# On blurring the boundaries between mathematics and the real world

CONSTANTINOS XENOFONTOS

*Oslo Metropolitan University*
*Norway*
*constantinos.xenofontos@oslomet.no*

## Abstract

*This article explores the complex relationship between mathematics and real-world contexts, a pivotal focus in mathematics education. Using a narrative review methodology, I critically examine five approaches, contributing to blurring the boundaries between abstract mathematics and practical applications: word problems, mathematical modelling, the history of mathematics, sociopolitical approaches, and interdisciplinary approaches. Each approach is analysed for its potential to enhance engagement, foster critical thinking, and promote inclusivity while addressing challenges such as teacher preparedness, curricular constraints, and assessment practices. Commonalities across these approaches highlight their collective ability to contextualise mathematics, making it more relevant and dynamic for learners. The discussion emphasises the transformative potential of integrating real-world contexts into mathematics education. The article concludes with practical recommendations for teachers, policymakers, and researchers, encouraging pedagogies that help learners apply mathematical knowledge and understanding to address real-world challenges.*

## Keywords

*Mathematics, real-word connections, boundaries, blurring*

## Résumé

*Cet article explore la relation complexe entre les mathématiques et les contextes du monde réel, un point central dans l'enseignement des mathématiques. En utilisant une méthodologie narrative, j'examine de manière critique cinq approches qui contribuent à brouiller les frontières entre les mathématiques abstraites et* *les applications pratiques : les problèmes de mots, la modélisation mathématique, l'histoire des mathématiques, les approches sociopolitiques et les approches interdisciplinaires. Chaque approche est analysée en fonction de son potentiel à renforcer l'engagement, à encourager la pensée critique et à promouvoir l'inclusion tout en relevant des défis tels que la préparation des enseignants, les contraintes liées aux programmes d'études et les pratiques d'évaluation. Les points communs entre ces approches soulignent leur capacité collective à contextualiser les mathématiques, ce qui les rend plus pertinentes et dynamiques pour les apprenants. La discussion met l'accent sur le potentiel transformateur de l'intégration de contextes du monde réel dans l'enseignement des mathématiques. L'article se termine par des recommandations pratiques à l'intention des enseignants, des décideurs politiques et des chercheurs, encourageant les pédagogies qui aident les apprenants à appliquer les connaissances et la compréhension des mathématiques pour relever les défis du monde réel.*

**Mots-clés**

*Mathématiques, liens avec des mots réels, frontières, flou*

***Cite this article***

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## Introduction

Establishing meaningful connections between mathematics and the real world has long been a focus of research in mathematics education. The emphasis on contextualising mathematical learning has evolved over time, mirroring shifts in educational priorities. Early approaches concentrated on solving practical problems, paving the way for more integrative methods that address interdisciplinary and societal challenges. Writing more than 30 years ago, for instance, Blum and Niss (1991) distinguish between purely mathematical and applied problems: the former being "entirely embedded in some mathematical universe" (p. 38), while the latter engages with real-world contexts where mathematical concepts, methods, and results play a crucial role.

Currently, the urgency of linking mathematics to the real world is heightened by global challenges such as climate change (Romero Ariza et al., 2024), social inequalities (Yolcu & Kirchgasler, 2024), and technological advancements, including the expansion of AI technologies and their integration in educational settings (Huang & Qiao, 2024). Furthermore, initiatives such as the Programme for International Student Assessment

(PISA) highlight the importance of connecting school mathematics to the real world, by assessing "how well students can apply what they learn in school to real-life situations" (OECD, 2020, p. 6).

The importance of linking formal knowledge to learners' practical experiences is stressed in well-known theoretical frameworks such as constructivism, socio-cultural theories, and critical pedagogy. Extending these perspectives to mathematics education shows how mathematics can encourage critical thinking, cultural awareness, and problem-solving skills essential for addressing complex real-world issues. With the significance of these connections widely recognised, the mathematics education literature discusses diverse approaches to facilitate them.

This article addresses the question: *What opportunities and challenges arise in establishing connections between mathematics and the real world?* To explore this question, I examine five approaches contributing to the broader goal of blurring the boundaries between mathematics and real-world contexts. While these are not the only approaches, I focus on those of personal and professional interest to me as a mathematics education researcher: (a) word problems, (b) mathematical modelling, (c) the history of mathematics, (d) sociopolitical approaches, and (e) interdisciplinary approaches. As discussed subsequently, these are not mutually exclusive; rather, they overlap in significant ways.

In the following pages, I describe the methodology employed for the narrative review. I then present five concise narrative reviews of the aforementioned approaches, examining how each establishes connections between mathematics and the real world. Following this, I explore commonalities across the approaches, focusing on the opportunities and challenges these connections entail. Finally, the paper concludes by outlining implications for practice.

