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Recommendations Based on Experiences of Pandemic-Led Remote Mathematics Teaching in Pre-K–12 Contexts: A Systematic Review From the Activity Theory Perspective

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ABSTRACT

Background: In the aftermath of the COVID-19 pandemic, it is critical to reflect holistically on the experiences gained in the past few years. We thus review research on remote mathematics teaching in Pre-K–12 contexts, utilising Activity Theory as a theoretical lens for research synthesis.

Objectives: Drawing from a comprehensive overview of the activity system, we aim to identify needs requiring follow-up action and make recommendations to enhance post-pandemic Pre-K–12 mathematics education.

Methods: We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 statement to search for relevant empirical studies published between January 2020 and December 2023 in the Scopus and Web of Science databases. Content analysis of these studies ($n = 180$) yielded relevant information pertinent to each constituent of activity theory: subjects (e.g., teachers; students with special education needs), tools (e.g., mathematics applications; online educational resources), objects and outcomes (e.g., decreased students' mathematics achievement; applications of fully online instructional approaches), community and division of labour (e.g., support from caregivers), and rules (e.g., remote assessment methods).

Results and Conclusions: It is now a priority to provide remedial programmes, which help students catch up with their learning. We also recommend utilising technology-enhanced instructional approaches on normal school days to equip both teachers and students for an increasingly digital world. This review contributes to our understanding of pandemic-led remote mathematics teaching and the future action needed to advance the Pre-K–12 mathematics education sector.

1 | Introduction

In a 2015 TED Talk, Bill Gates famously warned, 'The next outbreak? We're not ready' (TED 2015). Five years later, the world faced a global pandemic that indeed caught education systems unprepared. The COVID-19 pandemic, which interrupted campus operations in the past few years, has been declared to end (World Health Organization 2023). The transition to emergency remote teaching brought unique challenges as well as opportunities in Pre-K–12 mathematics education (Callaghan et al. 2023; Taylor et al. 2024). In the wake of this disruption, one pressing question remains: how can we better prepare for future crises? Understanding the impact of remote mathematics teaching during the pandemic is crucial because it highlights areas needing improvement, strengthens school systems to become more resilient and crisis-ready (Foster et al. 2022), and ensures that

Summary

- What is already known about this topic
  - The outbreak of COVID-19 led to widespread school closures, forcing teaching and learning activities to shift online.
  - The abrupt shift to remote mathematics teaching posed challenges for both teachers and students.
- What this paper adds
  - This paper provides a comprehensive perspective on the activity system of pandemic-led remote mathematics teaching in Pre-K–12 contexts.
  - It puts forth actionable recommendations aimed at enhancing Pre-K–12 mathematics education in the post-pandemic world.
- Implications for practice and/or policy
  - Teachers should aid students to make up for any pandemic-led learning loss.
  - Teacher educators should strengthen training related to remote mathematics teaching to prepare crisis-ready teachers.
  - School leaders and policymakers should involve all stakeholders in establishing robust guidelines and contingency plans for future emergencies.

students receive high-quality education regardless of the learning environment in the post-pandemic world (UNESCO 2020).

Studies have captured the immediate effects of this transition, revealing both challenges and opportunities at various levels, from individual classrooms (e.g., Capone et al. 2022; Cortez et al. 2023; Faggiano and Mennuni 2020) to particular regions (e.g., Battisti and Maggio 2023; Drijvers et al. 2021; Goldhaber et al. 2023). For example, some teachers faced significant difficulties in adapting face-to-face mathematics teaching activities to a fully online environment (Cao et al. 2021). Conversely, the pandemic may have driven teachers' instructional improvement, such as greater teacher confidence in using digital technologies (Drijvers et al. 2021), which can be leveraged to enhance teaching practices moving forward. While many of the unique constraints of the pandemic era may no longer exist, the experiences gained in the past few years remain valuable. They can provide momentum for and evidence-based insights into advancing both mathematics teaching and teacher education.

Systematic reviews have summarised the experiences gained in emergency remote teaching, uncovering the need for professional development and equipment associated with synchronous and asynchronous technology (Bond 2021). In addition, reviews have focused on specific areas, such as massive open online courses (MOOC; AlQaidoom and Shah 2020), fully online flipped learning (Lo 2024; Linling and Abdullah 2023), e-learning and mobile learning to sustain home-based instructional activities (Naciri et al. 2021; Saikat et al. 2021) and online assessment techniques (Montenegro-Rueda et al. 2021). While these reviews offered useful insights, they lacked a specific focus on mathematics education to inform the advancement of mathematics teaching in the post-pandemic world. Moreover, the majority of these reviews were based on empirical studies conducted at the course or institutional level, potentially limiting their ability to provide a comprehensive understanding of how entire education systems could evolve in response to the pandemic's impact.

To address these gaps, we employ Activity Theory (Engeström 1987) as a lens to synthesise relevant empirical studies. Our theoretical foundation is informed by the systematic review conducted by Tlili et al. (2020), who utilised Activity Theory to perform a content analysis of articles related to robot-assisted special education. Their work ultimately resulted in valuable recommendations for each constituent of Activity Theory, guiding the future design and implementation of robot-assisted interventions in special education. By adopting a similar approach, this review provides a holistic view of the activity system of remote mathematics teaching in Pre-K–12 contexts during the pandemic, offering a comprehensive perspective that can inform future educational practices and policies in mathematics education. The following research questions (RQ1 and RQ2) are posed to guide the review.

- RQ1: How does Activity Theory illustrate remote mathematics teaching in Pre-K–12 contexts during the pandemic?
- RQ2: What recommendations can be made for enhancing Pre-K–12 mathematics teaching and teacher education in the post-pandemic world?

2 | Theoretical Background

The theoretical background for this review is developed in two stages. First, we draw on the Activity Theory perspective and elaborate on this theory using recent empirical research. With this theoretical perspective, we summarise the general ideas for public action in post-pandemic education, as proposed by the United Nations Educational, Scientific and Cultural Organisation (UNESCO 2020). These ideas can serve as references for specific recommendations for advancing future mathematics education.

2.1 | Activity Theory Perspective

As shown in Figure 1, the third-generation Activity Theory comprises seven constituents (Engeström 1987). This theory enables researchers to investigate activities within a holistic social

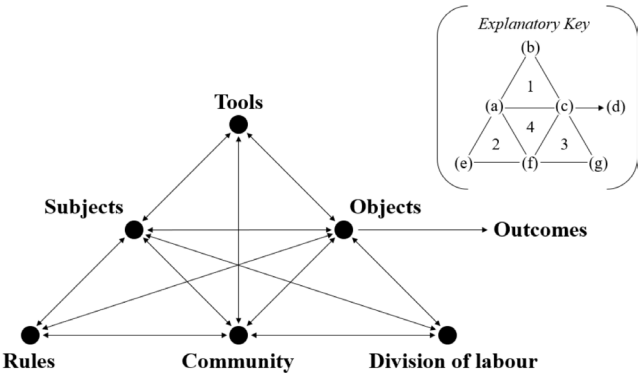

FIGURE 1 | Activity Theory framework with explanatory key.

setting (i.e., the activity system) and the mediating role of artefacts (Engeström 1999; Nardi 1996). Therefore, it has been used in other reviews of technology-enhanced learning research (e.g., Lin et al. 2020; Zhang and Zou 2023). The theoretical foundation of Activity Theory stems from Vygotsky's (1978) mediated action model (Triangle 1; Figure 1), which includes all action by (a) *subjects* (activity participants) using (b) *tools* (the artefacts that mediate activities) to achieve (c) *objects* (the purpose of activities) and (d) desired *outcomes*. For example, teachers (subjects) used video conferencing platforms (e.g., Zoom; tools) to conduct synchronous online lectures (objects) during the lockdown period (Drijvers et al. 2021). Effective student learning (outcomes) could thus be achieved to a certain extent (Panagouli et al. 2021).

Prior to the pandemic, some researchers, such as Kundu et al. (2023) and Lo and Hew (2020), implemented fully online instructional activities. Instructional materials, such as video lectures and online quizzes, were specifically created for the online environment and accessed asynchronously by students (Kundu et al. 2023; Lo and Hew 2020). While online discussions could take place in forums, they were often not conducted in real time, leading to many posts remaining unanswered (Chen et al. 2020). However, during the pandemic, the use of video conferencing platforms and specialised mathematics applications (e.g., GeoGebra and Desmos) became widespread. Teachers could use digital whiteboards and interactive simulations to explain mathematics concepts. Real-time discussion and student collaboration were facilitated through breakout rooms on video conferencing platforms, simulating classroom interactions.

Engeström (1987) extended Vygotsky's (1978) model (Triangle 1; Figure 1) by considering other contextual mediating constituents: (e) *rules* (the expectations that dictate how activities are conducted), (f) *community* (the people involved in the activity system) and (g) *division of labour* (the roles or distribution of responsibility among people). Blayone (2019) discussed how the mediating constituents interact with each other to form other three subsystems of mediation (Triangles 2 to 4; Figure 1). Through the lens of Activity Theory, Gedera et al. (2023) analysed over 900 students' pandemic-related challenges in New Zealand. In Triangle 2, without rules established by educators (community), most students (subjects) struggled with maintaining a study routine at home. In Triangle 3, Gedera et al. (2023) noted that some students (subjects) found online group work (division of labour) challenging because of disengaged and unresponsive peers (community). In Triangle 4, the researchers thus recommended that institutions (community) should establish support systems and communicate to students (subjects) how and where they can access support (objects).

