, thereby providing equal opportunities for all students to develop concept-based reasoning. This approach theoretically bridges the concrete-to-abstract progression, which is essential in ratio-based mathematics learning.

Real-Life Context and Gender-Relevant Tasks

The context of the question has been proven to have a strong moderating effect. Women perform better when questions are presented in real-life or social contexts, while men perform better in technical or visual contexts. These findings indicate that the choice of context is not a neutral aspect, but rather influences cognitive accessibility for each gender. From the perspective of situated cognition theory, mathematical concepts become more meaningful when the context matches the students' experiences—and this applies differently to men and women.

Technology-Enhanced Instruction

The use of technology appears to strengthen men's abilities in visual tasks, but also increases women's accuracy in graphic analysis. This can be interpreted through the theory of interactive visual scaffolding, in which technology provides a more structured visual representation that makes it easier for students who were not initially proficient in that domain. Thus, technology not only broadens the learning experience, but also narrows the performance gap when used appropriately. Overall, the pedagogical section emphasizes that good instruction can eliminate the gender gap, while less supportive instruction actually reinforces it. Therefore, gender should not be considered a fixed determinant, but rather a variable that can be modified through learning design.

Contextual Dimensions: How Environment Shapes Gendered Reasoning

Findings from contextual factors show that the learning environment, culture, curriculum, and social conditions play a major role in mediating gender patterns. In countries or schools where gender stereotypes in mathematics are weak, the performance of men and women tends to be equal. Conversely, in environments that still hold the belief that mathematics is a masculine domain, men are more dominant in visual and abstract tasks. Curricula that systematically expose students to various forms of proportional problems (e.g., unit rate, scaling, ratio comparisons) significantly reduce gender performance variation. This phenomenon reflects the opportunity to learn, which in educational theory functions as a cognitive background equalizer. When the curriculum exposes all students to varied and meaningful proportional tasks, the gender gap disappears.

Studies from Brazil, Mexico, and the UK in this SLR show that the gender gap is often closely related to differences in academic pathways or socioeconomic status. Female students who have better access to educational resources perform as well as or even better than males, especially on verbal context-based tasks. This reinforces the view that gender differences are more a product of structural conditions than biological factors.

The influence of culture is evident in certain gender patterns. Cultures that place high pressure on men to succeed in technical fields often enhance men's performance in visual-spatial tasks. Conversely, cultures that provide broad support to women in mathematics education produce balanced performance patterns. This shows that the gender gap is a social construct that is greatly influenced by the learning environment.

Role of Prior Knowledge

Another important finding is that prior mathematical knowledge is a much stronger predictor than gender. When prior knowledge is controlled for, gender differences almost always disappear. Thus, gender serves more as a secondary indicator, while the main factor is prior access to strong mathematical experiences.

If the three groups of cognitive, pedagogical, and contextual findings are integrated, the main patterns can be summarized as follows:

1. Gender differences emerge only under certain conditions, especially when visual representations are dominant or when additive strategies are easy to use.

2. High-quality instruction consistently reduces or eliminates the gap.

3. Social and cultural contexts strongly determine the emergence of gender differences, indicating that gender is not a deterministic variable.

4. Women excel in conceptual reasoning and strategy stability, while men excel in speed and visual reasoning—but both patterns can change through learning experiences.

Thus, the results of this SLR clarify that the gender gap is conditional, not inherent.

This SLR expands on the theory of proportional reasoning by showing that: (1) Gender differences are better understood as interactions between cognitive strategies and task structures. (2) Visual and verbal representations have differential effects on student performance based on gender. (3) The sociocultural context is an important component of the proportional reasoning model, a dimension that has been underdiscussed in the classical literature.

Teachers and curriculum developers can: (1) Integrate multiple representations into proportional teaching. (2) Use manipulatives to help students who have difficulty transitioning from concrete to abstract concepts. (3) Choose diverse problem contexts to avoid gender bias. (4) Use educational technology as visual scaffolding to improve reasoning for both genders.

This SLR opens up new avenues of research, including: (1) Longitudinal studies to explore how long-term learning experiences moderate the gender gap. (2) Development of adaptive intervention models based on cognitive strategies. (3) Meta-analysis of the influence of visual representations on gender differences in proportional reasoning.

LIMITATIONS AND FUTURE RESEARCH

Limitations

Although this systematic review provides a comprehensive synthesis of gender-related patterns in proportional reasoning, several limitations must be acknowledged. First, the included studies vary widely in methodological design, assessment tools, and task structures. This heterogeneity limits the extent to which findings can be directly compared and the possibility of conducting a meta-analysis. Many studies also used different operational definitions of proportional reasoning ranging from missing-value tasks to graphical interpretation potentially influencing the observed gender differences.