## Methodology

The methodology adopted for addressing the question above is that of a narrative literature review. Unlike systematic reviews, which follow structured protocols such as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Nøkleby et al., 2024) and focus on narrowly defined questions, narrative reviews are scholarly syntheses that provide broad, interpretative, and critical insights into a topic. These reviews are particularly suited to addressing complex, interdisciplinary issues, emphasising conceptual understanding, critique, and theory development (Andrews et al., 2021). Narrative reviews draw upon diverse sources of evidence, integrate insights from multiple disciplines, and engage with real-world complexities, often identifying knowledge gaps and generating new hypotheses (Baumeister & Leary, 1997; Ferrari, 2015).

While systematic reviews are essential for summarising evidence in a precise and methodical manner, narrative reviews offer the flexibility to explore multifaceted questions and foster theoretical advancement (Greenhalgh et al., 2018). Although narrative reviews are sometimes perceived as inferior to systematic reviews, they provide crucial context, critical appraisal, and deeper theoretical insights. As Greenhalgh et al. (2018) argue, the hierarchy that often places systematic reviews above narrative reviews is flawed. Both types of review serve distinct but equally important functions, enriching the research landscape and advancing our understanding of complex phenomena (Baumeister & Leary, 1997; Ferrari, 2015). Consequently, this article employs the narrative review approach to critically examine the selected approaches, providing an interpretative lens through which to understand their contributions to the field and their implications for connecting mathematics with real-world contexts.

The search was conducted via Google Scholar and databases such as Education Research Complete, ERIC, and Web of Science. Since this study adopts a narrative review framework, the aim was not to identify every article published within a specific timeframe. Rather, the objective was to select articles that contribute to a comprehensive narrative for each of the five approaches under examination. The temporal scope of this review prioritises studies published after 2000, reflecting contemporary developments in educational theories and practices relevant to the manuscript's broader discussion of connecting mathematics with the real world. Foundational works were included selectively to provide historical context and highlight enduring influences. To achieve a targeted synthesis, searches were conducted using specific keywords associated with the five pedagogical approaches central to the manuscript.

- *Word problems:* Keywords included terms such as "word problems", "story problems", "applied problems", "realistic contexts", or "authentic problem contexts", combined with "mathematics", "school mathematics", or "mathematics education."
- *Mathematical modelling:* Keywords included terms such as "mathematical modelling" and "modelling problems" (British English), and "mathematical modeling" and "modeling problems" (US English), combined with "mathematics", "school mathematics", or "mathematics education".
- *History of mathematics:* Keywords included the term "history of mathematics", combined with "mathematics education", "mathematics classrooms", or "school mathematics".
- *Sociopolitical approaches:* Keywords included terms such as "critical mathematics", "equity", "social justice", and "culturally responsive pedagogy", combined with "mathematics education", "mathematics classrooms", or "school mathematics".
- *Interdisciplinary approaches*: Keywords included "STEM education" and "STEAM education", combined with "interdisciplinary", "cross-disciplinary", "mathematics classrooms", or "school mathematics".

## Word problems

Many of us are familiar from our schooldays with tasks like:

- "Jim has 16 marbles and wins 10 more. How many does he have now?" (Van den Heuvel-Panhuizen, 2005, p. 5).
- "Farmer Alfred has three times as many chickens as cows. Altogether, there are 60 legs in the barn. How many cows does Farmer Alfred have?" (Vos, 2018, p. 2).

These types of tasks, commonly referred to as *word* or *story problems*, are framed within textual narratives to integrate numerical reasoning with imagined or real-world scenarios. They require learners to interpret and translate narrative contexts into mathematical terms, identify the underlying problem, and solve it accordingly. Although often described as *real-world problems*, their contexts are typically abstracted or idealised, making them more hypothetical than authentic (Palm, 2008; Sepeng, 2013; Vos, 2018).

Historically, word problems have held a central place in mathematics education, rooted in ancient pedagogical traditions designed to develop applied problem-solving and logical reasoning (Acosta-Tello, 2010). One of the main challenges learners face with these problems involves constructing a situation model, a mental representation of the narrative. This model enables them to navigate the dual demands of linguistic comprehension and mathematical reasoning (Mattarella-Micke & Beilock, 2010). The interplay between these skills distinguishes word problems from purely symbolic mathematical tasks, highlighting their potential to connect abstract concepts with practical application (Koedinger & Nathan, 2004).

Word problems offer significant opportunities for meaningful learning by contextualising mathematical ideas within relatable narratives. Such contextualisation can increase learner engagement, prompt critical thinking, and encourage the development of mathematical modelling skills that are essential for solving real-world problems (Verschaffel et al., 2020). Constructivist educational theories emphasise embedding mathematical tasks within realistic or familiar contexts to help learners connect abstract concepts with their own lived experiences (Depaepe et al., 2010; Van den Heuvel-Panhuizen, 2005). When carefully designed, word problems can activate intuitive reasoning and promote deeper conceptual understanding, making mathematical concepts more accessible (Koedinger & Nathan, 2004). Furthermore, they provide opportunities for creativity, collaboration, and higher-order reasoning, enabling learners to construct and solve mathematical representations tailored to diverse contexts (Van Garderen et al., 2012). Personalising word problems to align with learners' interests can reinforce their view of mathematics as a dynamic, relevant tool for addressing real-world challenges (Vos, 2018).