2.2 | UNESCO's Ideas for Public Action in the Post-Pandemic World

In the aftermath of the COVID-19 crisis, UNESCO (2020) proposed nine general ideas for public action to reshape education. We outline and categorise these ideas using the Activity Theory perspective. Beginning with the subjects in the activity system, UNESCO (2020) stressed the responsibilities of everyone in the education system, from government officials to teachers and parents, to empower students and advocate for their active participation and engagement in learning opportunities (Idea 4). The tools, which play a vital mediating role in realising the purposes of education, are addressed in three of UNESCO's (2020) ideas. The call to ensure students' right to education and access to knowledge and information highlights the essential role of digital connectivity and online platforms (Idea 2). Supporting the use of free and open-source technologies (Idea 6) and ensuring scientific literacy within the curriculum (Idea 7) are also crucial for promoting accessibility and critical thinking in education.

The UNESCO's (2020) ideas can further illustrate the bidirectional influence between the constituents in the activity system (see Figure 1). For example, there is a bidirectional influence between rules and tools through the constituent of subjects within UNESCO's Idea 6 'Make free and open source technologies available to teachers and students.' Specifically, the school policy (rules) mandates the use of these technologies (tools) in classrooms to ensure equitable access to educational resources for all students. The tools in this scenario include open educational resources (OER) and open source applications, such as GeoGebra. The school policy (rules) requiring the use of these tools directly influences how teachers and students (subjects) design and engage with teaching and learning activities, respectively. For example, mathematics teachers might use GeoGebra to introduce topics about shape and space, aligning with their school policy of e-learning (Lo et al. 2022). Conversely, if teachers find that certain tools enhance student engagement and learning outcomes, they may provide feedback to their school leaders. This feedback can lead to adjustments in the school policy (rules). For example, Werth and his colleagues (Werth et al. 2020; Williams and Werth 2021) shared that the school leadership at their university decided to move all courses to free materials based on feedback from campus constituents in response to the pandemic. Taking institution-wide action, such a conversion could be done within 6 months, and their students expressed a strong desire for the continuation of this pandemic-led initiative (Williams and Werth 2021). As the researchers concluded, by centring the institutional effort (rules), meaningful change (the use of tools by subjects) to ensure equitable quality education is possible.

Regarding the objects and desired outcomes of the activity system, UNESCO (2020) emphasised the protection of interactive learning spaces provided by schools (Idea 5) and the commitment to strengthen education as a common good (Idea 1). The rules that govern the activity system are highlighted in the protection of domestic and international financing of public education (Idea 8). Finally, the community and division of labour are addressed by valuing the teaching profession and promoting teacher collaboration (Idea 3) and by advancing global solidarity to ensure equity in education (Idea 9). These ideas stress the importance of collaboration among educators and international cooperation for creating equitable education systems.

3 | Methods

3.1 | Search Strategies

Considering quality concerns regarding pandemic-related studies (Khatter et al. 2021), we searched for peer-reviewed papers included in the Scopus and Web of Science databases. Using

these two databases increased our likelihood of identifying high-quality articles while avoiding the omission of relevant studies in mathematics education (Nivens and Otten 2017; Williams and Leatham 2017). Most importantly, these databases provided us with a substantial number of relevant articles ($n = 180$) for a synthesis. When selecting relevant articles, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 statement (Page et al. 2021). The search string, including the relevant keywords and Boolean operators, was as follows: (covid-19 OR pandemic OR epidemic) AND (student* or learner*) AND (online OR remote OR distance) AND (math* OR algebra OR trigonometry OR geometry OR calculus OR statistics). The asterisks denote wildcards, which increased the flexibility of our search string.

3.2 | Inclusion and Exclusion Criteria

Empirical studies published between January 2020 and December 2023 (i.e., the first 4 years since the COVID-19 outbreak) were reviewed, including advance online publications. To be included in this review, studies had to report on topics related to students' learning via remote mathematics teaching in Pre-K–12 contexts during the pandemic. No constraints were imposed on the sources of empirical data (i.e., any quantitative or qualitative data), but non-empirical studies were excluded. No constraints were imposed on the language of instruction, content areas, education contexts or study locations. However, the manuscripts had to be written in English.

3.3 | Quality Appraisal

In addition to the inclusion and exclusion criteria, we utilised the mixed methods appraisal tool (MMAT) developed by Hong et al. (2018, 2019) to guide our decisions regarding the inclusion of primary studies in this review. Similar to the review conducted by Li et al. (2024), we selected MMAT for its flexibility in assessing qualitative, quantitative and mixed-methods studies. MMAT consists of two screening questions focused on the clarity of research questions/objectives and data collection, along with five sections (i.e., qualitative, quantitative randomised controlled trials, quantitative non-randomised, quantitative descriptive and mixed methods). Each section contains five criteria which are rated as 'Yes', 'No' or 'Can't tell'. Following the standard adopted by Li et al. (2024), included studies were required to meet both screening questions and achieve at least two 'Yes' ratings out of the five criteria. In other words, studies that did not satisfy the two screening questions or received fewer than two 'Yes' ratings (i.e., 0 or 1) were excluded from the review.

3.4 | Data Extraction and Analysis

To code and analyse data, we aligned our approach with the research synthesis conducted by Tlili et al. (2020). The researchers conducted a content analysis on primary studies in robot-assisted special education. Adopting Activity Theory as their analytical framework, they mapped relevant information reported in their primary studies to the constituents of Activity Theory. This process ultimately led to valuable recommendations for improving robot-assisted special education within each constituent of the theory. Similar to Tlili et al. (2020), we used Activity Theory as a foundational starting point while remaining open to emerging themes and insights. While the initial coding focused on grouping, it served as a foundational step that contributed to a deeper understanding of the broader activity system. The overarching objective of this approach is to identify broader needs and provide actionable recommendations for enhancing post-pandemic Pre-K–12 mathematics education. A content analysis of the included articles was conducted according to the protocol adapted from Activity Theory (Engeström 1987; Figure 1). We contextualised the seven constituents based on Lin et al. (2020) to make the framework relevant to our research synthesis (Table 1).

Following Creswell's (2012) approach, codes were assigned to pieces of data. To establish coding reliability, the first 50 articles (27.8%) were independently coded by the first and third authors. The double-coding between the two authors yielded excellent inter-coder reliability, as evidenced by Cohen's Kappa of 0.88 (Nili et al. 2020). Any discrepancies regarding the data extracted and coded were reviewed, discussed and resolved until perfect agreement was achieved in the coding results. After the coding of the first 50 articles, all the codes assigned were reviewed and grouped by similarity to reduce redundancy. The outcomes of the double-coding for these articles are available in Supporting Information. The research team then convened to discuss preliminary findings, as well as the themes and recommendations outlined by the first author. After addressing questions and concerns during the discussion, the first author coded the remaining articles and the third author checked the coding. Although new codes were added to enrich the preliminary analyses, no new themes emerged after coding the first 50 articles. Nevertheless, multiple reviews and discussions among the research team were

TABLE 1 | Description of the constituents adapted for this review based on Lin et al. (2020).

Constituent	Description
Subjects	The research participants, including their education context and location.
Tools	The tools that supported remote mathematics teaching.
Objects and outcomes	The objectives of the studies, research methods to achieve the objectives and findings or research outcomes associated with the objectives.
Rules	The rules, regulations, guidelines and norms associated with remote mathematics teaching.
Community	The social circles involved in the studies.
Division of labour	The process whereby the roles and actions in the activity system were distributed among the members of the community.

conducted to ensure coding consistency. After coding all emerging instances and achieving data saturation, the research team analysed the relationships among codes, grouping them into themes through axial coding (Creswell 2012). This process ultimately provided a comprehensive understanding of the activity system underlying remote mathematics teaching in Pre-K–12 contexts during the pandemic, along with recommendations for enhancing post-pandemic Pre-K–12 mathematics education (see Section 4).

3.5 | Search Outcomes and Study Selection

Through the database search, a total of 2353 outcomes were retrieved on 11 September 2024 (the date of the final search conducted in response to reviewers' comments). We identified 1262 and 1091 from Scopus and Web of Science, respectively (please see Supporting Information for verification). It is important to note that both Scopus and Web of Science continuously update their databases by adding and removing articles, as well as modifying their journal lists. For example, Valz Gris et al. (2024) explained that Delisting of a journal from a scientific database such as Scopus and Web of Science refers to the removal of the journal from the database's index (265). In addition, factors such as previously missed or mislabelled, along with different versions of publications dates especially for Scopus can impact the indexing of articles (Liu et al. 2021). Consequently, these ongoing changes can lead to variations in the number of records retrieved and fluctuations in search results over time.

