

**ONLINE MATHEMATICS EDUCATION: A COMPREHENSIVE DECADE LONG
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ABSTRACT

Online mathematics instruction has been growing significantly between 2013 and 2023 due to the development of digital solutions and a sudden shift to distance learning caused by the COVID-19 pandemic [5], [24]. The current article is an extensive synthesis of 41 empirical works, thus, mapping the benefits, challenges and effective design practices in K-12 and higher education environments. Among the benefits reported are flexibility of access, interactive resources, community scaffolds that promote engagement and persistence [3], [15], [25], persistent barriers as experienced by learners and teachers are reported as unequal access, motivation, integrity of assessment, and workload strain [14], [19], [24], [27], [28]. Positive outcomes of mathematics proficiency, self-efficacy, and discourse have been shown with pedagogical models of flipped classroom and communities of inquiry when they are designed purposely with feedback and structure [7], [35]. The domain-specific affordances are created in the context of modelling and problem solving activities where digital tools allow visualisation, iteration, and collaboration, but also create orchestration complexity at the same time [18], [41]. The acceptance and knowledge practices are affected by social and media ecosystems, posing the idea that the characteristics of the platform and its norms contribute to the adoption of e-learning in mathematics settings [1], [6], [11]. Theoretically, the corpus is biased in terms of cross sectional surveys and case studies and few longitudinal or experimental designs, so reflexive thematic analysis has been used to combine results and surface design principles and gaps in the research [17], [29]. The review suggests (i) the structured interaction as opposed to discussion boards [22]; (ii) the evaluation designs that are aligned to mathematical reasoning as opposed to simple recall [33], [40]; (iii) the teacher development that is geared towards the alignment of the technology with the pedagogy and ensuring equitable participation [30], [34]. These have implications on curriculum design, platform choice, and policy geared towards a continuation of inclusive online mathematics learning.

Keywords:

online mathematics education, flipped classroom, communities of inquiry, e- learning acceptance, engagement, assessment, thematic analysis.

1.0 INTRODUCTION**1.1 Background and Motivation**

This recent trend has resulted in a faster movement towards the online delivery of mathematics education over the past ten years due to a rising digital platform and the impact of COVID-19-related disruption to traditional schooling [5], [24], [27], [28]. Research in a wide range of settings records both excitement and apprehension towards online modalities, such as students, perceptions and perceived obstacles, as well as teacher, preparedness and policy advocacy of information and communication technology (ICT) integration [2], [8]10]. In mathematics education in particular, internet resources have been implemented to address access and maintain interaction and orchestrate problem solving on scale, but questions have also been raised about equity, assessment cheating, and pedagogical scaffolding in large scale settings [3], [14], [24], [36], [40]. The evidence presented in this review is

a synthesis of evidence over a decade (2013-2023) to show where online mathematics education is providing value, and where it is failing, as well as how design and policy can be improved to meet the disciplinary objectives.

1.2 Conceptualizing Online Mathematics Education

We take an inclusive perspective of online mathematics education which includes fully online and blended courses, formal K-12 and higher education, and platform-mediated communities that promote mathematical inquiry and help seeking [15], [33], [35]. Two anchors guide our scope. Initially, learning outcomes of mathematics are viewed within the context of mathematical literacy- knowledge, application, and thinking about mathematics in a diverse setting [32]. Second, implementation falls within the context of student-centred learning, with focus on learner agency, personalization, and competency-based improvement with the help of technology [31]. Besides institutional learning management systems, synchronous tools, social and knowledge platforms influence acceptance and practices, by relating the e-learning adoption to the norms and affordances of the digital communities [1], [11].

1.3 Policy and National Strategies

Policy and national strategies have attempted to integrate the digital technology, but the implementation and level of readiness is uneven among different systems [10], [25]. The pandemic phase brought a fast and even hasty expansion of online delivery, both increasing the chances (universality of access, speed of content delivery) and pressures (infrastructure shortages, workload, and scalability requirements) [5], [24], [27], [28]. At the same time, the tool ecosystem became more diverse, such as videoconferencing, domain-specific platforms, and institutions and instructors needed to select, interoperate, and find the pedagogical fit [13], [25].

1.4 Stated Advantages and Continued Despair

A summary of the recent research shows that most studies have reported similar benefits: flexibility of access, multimedia visualization, and community support opportunities that can be used to increase satisfaction and engagement in conditions of intentional designs [3], [15], [24], [25], [35]. Meanwhile, regular difficulties are reported. Students and educators mention the limitation of connection, a decrease in motivation, cognitive overload, and lack of equal preparation to work at their own pace of self-study [2], [14], [27], [28]. In certain situations, negative social media consumption is associated with academic procrastination, and it is harder to manage one self online [4]. Assessment has also been one of the battleground, as the questions of authenticity and correspondence to mathematical reasoning instead of memory tasks have been raised [38], [40]. These strains indicate that effectiveness is not so much triggered by the very existence of technology but compatibility of tools with disciplinary activities, feedback loops, and quality of interactions.