However, despite their potential, word problems present significant challenges for learners. A common difficulty involves the suspension of sense-making, where learners focus on rote computation while disregarding the realistic applicability of their solutions (Palm, 2008). This issue often arises from traditional instructional methods that prioritise procedural accuracy over conceptual depth (Verschaffel et al., 2020). Additionally, learners may struggle to reconcile the linguistic and contextual demands of the problem with its mathematical requirements, particularly when the scenarios are contrived or lack realism (Sepeng, 2013; Walkington et al., 2012). Ambiguities or complexities in the narrative may obscure the mathematical task, leading to misrepresentation or errors in problem-solving (Koedinger & Nathan, 2004). Furthermore, socio-cultural and linguistic factors can exacerbate these difficulties, especially for learners navigating a second-language environment (Sepeng, 2013).

To address these challenges, word problems must carefully balance cognitive and linguistic demands while ensuring their contexts are authentic and relatable. Combining paradigmatic approaches, which emphasise abstract mathematical structures with narrative approaches, which prioritise contextual storytelling, can aid in bridging the gap between theoretical and applied mathematics (Chapman, 2006; Cooper & Harries, 2002). Aligning problems with students' experiences and interests not only enhances accessibility but also fosters engagement and promotes deeper learning (Vos, 2018; Walkington et al., 2012). Effective word problems demand attention to cognitive, linguistic, and cultural dimensions, ensuring their relevance and inclusivity. When thoughtfully designed, word problems serve as a powerful educational tool, bridging abstract theory with practical application, and equipping learners with critical thinking and modelling skills essential for addressing real-world challenges (Depaepe et al., 2010; Verschaffel et al., 2020).

## Mathematical modelling

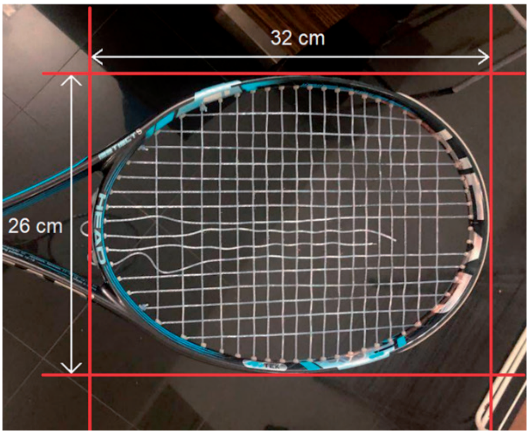
While many of us are acquainted with word problems (as noted in the preceding section), only few recall school experiences involving tasks like the one below, adapted from Ludwig and Reit (2013):

The string of this racket (Figure) is broken and must be repaired. The entire stringing section requires replacement.

(a) Estimate the total length of string required for this racket, employing a mathematical approach. The dimensions in the accompanying illustration may be helpful.

(b) Propose a straightforward formula that a sports shop assistant could use to determine the total string length for different rackets. The formula should depend on easily measurable racket dimensions.

**FIGURE**




Such tasks are often called *modelling problems* and can be clustered into different types depending on the educational purpose they serve (Abassian et al., 2020). Conversely, *mathematical modelling* is described as the process that employs mathematics to interpret, represent, analyse, and make predictions related to complex real-world phenomena, like the example of the racket. Scholars describe modelling as a reciprocal translation between the real world and mathematics with models serving as conceptual tools to simplify and structure complex scenarios (Blum & Niss, 1991; Frejd & Bergsten, 2016; Lesh & Lehrer, 2003). The modelling process is iterative, involving cycles of understanding the problem, simplifying it, mathematising, validating, and refining (Blum & Borromeo Ferri, 2009; Lesh & Harel, 2003). This variation in modelling cycles demonstrates its adaptability across educational contexts but also highlights a lack of consensus in how the modelling process is conceptualised, as different representations emphasise diverse aspects and priorities (Perrenet & Zwaneveld, 2012).

Mathematical modelling allows students to engage meaningfully with mathematics by connecting abstract concepts to real-world contexts. Research indicates that younger learners can independently develop constructs and processes through meaningful problem-solving, enhancing their capacity to mathematise complex situations (English, 2006; Lesh & Harel, 2003; Wei et al., 2022). Addressing authentic problems enables students to perceive mathematics as relevant and practical, cultivating motivation and a deeper understanding of mathematical ideas (Ärlebäck & Doerr, 2018; Berget, 2022; English, 2009). This approach nurtures critical thinking, problem-solving, and teamwork as students collaborate to interpret and construct models (Lesh & Lehrer, 2003). Furthermore, modelling demonstrates mathematics as a versatile tool for interdisciplinary challenges, often incorporating contexts from science, social studies, and economics.