Some search outcomes were removed due to replication across databases. After reviewing the titles and abstracts, we excluded 1376 articles outside the scope of this review. Following Bond's (2020) review, we placed 20 of these excluded articles, which focused on remote mathematics teaching in higher education during the pandemic, in "Appendix A". This approach could facilitate initial research syntheses for future reviews in higher education contexts. After screening, we assessed 205 full-text articles for eligibility. Of these, 25 articles were excluded based on the inclusion and exclusion criteria: (a) 15 articles did not pertain to Pre-K–12 contexts. For example, Stevanović et al. (2024) noted in their Methodology section that their research was conducted with 198 first year undergraduate students (5729); (b) seven articles did not focus on remote Pre-K–12 mathematics teaching. For example, Adeniji et al. (2023) primarily discussed how they redesigned their research methods to continue their investigations during the pandemic (16); and (c) the studies reported in three articles were conducted before the pandemic, such as during the 2017/2018 school year (Barana et al. 2021, 11). As Figure 2 shows, 180 articles were ultimately included in this review (see Appendix B), all of which met the quality appraisal standard outlined in Section 3.3.

4 | Findings and Discussion

The following subsections describe instances, as identified in the 180 articles that we mapped to the constituents of Activity Theory. The findings thus contribute to our overall understanding of people's activities associated with remote mathematics teaching in Pre-K–12 contexts during the pandemic (RQ1), enabling us to make recommendations for enhancing Pre-K–12 mathematics education in the post-pandemic world (RQ2). Table 2 provides a summary of the recommendations, representative supporting quotes and their intended audience.

4.1 | Subjects

Subjects were the most important entity in the activity system. As Figure 3 shows, the majority of the included studies focused on students ($n = 84$), teachers ($n = 53$) or both ($n = 13$). Other research participants included pre-service teachers ($n = 6$), teachers of students with special educational needs (SEN; $n = 5$), students with SEN ($n = 4$) and parents/caregivers ($n = 3$). Some other studies involved multiple stakeholders, such as both students and parents/caregivers ($n = 2$) and both teachers and school leaders ($n = 1$). In terms of research locations, as Figure 4 shows, the included studies covered the six continents of Asia ($n = 64$), Europe ($n = 59$), North America ($n = 36$), Africa ($n = 10$), Oceania ($n = 7$) and South America ($n = 2$).

4.2 | Tools

Prior research has laid the groundwork for understanding the tools used in remote mathematics teaching (Table 3). In his review of empirical studies conducted during the pandemic, Lo (2024) identified key ICT tools essential for synchronous online instruction (i.e., video conferencing platforms), collaborative learning (i.e., online sharing and collaboration applications), and resource management (i.e., learning management systems) across subject disciplines. In mathematics education, Alabdulaziz (2021) focused on the use of digital technology among 120 secondary school teachers in Saudi Arabia. Their major tools included touchscreens and pen tablets, computer algebra systems, digital learning resources and mobile technologies. These tools corresponded to broader categories of hardware for remote teaching, mathematics applications, educational resources and social media and messaging applications.

Some included studies (e.g., Alabdulaziz 2021; Azhari and Fajri 2022; Courtney et al. 2022; Keldgord and Ching 2022; Lavidas et al. 2022; Lo et al. 2022; Moldavan et al. 2022; Ruef et al. 2022; Vale and Graven 2023; Zhang et al. 2024) specifically investigated the mediating tools that supported remote mathematics teaching. As shown in Table 3, the tools were classified into seven major categories mentioned above. First, video conferencing platforms emerged as critical tools supporting synchronous online teaching, enabling real-time interaction between teachers and students outside a physical classroom (Drijvers et al. 2021). Hardware for remote teaching, such as touchscreens and pen tablets, was invaluable in assisting teachers to work out mathematics steps on-screen, replicating the traditional classroom blackboard in a virtual setting. As the teachers in Alabdulaziz's (2021) study shared, students' attention spans were positively affected when touchscreens and pen tablets were used for problem-solving tasks in the field of mathematics (7621). Because tangible teaching tools could not be used online, teachers used various mathematics applications, such as GeoGebra (Faggiano and Mennuni 2020; Lo et al. 2023) and Desmos (Machado et al. 2023; Roberts and Olarte 2023), to

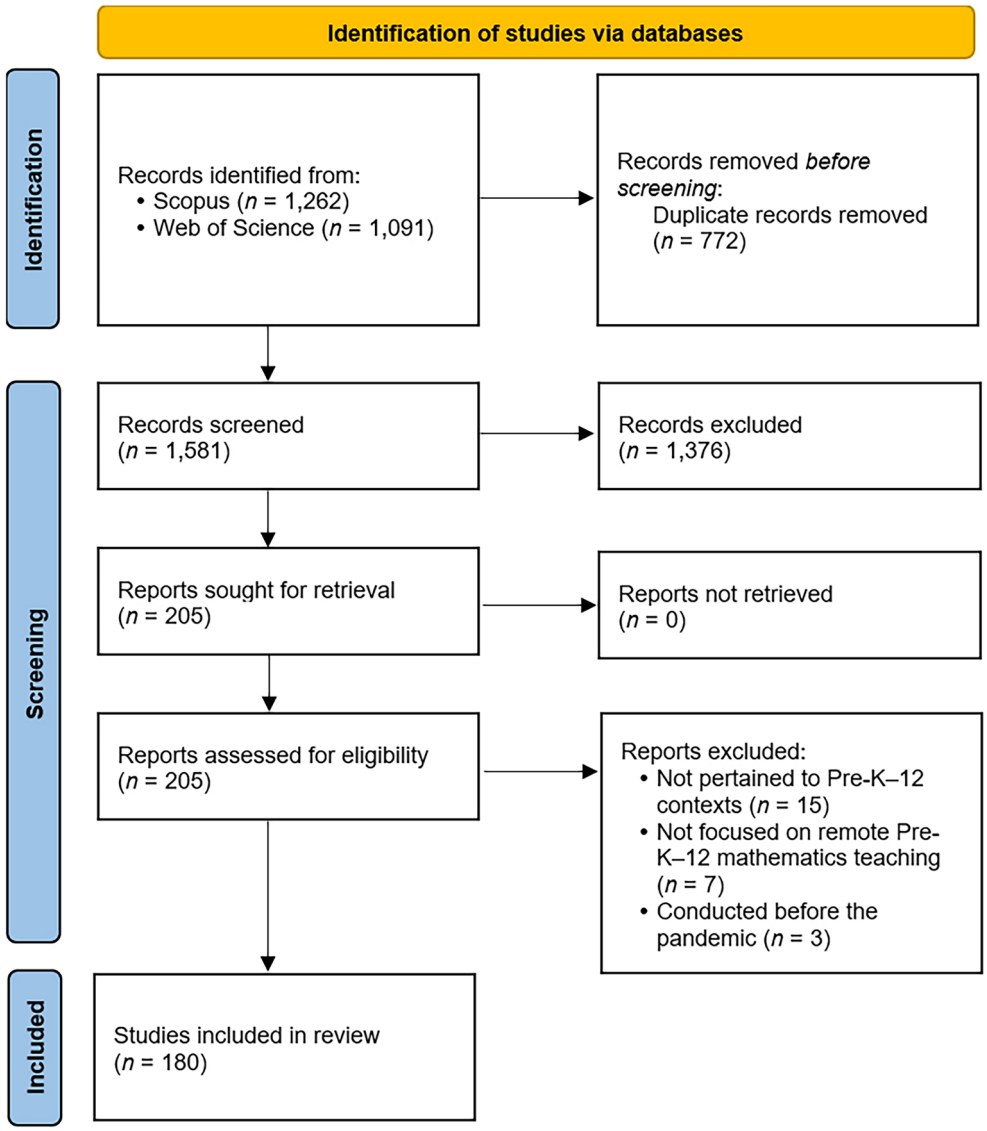

FIGURE 2 | PRISMA flow diagram of article selection.

visualise mathematics concepts in a virtual learning environment. Equally important were online sharing and collaboration applications, such as Google Jamboard and Google Docs (Bouck et al. 2024; Chen et al. 2023; Tesfamicael 2022). Students could work collaboratively through these kinds of virtual whiteboards and online documents, thereby mimicking the group-work dynamic of a physical classroom. These first four types of tools played a crucial role in supporting the synchronous aspect of remote mathematics teaching.

Three other categories of tools were integrated into remote mathematics teaching. Educational resources, especially those available freely online, played a significant role, as traditional materials might not be effective or usable in an online setting. For example, Xie et al. (2021) reported that a textbook committee developed a series of online instructional videos that benefited more than 25 million teachers and students in China. These resources not only assisted teachers in remote mathematics teaching but also supported education equity by ensuring that all students had access to learning materials at home (Lo et al. 2023; Xie et al. 2021). Second, learning management systems (e.g., Google Classroom and Moodle; Callaghan et al. 2023) were vital for the organisation and delivery of educational resources, providing structured and accessible platforms for both teachers and students. Last, social media and messaging applications were crucial in supporting communication between teachers, students and parents. For example, some teachers created WhatsApp groups with parents and students for the delivery of instructional materials and after-class communication (Haser et al. 2022; Vale and Graven 2023). Besides general support, social media and messaging applications enabled teachers' immediate mathematics-specific assistance. As one teacher shared, students send their problems to me. I solve them, take the photos of solutions and then send them to students. If it's a multi-step question, I'm shooting a video. They generally clearly understand them (Sengil Akar and Kurtoglu Erden 2021, 10). This addressed the unique communication needs in mathematics instruction, where immediacy of feedback is essential to support student learning (Ober et al. 2024; Small and Lin 2018). The tools shown in Table 3 collectively contributed to sustaining mathematics teaching in the absence of a physical classroom.