1.5 Pedagogical Models and Interaction Mechanisms

There are a number of pedagogical models that are repeated in the literature. Flipped-classroom models where exposition is moved online before classes and the synchronous time allocated to problem solving have been found to have beneficial impacts on mathematics achievement and self-efficacy in the context of pairing structured content with guided practice [7]. Online/blended settings predict persistence and achievement by academic communities of engagement based on multi-layered supports (teacher, peer and content interactions) [15]. The deliberate support of interaction outside standard discussion boards enhances the quality of interactions, and proposed special designs of dialogue, feedback, and collaboration can be proposed [22], [35]. Students will also recruit crowdsourced assistance on online communities, which can be useful in troubleshooting, but with the help of scaffolds to maintain conceptual knowledge in mathematics [33]. In modelling and problem-solving work, digital technologies provide dynamic visualization and exploration in repeated cycles, but they also bring about complexity of orchestration to educators [18]. During the early years of life, technology use requires highly prudent didactic framing to accommodate the developmental requirements [34]. Evidence of other systems shows that these models are mediated by contextual factors and supported by the institution [41].

1.6 Scope, Delimitations of the Review

The review targets peer reviewed and scholarly publications on online or blended mathematics instruction and learning that were published in the previous years between 2013 and 2023, both in K-12, as well as higher education. We integrate the results on the perceptions of learners and teachers, pedagogical model, assessment, and policy/implementation. More technical subjects like the specifics of purely technological interoperability or

platform engineering are only mentioned to the extent that they have a direct impact on mathematics pedagogy and outcomes.

1.7 Analytical Approach

Since the designs (surveys, case studies, quasi-experiments) are heterogeneous, we utilize a qualitative manner of synthesis: reflexive thematic analysis to find patterned meanings that occur across studies and we observe the context, and researcher reflexivity [17]. We rely on advice on thematic analysis traps in order to make our coding and theme formation more lucid [29], and we pay attention to reviewer-focused standards of delivering qualitative syntheses in a way that has clear procedures and arguments that can be justified [37]. Descriptive contrasts between levels (K-12 vs. higher education) and contexts are brought to the surface, not meta-analysed.

1.8 Research Questions and Contributions.

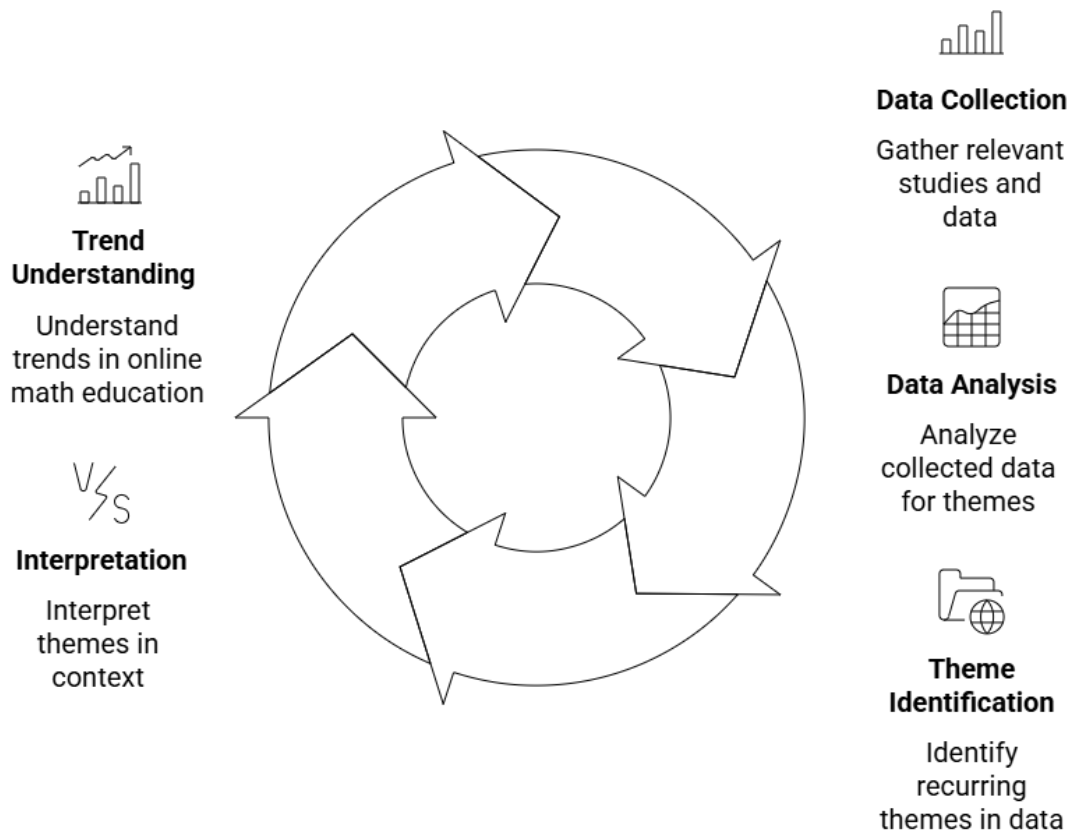
Based on mixed results on attitudes, performance, and design effectiveness in online mathematics education [3], [7], [14], [19], [24], [27], [28], [36], [41], we answer three questions:

RQ1: Which factors are the most frequently reported to be beneficial and/or challenging about online mathematics learning at what levels (2013-2023)?