The socio-critical dimension of modelling also encourages students to examine the ethical and societal implications of mathematical practices, equipping them to address pressing global issues such as climate change and social justice (Abassian et al., 2020; Gibbs & Park, 2022; Hauge et al., 2019; Steffensen & Kacerja, 2021).

The collaborative and iterative nature of modelling promotes reflective thinking and adaptive learning, encouraging students to test and refine their solutions. These processes align with constructivist pedagogies, wherein learners build knowledge through exploration and problem-solving (Wei et al., 2022). Teachers can employ modelling activities to address diverse learner needs, offering multiple entry points and promoting a range of problem-solving strategies. This flexibility contributes to the holistic development of mathematical literacy, preparing students for complex decision-making in both academic and real-world settings (Edelen et al., 2020; Kacerja et al., 2021).

Nevertheless, mathematical modelling presents significant challenges in educational practice. The inherent complexity of modelling problems can be daunting for both students and teachers. Teachers often face difficulties facilitating these activities due to limited training and the challenge of abstracting real-world problems into mathematical forms (Asempapa & Sturgill, 2019; Hernandez-Martinez et al., 2021; Wei et al., 2022). Institutional constraints, such as rigid curricula and overcrowded syllabuses, further hinder the integration of exploratory modelling tasks (Barquero et al., 2018). Students, too, may struggle with abstraction and validation, particularly when faced with ambiguous or incomplete data. Moreover, designing fair and accessible modelling tasks for learners from diverse backgrounds remains a challenge, as such tasks must accommodate varying levels of prior knowledge and experience (Borromeo Ferri, 2013; Jablonka & Gellert, 2011; Perrenet & Zwaneveld, 2012).

Various colleagues working in this area stress the importance of balancing guidance with facilitating student independence during modelling activities (e.g., Blum & Borromeo Ferri, 2009; Lesh & Lehrer, 2003). Traditional assessment practices, which regularly prioritise procedural fluency are ill-suited to evaluate the complex skills cultivated through modelling, such as creativity, reasoning, and contextual understanding (Berget, 2022; García et al., 2006; Zapata-Cardona, 2018). To capture the breadth of competencies associated with modelling, innovative assessment methods are required, reflecting its interdisciplinary and iterative essence.

Mathematical modelling offers a transformative approach to mathematics education, enabling students to tackle real-world challenges with analytical and creative reasoning (Blum & Niss, 1991; English, 2009). Its successful integration depends on supporting teachers through professional development that builds confidence in guiding modelling tasks, alongside curricula that prioritise exploratory and meaningful learning (Asempapa & Sturgill, 2019; Zapata-Cardona, 2018). Equally important are assessment practices that reflect the interdisciplinary and iterative nature of modelling, valuing contextual understanding and critical thinking alongside mathematical proficiency (Wei et al., 2022; Steffensen & Kacerja, 2021).

## History of mathematics

Some readers may recall learning about *'completing the square'* during their school years, a technique used to rewrite a quadratic equation of the form $ax^2+bx+c=0$ into an equivalent expression in the form $a(x+d)^2+e=0$, where $d$ and $e$ are constants derived from the original equation. Many, however (myself included, until recently), may not know that this method was proposed by al-Khwarizmi, a prominent mathematician, astronomer, and geographer who lived during the early Islamic Golden Age, between 780-850 CE. In describing a course with prospective mathematics teachers in the USA, Clark (2012, pp. 72-73) provides an English translation of al-Khwarizmi's rhetorical and geometric explanation for solving quadratic equations:

> … a square and 10 roots are equal to 39 units. The question therefore in this type of equation is about as follows: what is the square which combined with ten of its roots will give a sum total of 39? The manner of solving this type of equation is to take one-half of the roots just mentioned. Now the roots in the problem before us are 10. Therefore take 5, which multiplied by itself gives 25, an amount which you add to 39 giving 64. Having taken then the square root of this, which is 8, subtract from it half the roots, 5 leaving 3. The number three therefore represents one root of this square, which itself, of course is 9. Nine therefore gives the square.

Incorporating elements from the history of mathematics into classrooms involves embedding historical narratives, problem-solving methods, and artefacts into teaching practices (Bütüner, 2016). This can include examining ancient algorithms, discussing mathematicians' biographies, reconstructing historical methods, or analysing original mathematical texts. For example, activities such as exploring al-Khwarizmi's geometric interpretation of quadratic equations or comparing historical algorithms for extracting square roots with modern calculator functions create tangible connections between historical and contemporary mathematical practices.

This historical integration offers significant opportunities for learners. One major benefit is that it deepens students' conceptual understanding by illustrating the logical development of mathematical ideas over time. For example, tracing the evolution of concepts like quadratic equations helps students comprehend their interconnectedness and rationality (Clark, 2012; Goktepe & Ozdemir, 2013). This approach also enhances motivation and engagement by humanizing mathematics, transforming it from an abstract set of rules into a dynamic, evolving discipline (Bidwell, 1993; Karatas-Aydin

& Isiksal-Bostan, 2022). Stories of mathematicians' struggles and achievements can inspire curiosity, foster positive attitudes, and reduce maths anxiety, as seen through the use of biographical videos and historical anecdotes (Fried, 2014; Karatas-Aydin & Isiksal-Bostan, 2022).