TABLE 2 | Summary of the recommendations for enhancing Pre-K–12 mathematics education in the post-pandemic world.

Recommendation	Representative supporting quotes	Intended audience
1. Strengthen regular use of digital tools	'school leaders should encourage the use of relevant GeoGebra resources to facilitate the teaching and learning of the topics about shape and space' (Lo et al. 2022, 12).	Teachers; school leaders
2. Increase the creation and use of online educational resources	'More digital tools should be created and/or recreated in this context, providing enriched environments with suitable materials for learning mathematics' (Lavidas et al. 2022, 11).	Teachers; teacher educators
3. Strengthen teacher training related to remote mathematics teaching	'we suggest legislators to invest in teachers' training, giving them effective and clear information and providing them with technical advice to improve the teaching quality and promote motivation, especially during possible future distance learning periods' (Doz and Doz 2023, 11).	Teacher educators; policymakers
4. Utilise technology-enhanced instructional approaches in mathematics teaching	'we did see teachers who flipped their instruction evidencing the ability to continue to deliver content, had the other conditions favoured such continuity' (Vahle et al. 2023, pp. 9–10).	Teachers
5. Assist students in catching up with learning loss	'disadvantaged student groups in particular should receive additional support to compensate for the loss of learning opportunities in the classroom' (Schult et al., 2022b, 1).	Teachers; school leaders
6. Explore assessment methods suitable for online application	'Even for core mathematical functioning, moving to a wider assessment palette in these important pathways might have significant benefits' (Golding 2021, 274).	Teachers; teacher educators
7. Strengthen home–school collaboration and caregiver education	'The role of the parents is suggested to be empowered, via parents' support of children's educational activities and communication and co-operation with teachers' (Nikolopoulou 2022, 12).	Teachers; school leaders; caregivers
8. Reflect on past experiences and establish guidelines for future contingencies	'policymakers, particularly schools, should establish comprehensive strategies that prepare students to use e-learning. These strategies might include providing students vouchers for internet connection as well as incremental training of the use of e-learning prior to a crisis' (Mailizar et al. 2020, 8).	Teachers; school leaders; policymakers

Recommendation 1. *Strengthen regular use of digital tools.*

In alignment with UNESCO's (2020) Idea 2, we recommend the regular integration of digital tools in post-pandemic mathematics classrooms. Researchers (e.g., Callaghan et al. 2023; Huang et al. 2023; Maurer et al. 2021) have revealed that a lack of familiarity with technology can impair teachers' confidence and efficacy in remote mathematics teaching. Callaghan et al. (2023) found that teachers with prior experience of using digital tools had a smoother transition from face-to-face teaching to pandemic-led remote teaching. Except for video conferencing platforms and hardware for remote teaching, the tools listed in Table 3 can be applied during normal school days and have the potential to enhance the effectiveness of mathematics teaching. For example, a meta-analysis by Zhang et al. (2023) demonstrated that the use of GeoGebra to visualise mathematics concepts led to increased student achievement. Regular use of these tools can be promoted through school policies (Lo et al. 2022). This approach not only enhances the digital literacy of both teachers and students but also serves as vital preparation for potential future shifts in teaching modalities.

Recommendation 2. *Increase the creation and use of online educational resources.*

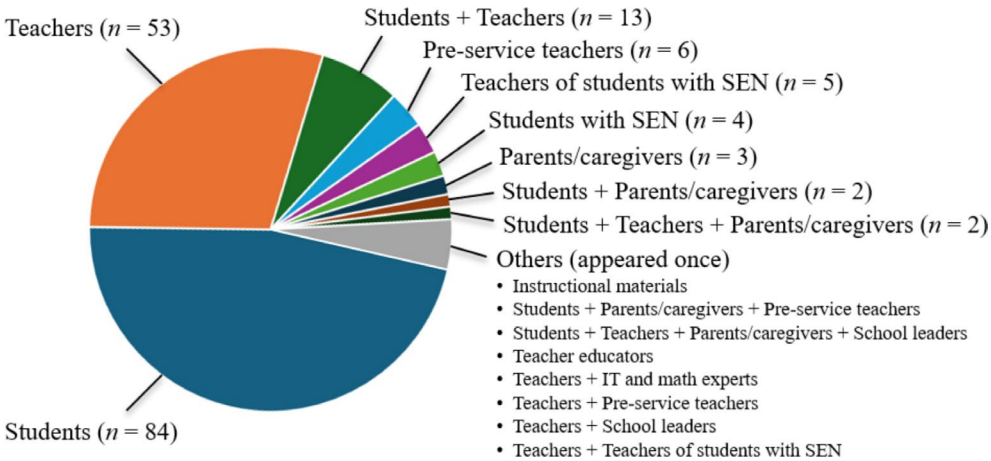

FIGURE 3 | Research subjects of the included studies ($n = 180$).

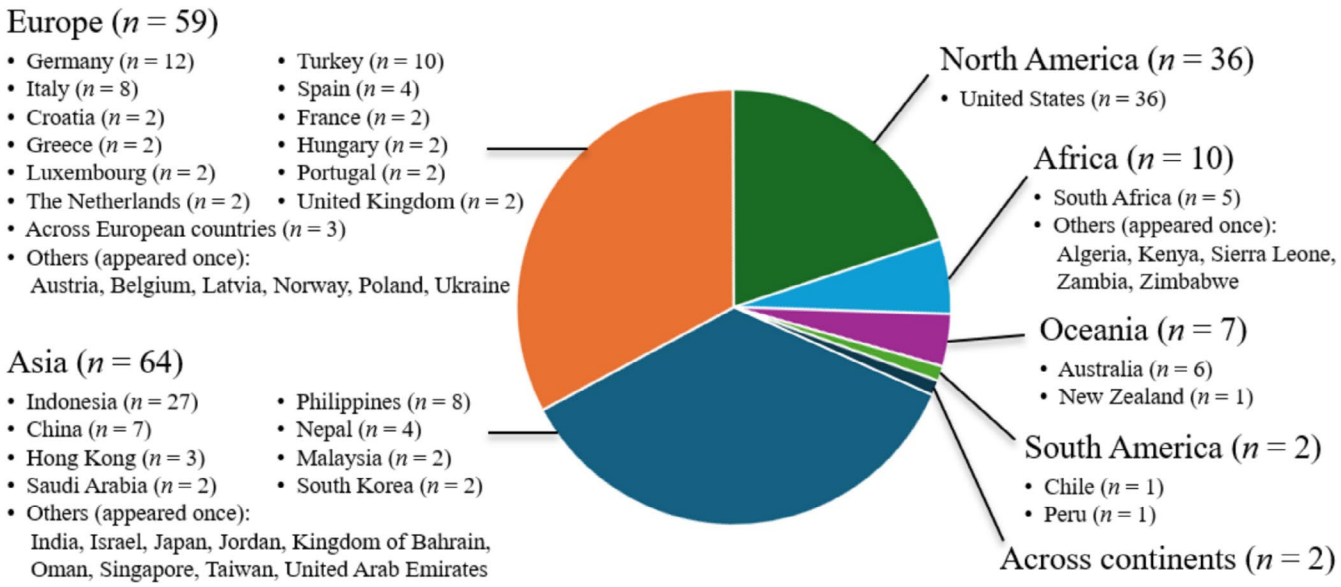

FIGURE 4 | Research locations of the included studies ($n = 180$).

In the past few years, teachers have encountered challenges in creating or finding suitable instructional materials to support remote mathematics teaching (Callaghan et al. 2023; Cao et al. 2021; Lo et al. 2022). Echoing UNESCO's (2020) Idea 6, we recommend increasing efforts to create and disseminate online educational resources. The use of these resources can provide students with additional opportunities to learn mathematics and can help to bridge the equity gap. In this review, studies with region-wide students' mathematics achievement data conducted in Hungary (Molnár and Hermann 2023; Vit 2023), Germany (Schult et al. 2022a, 2022b), Indonesia (Pandango et al. 2023), the Netherlands (Haelermans et al. 2022; Oostdam et al. 2024), South Korea (Jeong et al. 2023) and the United States (Brenner and Thompson-Brenner 2024; Goldhaber et al. 2023) found that students from lower socioeconomic backgrounds suffered most from the school closures because of a lack of resources. Teachers and teacher educators can take the initiative to develop free resources and online repositories (del Olmo-Muñoz et al. 2023; Lo et al. 2023; Tlili et al. 2023). A representative example is 'Math Nation', in which resources for learning algebra (a key area of mathematics) are available to students in five states in the United States (Leite et al. 2024). The provision of free or affordable online educational resources can be a crucial step towards ensuring equal opportunities for all students.

4.3 | Objects and Outcomes

The objects of the included studies were divided into four major themes pertaining to remote mathematics teaching: (1) teacher experiences ($n = 59$), (2) student engagement ($n = 36$), (3) students' mathematics achievement ($n = 30$) and (4) exploration of instructional approaches ($n = 30$). Other themes included the development/evaluation of online educational resources ($n = 13$), assessment ($n = 5$), teacher education ($n = 5$) and caregiver experiences ($n = 4$). Note that the totals did not add up to 180 because some studies addressed multiple themes. For example, Capinding (2022) and Doz et al. (2022) examined the impact of remote mathematics teaching on both student achievement and engagement (e.g., satisfaction, interest and

TABLE 3 | Representative tools that supported remote mathematics teaching by category.