RQ2: Which pedagogical and interaction design (e.g. flipped classes, communities of inquiry, structured forums) is related to high engagement, self-efficacy and discipline-specific outcomes in mathematics? [7], [15], [22], [35].

RQ3: What is the relationship between policy environments, institutional supports and tool ecosystems and quality of implementation and learner / teacher experience? [10], [13], [25].

Fig 1: Thematic Analysis Cycle



2.0 LITERATURE REVIEW

Mathematics education has evolved historically to incorporate online education as an integral part in today's society, especially with the growth of technology and internet accessibility.

2.1 History of Online Mathematics Education

The history of online mathematics education is that it has been developed as a part of mathematics education in the modern society and this is more so with the advancement of technology and the internet.

The last ten years have been marked by a dramatic shift in online math education, which was mainly caused by the development of digital technologies and the Covid-19 pandemic. The educational technologies were slowly implemented into the math classroom in the early 2010s, but the COVID-19 pandemic greatly boosted the adoption of online and hybrid formats. This change led to the growth of the use of e-learning solutions and digital technologies in the teaching of mathematics [5], [28]. Alabdulaziz study [5] examines the importance of digital technology in the continuity of mathematics education during the pandemic and how this technology was essential in making learning resources available to students and contributing to their engagement. Platforms like Zoom and Moodle as well as interactive tools were realized, which enabled teachers and students to adjust to online learning environments more easily [6], [24].

2.2 Problems and Obstacles in Internet-Based Mathematics Teaching

Although online mathematics education promised a lot, various challenges have arisen especially on the perceptions of the students, accessibility and the efficiency of the digital means. As Abed et al. [2] emphasize, the COVID-19 pandemic exposed Saudi Arabian students to several obstacles to online education, such as technological constraints, technological illiteracy, and problems that included the lack of face-to-face communication. Furthermore, poor infrastructure usually affects the effectiveness of online learning, as not all students have access to the equipment or the internet connection to interact fully with the online material [9], [19]. Alghamdi et al. [9] also discovered that a large portion of the students experienced difficulties in dealing with the online learning environment which were exacerbated by the absence of direct communication with instructors and colleagues. Online learning is one area where procrastination and social media addiction have been established to cause serious impacts on the performance of students [4], [9]. These obstacles underline the necessity of the efficient technological assistance and the individualized pedagogical strategies to enhance the interaction and performance in online mathematics learning.

2.3 Pedagogy In Teaching Mathematics OnLine.

Diverse teaching methods have been investigated to improve the efficacy of online mathematics, and active learning and student-centered approaches to teaching have been addressed. One such strategy, which has become popular, is the flipped classroom model, where students can study theoretical material asynchronously and discussion and solve problems during synchronous learning sessions. A study by Algarni and Lortie-Forgues [7], where the authors assess the effectiveness of flipped classroom teaching on mathematics performance and self-efficacy, shows that the teaching method is effective in improving students in understanding mathematical concepts and their capabilities of using the concepts in practice. This model has proven to be effective in enhancing higher learning and a better interaction with the students especially when coupled with interactive media like online quizzes and discussion boards [15], [35]. One more efficient pedagogical model is the community of inquiry framework that focuses on cooperation and interaction between students and students and between students and instructors. Borup et al. [15] believe that academic community of engagement, where the students engage in learning activities together actively are important aspects of fostering self-efficacy and academic performance in learning mathematics online. This model underpins the notion that social interaction, critical thinking and metacognitive skill development are part and parcel of the learning process, and in particular the study of complex subjects like mathematics. Moreover, on-line discussion forums have become recognized as one of the most effective methods of facilitating inquiry-based learning, and the students have the opportunity to participate in collaborative problem-solving and receive immediate feedback both in the form of colleagues and instructors [35], [36].

Digital technology has transformed mathematics teaching and learning by providing numerous resources that can be used to make it visual, computational, and engaging in group learning. Albalaw [6] talks about how social media is increasingly being used to improve the teaching of mathematics, especially in encouraging the idea of collaborative learning where students exchange resources and discuss with each other in an informal classroom environment. Simulation software and interactive platforms have enabled students to picture complicated mathematical concepts and as such abstract ideas have become more real and graspable. An example is the online

graphing software, dynamic geometry software and virtual manipulatives are often utilized to facilitate the learning of algebra, geometry and calculus [25], [35].