Furthermore, engaging with historical problem-solving techniques promotes critical thinking (Chorlay et al., 2022; Smestad et al., 2014). When students compare ancient methods with modern approaches, they gain a clearer understanding of the iterative nature of mathematics and the rationale behind contemporary practices. Additionally, integrating the history of mathematics fosters cultural awareness and inclusivity by highlighting contributions from diverse civilisations, challenging Eurocentric narratives, and emphasising the global nature of mathematical knowledge (Fried, 2008; Xenofontos & Papadopoulos, 2015). This cultural perspective broadens students' understanding of the subject and highlights its interdisciplinary connections with art, science, and society (Xenofontos & Papadopoulos, 2015).

While integrating historical elements into mathematics classrooms has clear benefits, it also introduces several challenges. Time constraints are a significant barrier, as overloaded curricula and the demands of high-stakes testing often leave little room for supplementary historical content (Clark et al., 2019; Panasuk & Horton, 2012). Moreover, many teachers lack adequate preparation to effectively incorporate history into their teaching (Farmaki & Paschos, 2007; Ho, 2008). This integration requires a deep understanding of mathematical concepts and an appreciation of their historical development, yet teacher training programs rarely address these dual requirements (Clark, 2012; Farmaki & Paschos, 2007). Resource limitations further complicate implementation. Teachers often struggle to access authentic historical materials or well-designed activities, leaving them without the necessary tools to meaningfully incorporate history into their lessons (Clark et al., 2019; Karaduman, 2010). Student perceptions can also pose challenges; some learners view historical content as irrelevant to contemporary mathematics, undermining engagement. Additionally, presenting historical mathematics inaccurately or oversimplifying its context, risks confusing students or perpetuating misconceptions about the discipline's evolution (Farmaki & Paschos, 2007; Fried, 2008).

Using elements from the history of mathematics in classrooms can enrich learning by connecting mathematical concepts with their historical and cultural roots (Fried, 2008). This approach fosters more profound understanding, enhances motivation, and promotes critical thinking, highlighting the multicultural contributions to the field (Fried, 2014; Karatas-Aydin & Isiksal-Bostan, 2022). However, successful integration requires overcoming challenges related to time, resources, teacher preparedness, and curriculum constraints (Bütüner & Baki, 2020; Panasuk & Horton, 2012). Thoughtful planning, professional development, and the availability of high-quality materials are essential to ensuring that history becomes an integral part of mathematics education rather than merely an add-on. When implemented effectively, the history of mathematics can transform classrooms, making mathematics more accessible, engaging, and inspiring for students.

## Sociopolitical approaches

"[W]ho pays more for their food and why?" asks Gates (2019, p. 45), reflecting on a promotional label spotted in a supermarket:

- Kellogg's Cornflakes 790g – £2.52 (32p/100g)
- Kellogg's Cornflakes 450g – £1.80 (40p/100g)

Questions like this were entirely absent from my schooling experiences, and I am fairly confident that many of us born in the '80s or earlier, would say the same. Interestingly, the field of mathematics education took a more explicit sociopolitical turn around the year 2000 (Gutiérrez, 2013), when researchers began engaging with sociopolitical theories and concepts – such as authority, power relations, identity, and the social construction of success and failure – to explore the complex interplay between mathematics curricula, policy, politics, and the processes of teaching and learning (Fúnez-Flores et al., 2024; Xenofontos et al., 2021). Yet, in spite of this shift, questions like the one posed by Gates are still rarely found in mathematics classrooms. This is not to underestimate the numerous attempts of researchers and teachers to establish meaningful connections between school mathematics and sociopolitical issues, such as social class, immigrant background, race/ethnicity, gender identity, sexuality, disability, and so on. Here, I use *sociopolitical approaches* as an umbrella term under which various other approaches with different labels can be placed: equity-based approaches, teaching mathematics for social justice, critical mathematics education, ethnomathematics, Indigenous education, and culturally responsive pedagogy, and so on. As Nolan and Lunney Borden (2023) comment, how different researchers see the connections between all these approaches remains a matter of perspective.

Connecting school mathematics to sociopolitical issues entails embedding mathematical learning within broader societal, cultural, and political contexts. This approach challenges the traditional perspective of mathematics as an abstract, culturally neutral discipline, positioning it instead as a tool for comprehending and addressing critical societal challenges. The incorporation of critical and reflective elements into teaching transforms mathematics into a means for promoting political agency, ethical contemplation, and social justice (Gutstein, 2003; Skovsmose, 1994; Taylor, 1996). Critical mathematics education highlights this transformative potential, urging learners to analyse global inequalities, critique financial systems, and explore the mathematical underpinnings of models that tackle issues such as climate change (Geiger et al., 2023; Maass et al., 2022; Skovsmose, 1994). This necessitates a considerable pedagogical shift, focusing on mathematical literacy as a key component of active citizenship. Such literacy enables pupils to reflect critically on societal structures, interpret real-world data, and engage with global challenges, promoting awareness of the influence of mathematical tools on societal and technological systems (Avci, 2021; Maass et al., 2022; Skovsmose et al., 2023).