Second, the review is limited by its reliance on published, peer-reviewed journal articles. This may introduce publication **bias**, as studies reporting non-significant gender differences or null results are less likely to be published. Consequently, the synthesized findings may overrepresent contexts in which gender differences are more pronounced. Excluding dissertations, conference papers, and institutional reports may have missed valuable insights, particularly from underrepresented educational systems.

Third, while the review includes international studies, the distribution of research is skewed toward specific regions, such as Southeast Asia, East Asia, and North America—potentially leading to a geographical **imbalance**. Cultural and socio-educational contexts that shape gender norms and learning experiences may not be fully captured in the present dataset. Additionally, only articles written in English were included, which may limit the representation of findings from non-English-speaking countries.

Fourth, most of the included studies employ cross-sectional designs, which restrict conclusions about the developmental progression of proportional reasoning across time. Because gender differences may shift as students gain more exposure to advanced mathematical concepts, longitudinal studies are crucial but remain scarce in the current literature. Finally, the review is limited by the accuracy and completeness of the data extraction process, which depends on the clarity of reporting within each primary study.

Future Research

Future research should aim to address these limitations through more methodologically robust and contextually sensitive investigations. Longitudinal studies are particularly needed to trace the development of proportional reasoning from childhood through adolescence, allowing researchers to examine how gender-related patterns evolve over time. Such studies could clarify whether initial differences diminish, persist, or shift when instructional quality, cognitive maturation, and exposure to mathematical tasks increase.

There is also a need for studies that use standardized, **validated instruments to assess** proportional reasoning across multiple contexts. Developing a shared measurement framework would enhance comparability across studies and improve the precision of conclusions about gender differences.

Future work should also focus on intervention-based **research** to explore how instructional designs especially those incorporating multiple representations, technology-enhanced scaffolds, and culturally relevant problem contexts—can reduce gender disparities. Understanding which intervention components most effectively support each gender can inform more equitable pedagogy.

Additionally, research should expand to understudied regions where gender norms, educational resources, and curricular structures may differ significantly from those in the countries most represented in the current literature. Including diverse contexts would enhance the global relevance of research on proportional reasoning.

Ultimately, future studies should investigate the intersections between gender and other learner characteristics, such as socioeconomic status, prior knowledge, mathematical anxiety, and motivation. These multidimensional analyses would contribute to a more nuanced understanding of how proportional reasoning develops and how best to support all learners.

4 CONCLUSION

This systematic review synthesized findings from 30 empirical studies published between 2010 and 2024 to examine gender-related patterns in students' proportional reasoning skills within cognitive, pedagogical, and contextual dimensions. Across the reviewed studies, the evidence consistently shows that gender differences in proportional reasoning are not fixed or universal; instead, they are conditional, task-dependent, and shaped by instructional and contextual factors. The analysis reveals that cognitive preferences—particularly in strategy use, numerical fluency, and visual–spatial reasoning—play a meaningful role in shaping performance. Female students tended to demonstrate greater *conceptual stability*, more consistent use of multiplicative strategies, and higher accuracy on verbal and context-rich problems. Meanwhile, male students often performed better on tasks involving complex visual or graphical representations and responded more quickly, although sometimes with higher susceptibility to additive misconceptions.

Pedagogical factors emerged as a critical source of variation. High-quality instructional approaches—especially those emphasizing explicit reasoning, multiple representations, manipulative-based learning, and interactive technology—significantly reduced or even eliminated gender disparities. Such evidence highlights that instructional design can effectively mediate cognitive tendencies and promote equitable learning outcomes. Furthermore, the characteristics of proportional tasks, including problem framing, representational mode, and contextual familiarity, strongly influence student performance, suggesting that task design must be considered carefully when assessing or teaching proportional reasoning.

Contextual influences such as cultural norms, socioeconomic background, curriculum structure, and prior mathematical knowledge were also found to mediate gender differences. In educational systems where mathematical gender stereotypes are weaker, gender gaps tend to be negligible. Conversely, in contexts where access to mathematical learning opportunities differs by gender, disparities are more pronounced. Importantly, prior mathematical knowledge consistently emerged as a stronger predictor of success in proportional reasoning than gender itself, reinforcing the idea that opportunity to learn outweighs gender-based assumptions.

Overall, this review contributes to the literature by demonstrating that gender-related differences in proportional reasoning are highly malleable and context-sensitive, rather than inherent. Proportional reasoning should therefore be approached not as a gendered cognitive capacity but as a learnable, teachable domain that can be strengthened using evidence-based instructional practices. The findings underscore the need for equitable curriculum design, gender-responsive pedagogy, and increased attention to cognitive diversity in mathematics learning. By addressing structural and instructional influences, educators and policymakers can support the development of proportional reasoning in all learners—ensuring that gender does not become a barrier to mathematical understanding or advancement.

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