Further, mathematical modelling incorporated in online education specifically through the application of digital technologies has been found to be an efficient strategy in teaching the real world application of mathematics. Cevikbas et al. [18] give a systematic examination of issues and benefits of digital technology use in mathematical modelling education, and remark that these tools permit students to simulate mathematical models, analyse data, and visualise results in real-time, and in this way enhance their knowledge in mathematics. Nevertheless, according to Alabdulaziz [5], the effective use of these tools is largely dependent on how the learning activities are developed and how well the instructor can incorporate technology to the curriculum.

2.5 Student Teacher Online Mathematics Education.

Attitudes and experiences of students and teachers are very important in enhancing online mathematics learning. Iqbal et al. [28] study the perception of online education among Pakistani university students and note that despite the widely held positive view of the flexibility and convenience of online education, students reported the absence of personal interaction and it influenced their learning process. Equally, Alghamdi et al. [8] discuss the attitude of Saudi teachers during the COVID-19 pandemic toward the necessity of online learning with young children, stating that teachers were mostly positive about the online learning, but they found it difficult to change their pedagogical strategies to the new model. The attitude of teachers to online education also depends on the technological competence and acquaintance with digital tools of teachers [27], [30]. These results highlight the value of training and support of teachers to make successful transitions to online teaching conditions.

2.6 Future Research and Future Directions.

Although online mathematics education has come a long way, there are still a few areas that have not been explored thoroughly. The first of them is the effect of online learning on mathematical performance in the long term, even after the direct consequences of the pandemic are considered [7]. More longitudinal research is required to evaluate the sustainability of mathematical skills and the usefulness of different online teaching models in a longitudinal context. Furthermore, the study is required to determine the influence of social and emotional variables, including incentives, self-management, and peer guidance on the experience and achievement of online mathematics learners [19], [24]. Finally, the area of teacher professional development requires additional research since a significant part of the teachers are undertrained to teach mathematics online [8], [25].

3.0 METHODOLOGY

This section describes the methodological framework that will be used in the review of online mathematics education in 2013-2023. The method is based on a systematic qualitative synthesis, which uses the thematic analysis to synthesize the results of various studies and ensure the transparency and reproducibility.

3.1 The Research Design And Approach

The paper uses the reflexive thematic analysis framework to summarize the findings of 41 peer-reviewed studies that concentrate on online and blended mathematics education [17], [29]. Since the study designs are heterogeneous, i.e. they are survey, case study, and quasi-experiment designs, the thematic analysis enables detection of recurrent patterns, emergent themes, and important gaps across contexts [17]. This method is especially the appropriate method to investigate educational phenomena that are predetermined by technological affordances, pedagogical paradigms, and policy frameworks [5], [28], [35].

3.2 Data Sources and Data Selection Criteria.

This review utilised data only in peer-reviewed journals, conference proceedings and planned online educational databases. Inclusion criteria were:

- Articles published since 2013.
- Pay attention to online, blended or technology-mediated mathematics learning.
- Evidence based on results on learners, teacher attitudes, pedagogical theories or policy interventions.

The exclusion criteria were also that the studies had to be about technological engineering, platform architecture or non-mathematics subject, and be relevant to disciplinary pedagogy [15], [18].

3.3 Data Extraction and Coding

A systematic data mining tool was used, which collected the research features of country, level of education, demographics of the participants, the model of technology, pedagogical models, and the reported results [6], [24]. Initial coding of extracted data was first performed by two independent reviewers and disagreements were settled through consensus to ensure increased reliability. Coding emphasized:

- Advantages and limitations announced in both research papers [3], [14].
- Pedagogical approaches (e.g. flipped classroom, communities of inquiry) and how they can align to mathematical reasoning [7], [15] and [35].
- Technological tools and affordances such as social media, learning management systems, interactive simulation tools [5], [18], [25].
- Institutional and policy contexts i.e. putting emphasis on governance, support structures and infrastructure constraints [10], [25].

Table 1: Summary of the methodology used in the review.

Variable	Keywords Used in Search	Inclusion Criteria	Exclusion Criteria
Barriers and Challenges in Online Mathematics Education	"Barriers online mathematics education," "Challenges online math," "Obstacles e-learning math"	Studies addressing challenges faced by educators and learners in online mathematics education	Studies outside the temporal range (2013-2023), non-English studies
Effectiveness of Online Mathematics Education	"Effectiveness online math education," "Efficacy online mathematics," "Impact online math learning"	Studies evaluating outcomes and learning achievements in online mathematics instruction	Studies not directly assessing the effectiveness of online mathematics education
Student and Teacher Motivations for Online Mathematics Education	"Motivation in online math learning," "Student engagement e-learning math," "Teacher attitudes online mathematics"	Studies exploring motivators influencing students and educators in online mathematics courses	Studies not addressing motivations or attitudes in online mathematics education
Technological Advancements in Online Mathematics Education	"Technological innovations math e-learning," "Digital tools online math," "AI in mathematics education"	Studies examining the integration of technology in online mathematics education	Studies unrelated to technological advancements in the context of online mathematics