The sociopolitical approach to mathematics education provides a wealth of opportunities for learners. Linking mathematics to real-world problems nurtures critical thinking and empowers pupils to challenge systemic inequities. For instance, exploring topics such as housing disparities through statistical analyses or examining the distribution of resources unveils the structural roots of inequality (Avci, 2021; Gutstein, 2003; Skovsmose, 1994; Taylor, 1996). Such an approach not only equips learners with the tools to question societal norms but also empowers them to envision and implement solutions, positioning mathematics as a vehicle for enacting social change (Geiger et al., 2023; Kokka, 2019). Incorporating lived experiences and cultural identities into mathematics education enhances its relevance and supports greater engagement, particularly for pupils from marginalised communities (Abdulrahim & Orosco, 2020; Ukpokodu, 2011). Culturally responsive teaching validates these pupils' realities, ensuring their socio-cultural identities are reflected within the curriculum (Nicol et al., 2013; Ukpokodu, 2011;). Collaborative learning environments further encourage dialogue among students from diverse backgrounds, promoting inclusivity, tolerance, and a deeper appreciation of different perspectives (Abdulrahim & Orosco, 2020; Skovsmose et al., 2023). From this perspective, mathematics serves as a pathway for cultivating justice-oriented citizenship, equipping pupils to address global challenges such as economic inequality and environmental sustainability (Geiger et al., 2023; Maass et al., 2022; Skovsmose et al., 2023).

Nonetheless, sociopolitical approaches to mathematics education pose significant challenges. A primary hurdle is teacher preparedness, as many educators lack expertise in both mathematical content and the sociopolitical contexts necessary for effective integration (Felton-Koestler, 2020; Steflitsch, 2023). Professional development and institutional support are vital for bridging this gap. Institutional constraints further hinder implementation, as rigid, standardised curricula and high-stakes testing often prioritise traditional, textbook-driven methods over context-rich pedagogies (Skovsmose, 1994; Maass et al., 2022). Resistance to change is another key issue. The perception of mathematics as objective and apolitical persists among educators, administrators, and communities, resulting in a reluctance to embrace approaches that emphasise critical reflection and cultural relevance (Skovsmose, 1994; Taylor, 1996). Addressing sociopolitical issues in the classroom can also raise challenges related to pupil engagement and equity dynamics. Pupils from differing socio-economic and cultural backgrounds may interpret these issues in other ways, complicating discussions about justice and potentially, resisting a reinforcement of existing privileges (Avci, 2021; Felton & Koestler, 2015;

Steflitsch, 2023). Encouraging critical thinking while maintaining objectivity is equally complex, requiring teachers to navigate sensitive topics without imposing specific viewpoints (Skovsmose et al., 2023; Taylor, 1996). External pressures also create obstacles, as sociopolitical content may bring opposition from parents, policymakers, or community members who view such approaches as inconsistent with local values or educational priorities (Skovsmose, 1994; Steflitsch, 2023; Taylor, 1996). This resistance can manifest in curriculum restrictions and debates over the role of education in fostering social awareness. These broader systemic and cultural barriers necessitate a concerted effort to reimagine mathematics education as a discipline embedded in cultural and social significance (Abdulrahim & Orosco, 2020; Gutstein, 2003; Skovsmose, 1994; Taylor, 1996).

## Interdisciplinary approaches

Imagine a classroom transformed into a bustling design studio, where students collaborate to create a mathematics museum. This project, detailed by Ortiz-Laso et al. (2023), required students to design and construct scaled models of museum structures, including geometric elements, like the Louvre pyramid. Alongside building these models, students analysed mathematical principles through art, such as exploring the Golden Ratio in architectural designs or using dynamic software to study symmetry in mosaics. These activities seamlessly integrated mathematics with art, engineering, and technology, fostering a collaborative, creative learning environment that highlighted the interdisciplinary nature of mathematics.

Interdisciplinary approaches, such as STEM (Science, Technology, Engineering, and Mathematics) and STEAM (which incorporates the Arts into STEM), emphasise connections between disciplines in tackling complex, real-world challenges (Ulbrich et al., 2024). These frameworks move beyond the traditional separation of subjects, favouring collaborative, context-driven learning that integrates knowledge and skills across diverse fields. For example, STEM education frequently employs mathematical modelling to address engineering or scientific problems, such as designing solar-powered devices or optimising structures for energy efficiency (Baker & Galanti, 2017; Kertil & Gurel, 2016). STEAM broadens this approach by incorporating artistic and creative dimensions, sparking innovation through projects, like designing eco-friendly buildings that balance mathematical precision with aesthetic appeal (Duo-Terron et al., 2022; Quigley & Herro, 2016).