Category	Representative tools	Representative supporting studies
Video conferencing platforms	Blackboard Collaborate, Google Meet, MS Teams, Webex, Zoom	Azhari and Fajri 2022; Pulungan et al. 2022; Tay et al. 2021; Tunç-Pekkan et al. 2023; Zhang et al. 2024
Hardware for remote teaching	Camera, microphone, touchscreens and pen tablets	Alabdulaziz 2021; Cao et al. 2021; Fuchs et al. 2023
Mathematics applications	Desmos, GeoGebra, Maple, MathLab, Mathematica, MathCAD, Maxima, MS Excel	Alabdulaziz 2021; Faggiano and Mennuni 2020; Lo et al. 2023; Machado et al. 2023; Roberts and Olarte 2023
Online sharing and collaboration applications	Dropbox, Edpuzzle, Google Docs, Google Forms, Google Jamboard, Kahoot!, Padlet	Bouck et al. 2024; Chen et al. 2023; Drijvers et al. 2021; Lo et al. 2022; Roberts and Olarte 2023; Tesfamicael 2022
Educational resources	Digital resource repositories, educational TV programmes, e-textbooks, MOOC, video tutorials, weblinks, YouTube	Alabdulaziz 2021; Capone et al. 2022; Leite et al. 2024; Lomos et al. 2024; Vale and Graven 2023; Yılmaz et al. 2021
Learning management systems	Blackboard, Canvas, Google Classroom, Moodle, Schoology, Seesaw	Callaghan et al. 2023; Cox et al. 2021; Leite et al. 2024; Moldavan et al. 2022; Vale and Graven 2023
Social media and messaging applications	Discord, Facebook, Instagram, Skype, Telegram, WhatsApp	Aldon et al. 2021; Callaghan et al. 2023; Ghobrini et al. 2022; Haser et al. 2022; Nasir et al. 2022

anxiety) among high school students in the Philippines and Italy, respectively.

First, about one third of the included studies examined the experiences of teachers with remote mathematics teaching. One of the major challenges identified was a lack of students' class participation and interaction (Cao et al. 2021; Haser et al. 2022; Huang et al. 2023). In the words of one teacher, there is no interaction in a live lesson because they are just listening (Sengil Akar and Kurtoglu Erden 2021, 6). Furthermore, teachers were unfamiliar with online teaching methods (Cao et al. 2021; Haser et al. 2022; Huang et al. 2023). As one teacher expressed, We could not do the calculations on the computer, it was very difficult (Haser et al. 2022, 6). As a result, some teachers resorted to setting up a whiteboard at home and pointing the camera towards it (Cao et al. 2021). Such a practice could have affected the visibility of the whiteboard drawings (Hew and Lo 2020). Nevertheless, Callaghan et al. (2023) and Lomos et al. (2024) found that teachers with more prior experience of using technology had smoother transitions to online teaching.

Second, in terms of student engagement, some indicators defined by Bond and her colleagues (Bond 2020; Bond et al. 2020) were investigated in the included studies, such as attitudes (e.g., Almarashdi and Jarrah 2021; Doz et al. 2022; Thurm et al. 2023), enjoyment (e.g., Chirinda et al. 2022; Guillaume et al. 2022), motivation (e.g., Capinding 2022; Mamolo 2022; Tsai et al. 2023) and anxiety (e.g., Herman et al. (2023); Mamolo 2022; Pirrone et al. 2022). Their findings generally leaned unfavourably towards remote mathematics teaching. We use large-scale quantitative studies to provide key illustrations. In a study of 580 high school students in the United Arab Emirates, Almarashdi and Jarrah (2021) reported that students' most negative perceptions were about missing the interaction with teachers and colleagues (292). Guillaume et al. (2022), surveying over 6500 middle and high school students in the United States, found that more than 60% experienced reduced enjoyment during home-based learning. Regarding student motivation, the results of a study by Tsai et al. (2023) indicated that 6th to 8th graders' ($n = 883$) levels of perceived school motivation and effort dropped sharply in May 2020 and continued to decrease across 2 years (1) in Peru. In a study of Spanish students' ($n = 496$) mathematics anxiety, Arnal-Palacián et al. (2022) found that their Fear of math increases during primary education, with the highest levels of fear and restlessness in the third and sixth grades (145).

Nevertheless, the findings from several included studies offer insights into addressing student disengagement in remote mathematics teaching. For example, Thurm et al. (2023) found a positive correlation between student satisfaction in online mathematics classes and teacher confidence, suggesting the need for teacher training to build confidence in managing future crises. Studies also illustrated the critical role of family and teacher support (Hofer et al. 2023; McLaren et al. 2022) and parent–teacher communication (Azhari and Fajri 2022; Cox et al. 2021) in improving student motivation. Combette et al. (2021) highlighted the importance of student motivation, as it positively predicted the amount of time that students spent on mathematics homework assignments. Regarding mathematics anxiety, Zhan et al. (2022) found that non-graded assessments helped reduce students' fear of making mistakes in remote learning environments. This finding suggests that teacher training in the use of formative, low-stakes assessments for online mathematics instruction could be useful to mitigate anxiety.

Third, in terms of students' mathematics achievement, researchers analysed region-wide data in K–12 contexts. In Australian primary schools, Gore et al. (2021) found that

there were no significant differences in students' mathematics achievement between 2019 (i.e., before the COVID-19 outbreak) and 2020. In contrast, learning loss was observed in several countries, including Germany (Gasteiger et al. 2023; Schult et al. 2022a, 2022b), Hungary (Molnár and Hermann 2023; Vit 2023), Indonesia (Pandango et al. 2023), Italy (Battisti and Maggio 2023), South Korea (Jeong et al. 2023), the Netherlands (Haelermans et al. 2022; Oostdam et al. 2024), the United States (Brenner and Thompson-Brenner 2024; Goldhaber et al. 2023; Ober et al. 2023; Uthappa et al. 2023), Spain (Moliner and Alegre 2022) and Turkey (Coşkun and Kara 2022). For example, Battisti and Maggio (2023) analysed data on mathematics test scores from the Italian National Institute for the Evaluation of the Educational System. They identified a decline in scores among all Italian students in the 5th, 8th and 13th grades during the 2021/22 school year, with an average national loss between 3.8% and 4.0%.

However, we must view these findings with caution because the region-wide datasets involved multiple schools, each potentially using different online teaching methods and environments (e.g., asynchronous, synchronous or a combination of both; live online classes, learning management systems, digital activities and varied class schedules). It is difficult for the researchers to account for these variations in pedagogical approaches and technological contexts when this information might not be available in the datasets. Despite this limitation, one important implication remains clear: immediate action must be taken to help students recover from the learning loss caused by the pandemic.

Fourth, researchers explored various experimental instructional approaches used during the pandemic. While many studies did not employ a comparative design, their findings enriched our understanding of practising various approaches to remote mathematics teaching, such as the uses of GeoGebra (Faggiano and Mennuni 2020) and Desmos (Machado et al. 2023), the applications of inquiry-based learning (Kalogeropoulos et al. 2021) and cooperative learning (Knopik and Oszwa 2021), and the offerings of enrichment programmes (Jacinto 2023; McLeod 2023) and live lessons via Instagram (Ghobrini et al. 2022). For students with SEN, Bouck et al. (2022a, 2022b, 2024) and Bouck and Long (2023) demonstrated the effective use of the virtual manipulative instructional sequence, explicit instruction and virtual—abstract instructional sequence in a fully online environment. These approaches could be implemented as after-school enrichment activities during normal school days, creating additional learning opportunities for students.

We highlight two comparative studies that examined technology-enhanced instructional approaches. In the first study, Chen et al. (2023) conducted a study with high school students in Taiwan. The control group ($n = 16$) participated in a synchronous online mathematics lesson via Google Meet, while the experimental group ($n = 20$) engaged in the online lesson incorporated with gamification strategies (e.g., points and levels). After the lesson, the gamified group showed a significant increase in motivation (from $M = 2.69$, SD = 0.54 to $M = 3.22$, SD = 0.67, $p = 0.008$), whereas the control group showed a significant decrease (from $M = 3.03$, SD = 0.29 to $M = 2.46$, SD = 0.45, $p = 0.001$). In the second study, Cortez et al. (2023) compared a synchronous online cooperative-flipped learning group ($n = 22$) with a synchronous online lecture-based group ($n = 22$) among 11th graders in the Philippines. In the flipped learning group, students watched pre-class videos and completed quizzes, followed by Jigsaw cooperative learning activities during synchronous sessions on MS Teams using breakout rooms. The flipped learning group showed a significant improvement in mathematics achievement between the pre-test and post-test, with a large effect size ($g = 1.25$). In contrast, the lecture-based group demonstrated no significant difference in achievement between the tests.