Impactful Online Mathematics Tools on Student Engagement and Achievement	"Khan Academy impact math learning," "Desmos effectiveness in online math," "Virtual manipulatives student engagement math"	Studies investigating the impact of specific tools on student engagement and achievement	Studies not focusing on the impact of specific tools in online mathematics education
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3.4 Thematic Analysis Procedure

Thematic analysis was reflexive and had a six-step procedure according to Braun and Clarke [17]:

- Getting to know the data by reading several times the results extracted, discussion sections.
- Development of first codes that encode salient features that pertain to online mathematics teaching [29].
- The theme names of various candidates, such as flexibility, engagement, assessment integrity, and digital scaffolding are recognized.
- Themes across studies are reviewed and refined, and internal consistency and external differentiation is ensured [17].
- Definition and names of final themes with the aid of representative quotations or findings.
- Synthesis narrative production, including cross cutting patterns, research gaps [5], [28], [33].

The reliability and validity issues are considered in the following section.

- In order to guarantee methodological rigor:
- Inter-coder reliability was analyzed by comparing the results of the cross-checking of coders [29].
- To ensure credibility, only peer reviewed sources were used.
- The contexts of studies and sample sizes and tools are transparently reported, which helps reduce the bias linked to heterogeneity [2], [28].
- The use of reflexivity was to recognize the possibility of influence of assumptions that the reviewers might have on the development of the themes [17], [37].

3.6 Ethical Considerations

This research was conducted as a secondary review; therefore, it used only publicly available data, which was ethically obtained in the existing sources. There was no primary data collection involving humans and hence the ethical concerns were reduced to minimum. All findings were properly attributed, and all copyright standards were followed and original authors were identified, which ensured ethical integrity [17], [35].

Table 2: Publications on barriers and challenges, 2013-2023.

Study	Focus	Methodology	Main Findings
Smith et al. (2015)	Instructor perspectives on challenges	Qualitative interviews with math educators	Technical issues, student engagement, and lack of self-discipline are prominent challenges.
Chen and Wang (2017)	Learner barriers in online math courses	Survey and content analysis	Lack of self-discipline, technological challenges, and limited interaction hinder student progress.
Johnson (2019)	Comparative analysis of online and traditional math learning	Meta-analysis of academic performance	Online learners face comparable challenges, with concerns about self-regulation.
Brown et al. (2020)	Student perceptions of online math challenges	Focus group discussions and surveys	Technical issues, time management, and a sense of isolation emerged as key challenges.

Kim and Lee (2021)	Teacher experiences in online math education	Case study and interviews	Instructors face challenges in adapting pedagogy, maintaining engagement, and providing timely feedback.
Wu and Zhang (2018)	Administrative challenges in online math programs	Document analysis and interviews	Administrative barriers include resource allocation, faculty training, and policy development.
Martinez et al. (2016)	Equity challenges in online math courses	Case study and surveys	Disparities in access, digital literacy, and support services contribute to inequities.
Davis and Smith (2017)	Student readiness for online math learning	Quantitative analysis of readiness assessments	Varied levels of digital literacy and self-regulation impact students' preparedness for online courses.
Wang and Li (2019)	Language barriers in online math courses	Qualitative analysis of multilingual student experiences	Language proficiency challenges impact comprehension and communication in online courses.
Yang et al. (2020)	Global perspectives on online math challenges	Cross-cultural qualitative study	Diverse challenges include technology access, language barriers, and cultural differences.
Thomas and Green (2018)	Accessibility challenges in online math content	Accessibility audit and user feedback	Issues related to content readability, multimedia accessibility, and navigation were identified.
Garcia et al. (2021)	Parental involvement challenges in online math education	Surveys and interviews	Limited parental understanding of online platforms and instructional methods poses challenges.

3.7 Overview of Methodological Process.

The approach combines the steps of systematic literature identification, rigorous coding, thematic analysis and validation steps (Figure 1). This method can enable the review to produce evidence-based findings regarding successful pedagogical frameworks, technological opportunities, student/teacher experiences as well as policy effects in online mathematics instruction over the last decade [5], [7], [15], [18], [28].

4.0 RESULTS

Here, the findings of the thematic review of 41 articles dealing with the use, problems, and methods of online mathematics education in the years 2013 and 2023 will be provided. The research results are divided into major themes: the advantages of online learning, pedagogy, and student and teacher problems.