These interdisciplinary methods are evident in a variety of educational activities. For instance, integrating 3D computer-aided design software into geometry lessons links spatial reasoning with technological skills, enabling students to visualise and manipulate shapes dynamically (Ng & Chan, 2019). Similarly, STEAM projects found in mathematics museums encourage learners to engage in collaborative tasks that combine mathematical concepts with artistic representation, promoting creative problem-solving (Ortiz-Laso et al., 2023). These projects illustrate how interdisciplinary strategies make learning more engaging and applicable to everyday contexts.

Integrating mathematics within interdisciplinary frameworks brings substantial benefits by placing mathematical concepts in meaningful and practical settings. Such contextualisation demonstrates the relevance of mathematics and enhances student engagement and comprehension. In STEM education, for example, the engineering design process often requires students to apply mathematical principles to optimise solutions. A study involving secondary school students designing billy carts exemplifies this approach: students calculated forces, interpreted data, and refined their designs, making mathematics a critical component of their problem-solving process (Tytler et al., 2023). Interdisciplinary methods also strengthen conceptual understanding through mathematical modelling and computational tools. In STEM contexts, modelling enables students to explore and predict outcomes in scientific and engineering tasks, fostering analytical skills (Kertil & Gurel, 2016). Additionally, tools such as coding and simulations allow students to implement algorithms and apply mathematical reasoning in developing innovative solutions, enhancing computational thinking (So, 2023). The inclusion of the Arts within STEM further encourages creativity and positively influences students' perceptions of mathematics. For example, STEAM activities have been found to increase engagement and self-confidence in mathematics by presenting it in visually rich and contextually relevant forms, though their impact on achievement may vary (Duo-Terron et al., 2022). Incorporating mathematics into broader contexts helps to make abstract concepts more accessible and relevant, promoting a deeper appreciation for the subject.

Interdisciplinary approaches face significant challenges, despite their potential, particularly in maintaining the depth and integrity of mathematical learning. A key concern is the marginalisation of mathematics within interdisciplinary contexts. In many STEM and STEAM projects, mathematics is often treated as a supporting tool rather than a central discipline, which risks diluting its content and limiting opportunities for rigorous mathematical inquiry (Baker & Galanti, 2017; Tytler et al., 2023). Another challenge lies in teacher preparedness. Designing interdisciplinary tasks that integrate mathematics meaningfully requires specialised skills and knowledge, which many teachers lack. This imbalance can result in projects that prioritise other disciplines at the expense of robust mathematical engagement (Hall & Miro, 2016; Just & Siller, 2022). For instance, while engineering and coding projects can enhance problem-solving abilities, they may only superficially include mathematical reasoning, thereby reducing opportunities for deeper exploration of complex concepts (Ortiz Laso et al., 2023). Curricular and assessment constraints further complicate implementation. Traditional curricula, structured around discrete subject areas, often leave little room for integrated projects, creating tensions between covering the required content and fostering interdisciplinary learning (Li & Schoenfeld, 2019). Similarly, conventional assessment methods may struggle to capture the depth of mathematical understanding demonstrated in interdisciplinary contexts, necessitating innovative evaluation strategies (Fitzallen, 2015; So, 2023).

## Common grounds across approaches: opportunities and challenges

Mathematics education is a dynamic field increasingly concerned with bridging the gap between abstract mathematical concepts and their practical, cultural, and societal applications. The five approaches discussed in this narrative review (word problems, mathematical modelling, the history of mathematics, sociopolitical approaches, and interdisciplinary approaches) are distinct in their focus. Yet, they share significant commonalities and frequently overlap in practice. For example, word problems often serve as simplified entry points for mathematical modelling by encouraging pupils to translate real-world scenarios into mathematical terms. Similarly, interdisciplinary approaches commonly draw upon modelling and historical narratives, as seen in projects that integrate STEM and STEAM frameworks with the evolution of mathematical ideas. Sociopolitical contexts, meanwhile, are inevitably embedded in interdisciplinary projects and can enhance the authenticity and cultural relevance of word problems or modelling tasks. For instance, analysing historical tax records within a sociopolitical framework could combine historical insights, modelling techniques, and real-world applications. These overlaps highlight the collective potential of these approaches to transform mathematics education. Together, they provide opportunities to contextualise mathematics, encouraging engagement and critical thinking, while also promoting equity and inclusivity.