Recommendation 3. *Strengthen teacher training related to remote mathematics teaching.*

The COVID-19 outbreak posed challenges for mathematics teachers, particularly those unfamiliar with technology-enhanced instructional approaches. In the post-pandemic world, it is crucial to strengthen teacher training to equip crisis-ready educators with the skills and knowledge necessary for remote mathematics teaching. Teacher training should be supported at the government level through allocating additional resources and organising professional development activities (Doz and Doz 2023; Ata Baran and Baran 2021). This training should cover various aspects, from technology and pedagogies that engage students in online class activities to having part of the internship experience online even if things go back to pre-pandemic normal (Tunç-Pekkan et al. 2023, 5757). Special emphasis should be placed on hands-on experience with various digital tools and platforms for online teaching, as identified in Table 3, because digital learning environments will be with us forever (Chirinda et al. 2021, 12). Training programmes should also provide guidance on maintaining student engagement during online lectures. For example, Roberts and Olarte (2023) found that the mathematics language routines (i.e., three reads; clarify, critique and correct; co-craft questions; stronger and clearer) proposed by Zwiers et al. (2017) can be used to foster student participation, manage online discussions and provide effective support. By strengthening teacher training related to remote mathematics teaching, we can ensure that teachers are well prepared to transition to online instruction as needed and to create teaching and learning opportunities in a virtual educational landscape.

Recommendation 4. *Utilise technology-enhanced instructional approaches in mathematics teaching.*

During the pandemic, several technology-enhanced instructional approaches demonstrated desirable results in enhancing students' mathematics achievement and learning motivation. We thus recommend going beyond emergency remote teaching and incorporating these approaches into everyday mathematics teaching. One effective instructional approach is flipped learning, as supported by meta-analyses in mathematics education (Güler et al. 2023; Lo et al. 2017). Furthermore Vahle et al. (2023) found that teachers with prior experience of flipped learning encountered fewer challenges when transitioning to remote mathematics teaching. This was attributable to their preparedness to create online spaces and establish norms for virtual work at the start of the school year. In addition, the use of gamification strategies, such as digital badges and leaderboards, can enhance students' engagement in mathematics learning. These strategies have the potential to motivate students in not only remote

mathematics classes (Chen et al. 2023) but also in-person classes (Sailer and Homner 2020). By using these technology-enhanced instructional approaches, teachers can foster more engaging and effective environments for mathematics teaching. Most importantly, this promotes readiness and the accessibility of technology, equipping both teachers and students for an increasingly digital world.

Recommendation 5. *Assist students in catching up with learning loss.*

The pandemic has affected students worldwide, resulting in substantial learning loss in mathematics. Therefore, we recommend implementing strategies to help students recover from this educational setback. Resonating with UNESCO's Idea 4, school leaders and teachers can provide students with additional learning opportunities through summer or after-school programmes. These remedial programmes can incorporate the technology-enhanced instructional approaches discussed in Recommendation 4, offering intensive targeted instruction in mathematics. Special attention should be given to low-achieving students and students from low socioeconomic backgrounds, as they were most affected by the pandemic (Molnár and Hermann 2023; Oostdam et al. 2024; Schult et al. 2022a, 2022b; Taylor et al. 2024). Second, teachers should provide students with relevant resources that enable their self-directed learning according to their needs. For example, a substantial number of instructional videos were created during the pandemic in China (Xie et al. 2021), offering students the flexibility to learn and review at their own pace. Spitzer and his colleagues (Spitzer and Musslick 2021, Spitzer and Moeller 2023; Spitzer et al. 2021, 2023) documented the availability of a curriculum-based online learning software programme, Bettermarks, that covers 100 mathematics topics for K–12 students in Germany as well as Austria, the Netherlands and Uruguay. This software can provide hints and immediate feedback, serving as a valuable complement to teacher-led lessons and an additional practice tool for independent study. Data from the software indicated an increase in students' performance during the pandemic in 2020 compared with the previous year, with low-achieving students showing greater improvements than their high-achieving counterparts (Spitzer and Musslick 2021). By incorporating online educational resources, teachers can assist students in recovering from their learning loss and ensure that they remain on track with their mathematics education.

4.4 | Rules

Relatively few studies reported instances associated with rules in the activity system. The identified instances related to synchronous online instruction (e.g., Hunter et al. 2022; Vahle et al. 2023) and remote assessment methods (e.g., Leite et al. 2024; Zhan et al. 2022). At the onset of the COVID-19 outbreak, some regions implemented regulations limiting the frequency of synchronous online class meetings with students (Vahle et al. 2023) and did not expect students to engage with online learning materials or complete work (Hunter et al. 2022). However, these rules caused concerns. In the words of one teacher, it is hard to motivate kids when they know they do not have to do it (Vahle et al. 2023, 7). Additionally, researchers identified teachers' use of diversified assessment methods in remote mathematics teaching, such as frequent online quizzes (Leite et al. 2024), graded and non-graded assessments (Zhan et al. 2022) and presentations (Enders and Kostewicz 2023). Assessments, whether conducted in-person or remotely, operate under certain rules and requirements to ensure fairness, validity and reliability. In a remote setting, however, the challenge to avoiding cheating seems to be persistent (Maras 2022). If students' work involves handwritten responses or mathematical steps, plagiarism checkers may not be effective in detecting misconduct.

Recommendation 6. *Explore assessment methods suitable for online application.*

Consistent with Montenegro-Rueda et al. (2021), we recognise that there was no panacea for the problems with remote assessment methods in the included studies. Given the limited research on remote assessment methods in Pre-K–12 contexts, it is crucial for teachers and teacher educators to continue exploring assessment methods suitable for both normal school days and online applications. Beyond Pre-K–12, Fitzmaurice and Ní Fhloinn (2021) surveyed over 250 teachers from 29 countries and found that some teachers used alternative remote assessment methods, including oral assessments oral exams and projects, to deter students from copying others' work. Oral assessments are a potential alternative in Pre-K–12 contexts (Enders and Kostewicz 2023), enabling teachers to ask follow-up questions and elicit immediate responses from students to examine their understanding. Not only is a wider assessment modality likely to be beneficial, but they can also provide a more comprehensive picture of students' mastery of the subject matter (Golding 2021).

4.5 | Community and Division of Labour

In all the included studies, the community involved in remote mathematics teaching primarily consisted of teachers and students. As shown in Table 4, we further identified other members and their corresponding roles and responsibilities. Caregivers, including parents and other family members of students, emerged as important participants throughout preschool (Lavidas et al. 2022; Nikolopoulou 2022), primary school (Gunzenhauser et al. 2021; Nikolopoulou 2022; Orbach et al. 2023) and secondary school (Chirinda et al. 2021; Hofer et al. 2023; Martin et al. 2021) contexts. These caregivers supported home-based mathematics learning in several ways, such as assisting students in finding materials needed (Nikolopoulou 2022, 12) and encouraging the students to solve the problems and share thinking (Hunter et al. 2022, 220). However, Lambert and Schuck (2021) observed that some caregivers might become overly involved in student learning, attending all their children's online classes and making substantial amendments to their work. As coined by Barlovits et al. (2021), the Unclear role of parents (12) became a problem during online mathematics lessons. These findings highlight the critical need to guide caregivers on how to provide adequate support in online learning while ensuring that students retain responsibility for their learning (Lambert and Schuck 2021).

The roles and responsibilities of school leaders and government officials and policymakers are also important. Although the

TABLE 4 | Roles and responsibilities of members within the remote mathematics teaching community.

Community members	Roles and responsibilities (representative supporting studies)
Caregivers	• Assisting students in accessing educational resources (Chirinda et al. 2021; Haser et al. 2022; Nikolopoulou 2022) • Facilitating students' learning progress (Gunzenhauser et al. 2021; Hunter et al. 2022; Murphy et al. 2023)
School leaders	• Providing technical support for students and their families (Kalogeropoulos et al. 2021) • Building relationships and showing care to families (Hunter et al. 2022)
Teacher educators	• Providing training in remote mathematics teaching (Lomos et al. 2024; Rakes et al. 2022; Tunç-Pekkan et al. 2023) • Developing online educational resources for teachers' use (Lo et al. 2023; Lomos et al. 2024; Sutarto et al. 2022)
Textbook publishers	• Developing online educational resources for teachers' use (Xie et al. 2021)
Government officials and policymakers	• Providing teachers with recommendations on teaching routines (Huang et al. 2022) • Providing students with necessary tools for online learning, such as laptops, Internet access and cameras (Fuchs et al. 2023; Lomos et al. 2024) • Developing and disseminating educational resources, such as instructional tasks (Gülbağcı Dede et al. 2023), workbooks (Vale and Graven 2023) and educational TV programmes (Yılmaz et al. 2021)

actions that they took during the pandemic were not extensively detailed in the included studies, some researchers documented that their resources and authority extended beyond the course and family levels. First, some school leaders took a lead role in offering institutional support to students and their families. For example, an assistant principal in the study by Kalogeropoulos et al. (2021) provided the technical support for their families if it was requested (9), whereas another school principal showed care by providing food packages to families (Hunter et al. 2022, 214). Such actions not only facilitated remote mathematics teaching but also reinforced the community's solidarity during the pandemic. Second, some government officials and policymakers made significant contributions at the macro level. For example, Fuchs et al. (2023) and Lomos et al. (2024) found that they provided students with essential tools required for online learning. In some countries, the government developed and distributed educational resources, such as instructional tasks (Gülbağcı Dede et al. 2023), workbooks (Vale and Graven 2023) and educational TV programmes (Yılmaz et al. 2021). These resources were able to reach and support students with limited Internet access. These actions highlighted the macro role of government officials and policymakers in mitigating the adverse educational impact of the crisis, thereby indirectly supporting the teaching and learning of mathematics.