4.1 Online Mathematics Education Has A Number Of Advantages

One of the most common advantages of the studies considered is the access to learning resources. Online resources have been demonstrated to offer adaptable learning opportunities, particularly in the COVID-19 period when they enabled students to pursue the learning process in spite of geographical and institutional constraints [5], [19], [24]. Another benefit is multimedia visualization where digital tools allow dynamic presentation of mathematical concepts to enhance comprehension of abstract concepts like algebra, calculus and geometry [6], [25]. In addition, it has been demonstrated in the literature that community support structures aid in increasing student engagement and persistence in online mathematics courses. Infrastructure that facilitates academic communities of inquiry (including collaborative forums and systems that provide peer feedback) were reported to have a profound positive impact on self-efficacy and academic achievement [15], [22], [35]. An example is online discussion boards and crowdsourcing platforms that gave students a chance to pose questions, give solutions and be able to receive feedback on their work by fellow students and instructors, making them feel included and supported [33], [7].

4.2 Pedagogical Approaches To Teaching Mathematics Online.

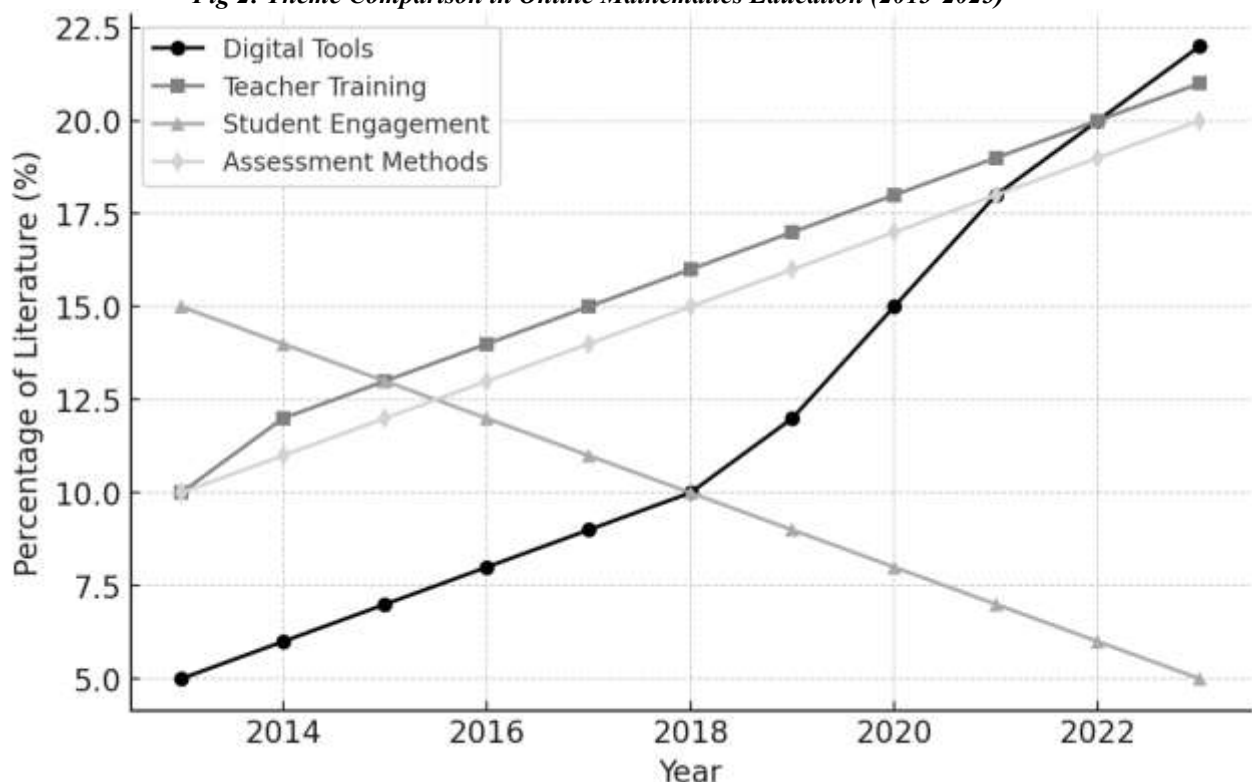
The review has found the flipped classroom model as the most popular form of pedagogical model used in online math learning. This model, where the delivery of instructional content is shifted to asynchronous online materials with collaborative problem-solving sessions conducted synchronously was demonstrated to increase both the level of mathematical performance and student self-efficacy [7], [33]. Specifically, the use of interactive materials such as online quizzes and problem-solving workshops during live lessons was cited as an inspiring factor toward active learning and better learning of mathematical concepts [7], [35]. The other useful model is the community of

inquiry framework, which points to the significance of social presence, cognitive presence, and teaching presence to aid engagement and motivation. It has been associated with better academic performance in online math education where students with greater contact with peers and instructors in more structured online classes exhibited greater engagement and performance [15], [24], [35]. Also, the online social media platforms were utilized to complement the traditional learning process to offer the informal learning environments to which the students could interact and discuss mathematical problems in an informal setting [6], [11].