A significant strength of these approaches lies in their ability to enhance student engagement and motivation. Contextualising mathematics within relatable scenarios – such as real-world modelling tasks or culturally grounded word problems – encourages students to view the subject as relevant and dynamic rather than abstract and distant (Koedinger & Nathan, 2004; Verschaffel et al., 2020). Furthermore, drawing on historical narratives or sociopolitical contexts sparks curiosity, fostering connections between mathematics and broader human and societal experiences (Fried, 2008; Gutstein, 2003). These methods also cultivate critical thinking and problem-solving skills. For example, mathematical modelling engages students in iterative cycles of understanding, abstraction, and validation, mirroring the complexity of real-world challenges (Blum & Borromeo Ferri, 2009). Similarly, sociopolitical mathematics tasks invite learners to address systemic issues such as inequality and climate change, equipping them with the analytical tools needed to tackle global challenges (Skovsmose, 1994; Maass et al., 2022).

Another key opportunity lies in promoting equity and inclusivity. Sociopolitical and historical approaches, in particular, disrupt Eurocentric narratives by amplifying diverse cultural contributions and granting marginalised people their own voice (Fried, 2014; Xenofontos & Papadopoulos, 2015). This enriches the curriculum and fosters a sense of belonging, particularly among underrepresented learners. Finally, these approaches demonstrate the interdisciplinary relevance of mathematics. Whether through STEM initiatives, STEAM projects integrating the arts, or examining historical connections between mathematics and other disciplines, they reveal the subject's integral role in addressing multifaceted challenges across diverse fields (Kertil & Gurel, 2016; Ortiz-Laso et al., 2023).

Although promising, these approaches confront significant barriers that must be addressed to achieve their transformative potential. A recurring obstacle concerns teachers' limited pedagogical preparedness. Implementing modelling tasks or sociopolitical discussions requires specialised skills that many teachers lack due to insufficient training (Asempapa & Sturgill, 2019; Felton-Koestler, 2020). Similarly, teaching the history of mathematics demands a deep understanding of both mathematical and historical contexts, a dual expertise rarely developed in standard teacher preparation programmes (Farmaki & Paschos, 2007). Time and curricular constraints also impede the integration of these approaches. High-stakes assessments often prioritise procedural fluency, leaving little room for exploratory or interdisciplinary activities such as extended modelling cycles or culturally responsive discussions (Barquero et al., 2018). Additionally, existing assessment practices present a challenge. Traditional methods focus on procedural accuracy and struggle to evaluate the creativity, critical thinking, and collaborative skills these approaches foster. For example, the iterative nature of modelling tasks does not align easily with conventional grading frameworks (Berget, 2022; Zapata-Cardona, 2018). Lastly, resistance to change remains pervasive. Mathematics is frequently perceived as objective and apolitical, a view that conflicts with the contextual and subjective elements emphasised in sociopolitical and interdisciplinary approaches (Skovsmose, 1994). Such resistance is evident not only among teachers and students but also within policymaking and broader community contexts.

## Implications for practice

Realising the potential of these approaches necessitates concerted efforts among educational stakeholders. The recommendations that follow address current challenges while offering pathways for advancement.

Teachers play a pivotal role in making mathematics education more inclusive and engaging. They should aim to design learning tasks that connect deeply with students' lived realities. For instance, integrating sociopolitical themes into mathematical problems or spotlighting the contributions of diverse mathematicians can enrich the learning environment and enhance inclusivity (Fried, 2014; Gutstein, 2003). Technology, including dynamic geometry software and virtual simulations, offers innovative avenues to explore mathematical concepts interactively and creatively (Ng & Chan, 2019). Collaboration within classrooms is equally essential. Activities that encourage teamwork not only enhance communication skills but also embrace diverse perspectives. Interdisciplinary projects, such as integrating mathematics with art or engineering are particularly beneficial as they simulate real-world problem-solving contexts (Lesh & Lehrer, 2003; Ortiz-Laso et al., 2023).

Policymakers must advocate for curricula that are both flexible and inclusive, providing room for exploratory and interdisciplinary learning activities (Barquero et al., 2018; Tytler et al., 2023). Investment in professional development remains critical to equip educators with the skills necessary for implementing such innovative pedagogical approaches. Targeted workshops could help teachers integrate real-world scenarios into lessons or draw on historical contexts to make mathematics more relatable and engaging (Asempapa & Sturgill, 2019; Farmaki & Paschos, 2007). Equity-centred policies are imperative, including resources that prioritise diverse cultural contributions and offer support tailored to the needs of underrepresented groups, ensuring this way that inclusivity is not merely aspirational but achievable (Fried, 2014; Ukpokodu, 2011).

Researchers play a critical role in advancing these efforts by developing comprehensive assessment frameworks that capture a broad range of skills nurtured by these methods, such as creativity, critical thinking, and collaboration. Alternative assessment forms, like project-based tasks and portfolios, offer promising avenues worth exploring (Berget, 2022; Zapata-Cardona, 2018). Further research is needed to balance the depth and breadth of interdisciplinary initiatives, ensuring rigorous mathematical engagement within broader STEM or STEAM contexts (Tytler et al., 2023; Ortiz-Laso et al., 2023). Finally, longitudinal studies examining the impact of these approaches on students' attitudes and performance can provide valuable insights into their effectiveness and scalability.

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