Recommendation 7. *Strengthen home–school collaboration and caregiver education.*

The COVID-19 pandemic revealed the importance of robust home–school collaboration in maintaining the continuity of education (Coulange et al. 2021; Gunzenhauser et al. 2021; Hofer et al. 2023). Echoing UNESCO's (2020) Idea 4, schools and families should work together to ensure that students' academic needs are fulfilled even without the threat of school interruptions. As demonstrated in the included studies, this collaboration could take the form of regular communication to align mutual goals and perspectives (Cox et al. 2021) and to support teaching and learning activities (Hunter et al. 2022; Lambert and Schuck 2021). Caregivers are instrumental in supporting students' learning at home, and there is a need to enhance caregiver education (Lambert and Schuck 2021). Schools should provide resources and training to equip caregivers with an understanding of online learning tools and effective learning strategies at home. This could involve parenting workshops, online tutorials and easily accessible educational materials. By strengthening home–school collaboration and caregiver education, we can ensure that students receive the necessary family support for uninterrupted education.

Recommendation 8. *Reflect on past experiences and establish guidelines for future contingencies.*

The ability to adapt and respond effectively to unforeseen challenges is crucial in managing educational crises. Therefore, it is vital for school leaders and government officials and policymakers to reflect on past experiences and establish comprehensive guidelines to prepare for future contingencies. For school leaders, this could mean ensuring regular communication with caregivers and students (Hunter et al. 2022; Lambert and Schuck 2021) and developing protocols to facilitate the integration or transition to online learning (Lo et al. 2022; Vale and Graven 2023). In the words of one teacher, My school wants us to use blended learning. That is, to use some e-learning platforms for students' pre-class, in-class and post-class learning (Lo et al. 2022, 17). In this scenario, the school's rules mandate the implementation of blended learning. These rules influence the selection and utilisation of various e-learning tools via teachers (subjects) and thus their teaching practices to facilitate students' pre-class preparation, in-class activities and post-class assignments. This directive shapes how teachers plan their lessons, interact with students and assess their learning progress using these digital tools. Consequently, the availability and effectiveness of tools

can further influence how the rules are implemented and refined over time. Besides, government officials and policymakers must devise policies that address potential disruptions to campus operation. In alignment with UNESCO's (2020) Ideas 6 and 9, we also advocate for public funding and governmental support in the development of online educational resources. However, it is worth noting that Vahle et al. (2023) discovered that teachers were sceptical about certain pandemic-led policies. This highlights the importance of involving all stakeholders in the policy-making process and ensuring that their concerns are addressed and that the resulting policies are practical and effective.

5 | Conclusion, Limitations and Recommendations for Future Research

This review analysed 180 articles on remote mathematics teaching in Pre-K–12 contexts during the COVID-19 pandemic. The insights extracted from the synthesis resulted in eight specific recommendations for immediate actions and policy interventions. For example, Recommendation 5 emphasises the imperative for schools and teachers to help students make up for any pandemic-led learning loss. Recommendation 3 urges policymakers and teacher educators to reinforce teacher training related to remote mathematics teaching, which is a crucial step towards reshaping teaching and teacher education. The outcome of this review can thus contribute to advancing the Pre-K–12 mathematics education sector in the post-pandemic world.

Although this review provides valuable insights, some limitations must be acknowledged. Although we analysed a collection of 180 articles, our literature search was limited to the Scopus and Web of Science databases. Nevertheless, the breadth of our findings lays a robust groundwork for subsequent larger-scale reviews. Second, our analysis was derived from the perspectives and narratives in the included studies. The absence of certain themes does not imply their non-existence in the activity system; instead, it merely suggests that these themes were not the focal points of the research. Third, it is important to recognise that various online teaching methods and environments were adopted both across different school settings and even within the same school. This diversity might have presented a significant challenge for researchers attempting to categorise and analyse datasets by instructional modality with precision. Further research is required to rigorously examine the effectiveness of different pandemic-led instructional approaches. Fourth, our review focused on remote mathematics teaching in Pre-K–12 contexts. Our findings and recommendations may thus be subject- and context-specific. Further studies are required to explore the activity system of remote teaching in other subject disciplines and educational settings. Fifth, as our review aimed to identify needs requiring follow-up action and make recommendations for enhancing post-pandemic Pre-K–12 mathematics education to inform a wide range of educational stakeholders and encourage subsequent research, future efforts should also address other equally important factors, such as students' developmental differences.

Finally, we suggest the following research directions in relation to our findings and proposed recommendations. First, the sudden shift to remote mathematics teaching during the pandemic revealed unpreparedness among both teachers and researchers. By leveraging these experiences, follow-up studies should aim to design effective fully online instructional approaches (e.g., fully online flipped learning and gamification strategies) and identify best practices for their use (Recommendation 4). Second, future research should focus on the development, implementation and evaluation of alternative assessment methods (e.g., oral assessments; Recommendation 6). These methods should reflect student performance, be suitable for online applications, and minimise the risk of academic misconduct. Third, it is crucial for researchers to undertake policy research that examines experiences of different stakeholders (e.g., teachers and school leaders) and incorporates their perspectives. This will facilitate the establishment of practical guidelines for future contingencies (Recommendation 8), thereby ensuring that the community is better prepared to handle potential disruptions to the education system.

Author Contributions

Chung Kwan Lo: conceptualization, investigation, funding acquisition, writing – original draft, methodology, validation, visualization, software, formal analysis, project administration, resources, supervision, data curation. **Khe Foon Hew:** validation, conceptualization, writing – review and editing. **Simin Xu:** data curation, formal analysis, validation. **Yanjie Song:** conceptualization, validation, writing – review and editing. **Gaowei Chen:** software, writing – review and editing. **Morris Siu-Yung Jong:** writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Appendix A