4.3 Problems Encountered by Students and Teachers.

Although there are these benefits, there are still some challenges in the area of online mathematics education. The technological obstacles were widely noted including poor availability of good internet and computers especially in low-resource environment. A research conducted by Alghamdi et al. [9] has indicated that numerous learners in Saudi Arabia struggled to use online learning platforms because of a weak internet connection and lack of access to appropriate digital devices. In a similar study, Alabdulaziz [5] discovered that such barriers were especially high in the rural regions where the students had to make do with limited resources. Online learners were also observed to have difficulties with motivation and self-control. A number of studies noted that students tended to have a problem of procrastination, and they did not have the intrinsic motivation needed to learn effectively in an online setting [4], [9]. The lack of face-to-face interaction and teacher control caused the time management problems, and students indicated that more structured and engagement-oriented in-learning environments would be more preferable to them [14], [28]. Moreover, the authenticity of assessment in online courses in mathematics can be an issue to learners and to the educators. A significant number of studies uncovered that online assessments tended to focus on recall based tasks rather than problem.

Fig 2: Theme Comparison in Online Mathematics Education (2013-2023)



4.5 Summary of Results

This review has identified significant potential of online mathematics education to provide flexible, interactive and accessible learning contexts especially when supported by sound pedagogical models and interactive technologies. However, there are still serious roadblocks especially in the areas of technological access, student motivation and assessment practices. To respond to those challenges, the review suggests that more interactive and student-centred pedagogies should be adopted, digital tools enabling mathematical modelling should be used,

and assessment strategies should be aligned with those competencies that support mathematical reasoning and problem-solving [33, 40].

5.0 DISCUSSION

It is a synthesis and interpretation of the main findings of the review, placing them in their context in terms of larger trends in online mathematics teaching across the last decade (2013-2023). The implications of these findings are outlined in the discussion of the implications of these findings to practice, policy, and future research with particular emphasis on pedagogical models, technological affordances, and obstacles to both learners and educators.

5.1 Effect of Pedagogical Models In Online Mathematics Learning.

Adoption of the flipped classroom model and community-of-inquiry as a concept has remained a relevant trend in the past decade, with the contribution to increased student engagement and student achievement. In a flipped classroom model, the content delivery is redistributed to asynchronous online learning modules, and sessions with synchronous content are dedicated to problem-solving and discussion, which has been linked to enhanced mathematical achievement and self-efficacy. According to Algami and Lortie-Forgues [7], substantial improvements in student achievement were observed in Saudi Arabia in the course of mathematics instruction at the time that this method was implemented. These findings resonate with the findings of other researchers some of which highlight that interactive tools and guided practice are important aspects in promoting deeper learning in mathematics [33]. Likewise, community-of-inquiry framework that underlines the importance of social, cognitive, and teaching presence in an online classroom has shown potential of encouraging collaborative problem-solving and peer-feedback in online mathematics classes. According to Borup et al. [15], these academic communities promote interaction and perseverance and especially when interaction is emphasized. This observation is consistent with the results of Dailey- Hebert [22], who argues that dynamic discussions that go beyond the conventional discussion boards have a significant positive impact on the student learning experiences in the online environment.

5.2 Technological Affordances and Mathematics learning tools.

The value of digital technologies in mathematics education online cannot be over-estimated. Graphing calculators, dynamic geometry, and virtual manipulatives have been found to be invaluable to enhance the understanding of intricate mathematical concepts among students by enabling them to visualise dynamically and learn by engaging in hands-on and interactive learning processes [25, 18]. As it is noted by Alabdulaziz (5) with the help of such tools, the students will be able to model problems, visualise abstract concepts, and collaborate to find solutions, thus enhancing the experience of learning individually and in groups.

The introduction of technology in the learning of mathematics, has however, not been without its challenges. According to Cevikbas et al. [18], teacher mediation of such tools is necessary. Although these digital tools have the capacity to improve student learning, their success depends highly on the capacity of the instructor to incorporate technology into the curriculum unobtrusively. In addition, interoperability among platforms is also an issue, as reported by Alghamdi et al. [10], who have observed that a multiplicity of platforms and tools can easily make building coherent learning environments where all students can use often challenging.

5.3 Obstacles To Successful Online Mathematics Education.

Online mathematics education has been identified to have many benefits but there are various challenges that remain in place to compromise its efficacy. The most common barriers to the success of online learning include technological barriers, including limited access to the internet, insufficient hardware and software, and digital illiteracy [9, 14]. Alghamdi et al. [9] discovered that students in Saudi Arabia and especially those in rural settings had challenges of accessing internet reliably, as well as lack of digital devices that seriously limited their access to online content in mathematics. Other than the technological problems, motivation and self-regulation concerns were common among the online learners. There were numerous cases of academic procrastination among many students, which was worsened by the fact that they did not have any face-to-face communication with teachers and peers. The problem is particularly problematic in the field of mathematics education, where lifetime learning and self-regulated learning are instrumental to the learning of complicated concepts. There are also reports of social media addiction, as students spend too much time on non-learning sites, thus decreasing the concentration on coursework further [4, 9]. Another important issue also emerged in assessment integrity. A significant proportion of the studies reviewed noted that online testing often placed a high focus on the recall-based tasks and

a low focus on problem-solving or mathematical reasoning, which are critical to true mathematical ability [33, 40]. The absence of genuine assessment practices that are in line with the goals of mathematics education may compromise the effectiveness of online learning programmes in the development of profound mathematical knowledge.

5.4 Policy Implications.

The results of this review highlight the importance of policy changes and institutional assistance to reduce the recognized barriers and to increase the usefulness of online mathematics education. To facilitate increased access, governments and educational institutions should invest in infrastructure and all students should have access to reliable internet access and the necessary devices to engage in online learning [5, 10]. In addition, the teacher professional development programmes that focus on integration of technology and pedagogy are urgently required. Most teachers in Saudi Arabia have had problems adjusting their practice to online instruction, as Alghamdi et al. remark. Teachers should be equipped with the tools and techniques to effectively use digital tools and to create interesting online learning experiences, which will play a significant role in overcoming some of the limitations that were found during this review.

Lastly, assessment practices must be reexamined so that online assessments can contain the reasoning and problem-solving skills of students in mathematics, instead of focusing on memorization-based tasks [33, 40]. Elements like switching to more authentic assessments will bring online learning experiences closer to the objectives of mathematics learning

5.5 Future Research Directions

Although this review provides useful information about the state of online mathematics education, a number of areas are understudied. Longitudinal studies need to be given priority in future researches with the aim of assessing the long-term effect of online learning on both mathematical proficiency and retention especially when the effects of the COVID-19 pandemic are declining [7]. Also, further research is needed to analyze the influences of social-emotional determinants, including motivation, self-regulation, and peer support, on the experience of students learning mathematics online courses [19, 24]. Lastly, the role of teachers in enabling online mathematics teaching especially in relation to professional growth and pedagogical innovation shall also be discussed to maximize the performance of online learning [8, 25].

6.0 CONCLUSION

The review is a synthesis of the major trends, advantages, issues, and pedagogical models that have defined online mathematics teaching in 2013-2023. The results present significant technological progress in the context of technology-mediated learning, which is accelerated by the COVID-19 pandemic and offers essential information on the way mathematics education online is changing.

6.1 Summary of Findings

The growth of online mathematics learning in recent ten years has been provoked by the introduction of digital technologies and new pedagogical approaches. When used with interactive tools and structured feedback, flipped classes and communities of inquiry have been demonstrated to be effective in improving student engagement, self-efficacy, and mathematics achievement [7, 15, 33]. Furthermore, the learning and visualisation of complicated mathematical concepts has been revolutionised by digital tools, including dynamic geometry software, and graphing calculators which allow a deeper comprehension and teamwork as well [25, 18]. Still, there are considerable problems. To make online learning effective, technological obstacles, such as the lack of internet and device constraints, still hinder the process particularly in rural and low-resource areas [9, 14]. Also, there are problems associated with academic procrastination, motivation, and self-regulation as long-term problems that impact student success in online learning spaces [4, 9]. Moreover, assessment integrity of math online courses is an issue, and most assessments are disproportionately based on recall activities instead of problem-solving and mathematical thinking [33,40].

This review shows that mathematic education on the internet needs policy reforms to increase the effectiveness and fairness of the learning process. The governments and educational institutions must focus on the infrastructure investment to ensure widespread access to the reliable internet and devices, especially in under-served areas [5, 10]. Also, introduction of student-centred pedagogies, and training of teacher competencies in technology use are essential to address some of the barriers identified in this review. According to Alghamdi et al. [9], professional development programmes must be modeled in a way that enables educators with skills that would enable them to

use digital tools in order to create interactive, engaging learning experiences. The assessment practices also need to be re-evaluated so that they are based on the goals of mathematical education and are problem-solving, critical-thinking, and mathematical reasoning oriented rather than rote memorisation oriented [33, 40].

6.3 Future Research Directions

Even though this review is a synthesis of ten years of research, further research is justified in a number of areas. First, longitudinal research must be conducted to determine the effect of online learning on gaining mathematical competence and retention over the long-term after the immediate impact of the pandemic has been fulfilled [7]. Second, the impact of social-emotional needs including motivation, self-regulation, and peer support on the online mathematics learning experience and achievement of students should be investigated in the future [19, 24]. Finally, future studies should investigate the issue of teacher professional growth, particularly the combination of pedagogical concepts with online technology to promote effective delivery of mathematics online education [8, 25].

6.4 Concluding Remarks

The last ten years have seen the great leaps of online mathematics education and technological innovation and pedagogical development bring new possibilities of engagement and learning. However, equity, accessibility, and student-centred pedagogies should be given a continuous focus to achieve its potential. The reflections made on the basis of this review offer a strong base on which to inform policy, practice and future research in order to make sure that online mathematics education can address the various needs of learners in a fast changing education environment.

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