Further Reading

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Appendix B

Summary of the Included Studies

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[1]	Abrams (2021)	United States	Students (3) and teacher (1)	High school	Qualitative	'the game-informed learning environment supported the students' development and discussion of their multimodal numeracies, and the highlighted activity reveals how the generation of math memes can foster students' engagement in creative and empowered practices' (16).
[2]	Ahmad et al. (2021)	Indonesia	Teachers (141)	Junior high school	Quantitative	'78.70% of mathematic teachers always provide direction to the students in starting the online class. 40.30% of them never ask students to correct incorrect assignments during online learning' (271).
[3]	Alabdulaziz (2021)	Saudi Arabia	Teachers (120)	Secondary school	Qualitative	'98% [of the participants] contended that the use of digital technology in mathematics by schools had expanded considerably as a result of the coronavirus outbreak, and this was a positive aspect of the pandemic' (7625).
[4]	Alabdulaziz and Tayfour (2023)	Kingdom of Bahrain	Students (120)	Primary school	Quantitative	'there were statistically significant differences (p value <0.05) in the concepts of expanding pictures of numbers (verbal, analytic and standard), compare numbers, basic arithmetic operations, units of measurement, geometric shapes, sides and data visualisation in favour of the group of students who were taught in a face-to-face learning mode' (1).
[5]	Aldon et al. (2021)	France, Germany, Israel, and Italy	Teachers (684)	Primary, middle, and secondary schools; and university	Qualitative	'four tasks corresponding to the main challenges that teachers had to face during the time of lockdown: (a) managing distance learning to support students' learning through specific methodologies; (b) managing distance learning to develop assessment; (c) managing distance learning to support those students that face difficulties and/or are living a difficult situation/developing inclusive teaching; and (d) managing distance learning to exploit its potentialities for fostering typical mathematical processes' (1).
[6]	Almarashdi and Jarrah (2021)	United Arab Emirates	Students (580)	High school	Quantitative	'the students had an ambivalent view of their distance learning experience. Notably, students' most negative perceptions were about missing the interaction with teachers and colleagues, and disapproving of the unfavourably long screen times' (292).
[7]	Amedu and Hollebrands (2022)	United States	Teachers (2)	High school	Qualitative	'both teachers found teaching mathematics online more difficult compared to classroom-based instruction. The main concerns expressed by these teachers focused on challenges related to receiving feedback from students and limited student interaction' (abstract page).
[8]	Anwar et al. (2023)	Indonesia	Students (NR)	Junior high school	Quantitative	'This study demonstrates that a higher percentage of COVID-19 positive patients can lower math test scores' (780).
[9]	Ariyanti and Santoso (2020)	Indonesia	Students (96)	Senior high school	Quantitative	'the average of mathematics learning outcomes before online learning is greater than the average after online learning and students' average positive response towards mathematics before online learning is greater than the average after online learning' (4).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[10]	Arnal-Palacián et al. (2022)	Spain	Students (496)	Primary school	Quantitative	'Fear of math increases during primary education, with the highest levels of fear and restlessness in the third and sixth grades; the girls presented the highest levels in all aspects, except for nervousness during classes' (145).
[11]	Ata Baran and Baran (2021)	Turkey	Teachers (10)	Middle school	Qualitative	'participating teachers carried out emergency remote teaching period in ways that they could transfer the face-to-face learning environment to online environment. Again, it was seen that mathematics teachers pointed to their lack of knowledge and skill about online learning' (102).
[12]	Azhari and Fajri (2022)	Indonesia	Teachers (353)	Junior and senior high schools	Mixed	'teachers could not directly utilise various Information and Communication Technology (ICT) devices and online learning platforms that are widely available in supporting distance implementation, either due to the ability of teachers, parents' economic factors, limited internet access, and the absence of guidance' (1934).
[13]	Barlovits et al. (2021)	Germany and Spain	Teachers (248)	Primary and secondary schools; vocational school and university	Mixed	'German teachers conducted more lessons asynchronously. In contrast, Spanish teachers used synchronous teaching more frequently, but still regard the lack of personal contact as a main challenge. Finally, for both countries, the digitization of mathematics lessons seems to have been normalised by the pandemic' (1).
[14]	Battisti and Maggio (2023)	Italy	Students (2,248,194)	Primary, middle, and secondary schools	Quantitative	'Results suggest a national average loss between 1.8%–4.0% in Mathematics and Italian test scores. After collecting the precise number of school closure days for the universe of students in Sicily, this work also estimates that the average days of closure decrease the test score by 2.4%' (1).
[15]	Bouck and Long (2023)	United States	SEN students (3)	Elementary school	Mixed	'Researchers determined a functional relation existed between the intervention package and student accuracy. Researchers also found students were independent and able to maintain accuracy when instruction did not proceed either following the intervention or with the support of boost sessions' (313).
[16]	Bouck et al. (2022a)	United States	SEN students (3)	Elementary school	Mixed	'All three students learned to solve the targeted division with remainder problems with at least 75% accuracy and 85% independence across virtual, representational and abstract sessions. Further, all three students maintained their accuracy for up to two weeks following the completion of intervention' (16).
[17]	Bouck et al., (2022b)	United States	SEN students (6)	Elementary school	Mixed	'students learned to solve their targeted mathematical problems with 100% accuracy and over 90% independence. Students were able to maintain their skill accuracy at 80% or higher for two weeks post intervention' (126).
[18]	Bouck et al. (2024)	United States	SEN teacher (1)	Secondary school	Qualitative	'Online mathematics teaching and learning for secondary students with LD [learning disabilities] can be used to increase instructional intensity (including supporting student credit recovery) and decrease interruptions in students' schedules due to future pandemics and snow days' (64).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[19]	Bozkurt and Peker (2022)	Turkey	Teachers (8)	Middle school	Qualitative	'the mathematics teachers believed that distance education offered some advantages for mathematics lessons, on the other hand, they highlighted the barriers it contained. They defined distance education as an inefficient method for mathematics lessons' (885).
[20]	Brenner and Thompson-Brenner (2024)	United States	Students from 267 schools	High school	Quantitative	'Multiple linear regression analysis examining variance in the loss of educational attainment was most strongly predicted by the percentage of students from low-income households in the high school' (1).
[21]	Callaghan et al. (2023)	South Africa	Teachers (111)	Primary and secondary schools	Qualitative	'Participants emphasised the importance of using educational technology meaningfully as a cognitive tool that allows for learners to learn with the technology and not from the technology' (193).
[22]	Cao et al. (2021)	China	Teachers (152)	Primary and secondary schools	Qualitative	'the teachers believed that the effectiveness of online teaching largely depends on student self-discipline. Analysis suggested a need to expand technology use during instruction, reshape the way teachers interact with students, and reorganise teaching methods in face-to-face classroom instruction' (157).
[23]	Capinding (2022)	Philippines	Students (207)	High school	Quantitative	'despite the uncertainty, students are still motivated and interested in learning mathematics. However, the students all agree that they are anxious about learning mathematics' (930).
[24]	Capone et al. (2022)	Italy	Students (15) and teachers (5)	High school	Qualitative	'ICT [Information and Communication Technology] could be considered as a resource for the documental genesis, which generates processes aimed at social knowledge mediated by the teacher' (1).
[25]	Chen et al. (2021)	United States	Students (8)	6th to 10th grades	Mixed	'most students gained knowledge from watching the videos. In addition, students gave positive written feedback on the multilayer videos. However, they still preferred the conventional in-person learning approach to the multilayer video learning approach' (322).
[26]	Chen et al. (2023)	Taiwan	Students (36)	High school	Mixed	'the gamified learning activity was not significantly effective in terms of enhancing learning achievement. In terms of learning motivation, a significant decrease in motivation was found for the group using general synchronous learning, while a significant increase in motivation was found for the group using synchronous gamified learning' (13207).
[27]	Chin et al. (2022)	Malaysia	Teachers (202)	Primary and secondary schools	Mixed	'the mathematics teachers employed a variety of digital education tools during the pandemic and the most commonly used tool was WhatsApp. Second, the top two issues faced by the teacher respondents were due to internet problems and students' engagement during the online learning' (60).
[28]	Chirinda et al. (2021)	South Africa	Teachers (23)	Secondary school	Qualitative	'the WhatsApp platform is a valuable tool that can support the teaching and learning of mathematics beyond the classroom in the contexts of historical disadvantage. The findings also provided insights into how mathematics teachers became learners themselves during emergency remote teaching' (1).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[29]	Chirinda et al. (2022)	South Africa	Students (137)	Secondary school	Mixed	'most learners in resource constrained contexts neither enjoyed nor benefitted from the ERTL [emergency remote teaching and learning] of mathematics and preferred face to face classroom interactions with the teachers. Many learners stated that they were used to seeing the teachers' gestures, body language, and facial expressions' (179).
[30]	Christopoulos and Sprangers (2021)	Belgium	Students (335) and teachers (15)	Primary and secondary schools	Mixed	'educational technologists should pay special attention to the degree of gamification, especially beyond the primary school level, as it may negatively impact incentives for student interaction and engagement' (1).
[31]	Colajanni et al. (2023)	Italy	Students (25)	High school	Mixed	'distance learning was quite challenging for the students in terms of concentration and attention and did not allow us to have direct feedback from them … Most of the students (79% and 67%, respectively) found a few or no positive aspects to distance learning' (118).
[32]	Combette et al. (2021)	France	Students (170)	Middle school	Quantitative	'the link between identified motivation and school engagement was specific to T1 [the first lockdown period], when schools were closed, as indicated by a significant interaction between identified motivations by type of lockdown' (1).
[33]	Cortez et al. (2023)	Philippines	Students (44)	High school	Mixed	'Significant differences were manifested in the pre-test and post-test results of mathematics achievement of the CFc [cooperative-flipped classroom] group as well as in the post-test result of CFc and the pure online groups' (1).
[34]	Coşkun and Kara (2022)	Turkey	Students (1379)	Primary school	Quantitative	'the school closures due to the COVID-19 pandemic negatively influenced mathematical reasoning skills' (1).
[35]	Coulange et al. (2021)	France	Teachers (368)	Secondary school	Quantitative	'the unprepared move to distance learning impeded the employment of dialogic practices. The socio-economic situation of the teaching was identified as a determining factor in the teachers' different interpretations of the term pedagogical continuity' (75).
[36]	Courtney et al. (2022)	United States	Teachers (50)	6th to 12th grades	Qualitative	'Integration of technology did not positively impact students' mathematical proficiency across all teachers. Common resources used across planning of lessons, implementation of instruction, and assessment included the Google platform, Desmos, and GeoGebra' (1).
[37]	Cox et al. (2021)	United States	SEN teacher (1)	Appeared to be elementary school	Qualitative	'a special education teacher can utilised VBI [video-based instruction] through free online platforms (i.e., SeeSaw, Loom) to implement a mathematical problem solving instructional strategy (modified schema-based instruction; MSBI) for students with autism spectrum disorder (ASD) while at home' (97).
[38]	Crawfurd et al. (2023)	Sierra Leone	Students (4399), teachers (NR), and parents (NR)	Primary school	Mixed	'Tutoring calls led to some limited increase in educational activity, but had no effect on mathematics or language test scores, whether for girls or boys, and whether provided by public or private school teachers' (1).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[39]	Dai et al. (2022)	China	Students (428)	Junior high school	Quantitative	'This study showed the heterogeneity in the online mathematics self-regulated learning patterns of Chinese junior high school students during the COVID-19 pandemic' (1).
[40]	del Olmo-Muñoz et al. (2023)	Spain	Students (133)	Primary school	Quantitative	'student socioeconomic level was a determining factor in the participation rate with an intelligent tutoring system, regardless of whether or not the administration guaranteed students' access to technological resources during the COVID-19 situation' (35).
[41]	Doz (2021)	Italy	Students (231)	Middle and high schools	Quantitative	'the results showed a statistically significant difference in pre- and post-COVID-19 quarantine grades. End-of-year grades were higher than those before the COVID-19 confinement' (36).
[42]	Doz and Doz (2023)	Italy	Students (117)	Middle and high schools	Quantitative	'high-MA [math anxiety] students reported significantly lower MA levels during distance learning, however no difference was observed for moderate- and low-MA individuals. Furthermore, satisfaction with the teaching methods, effort in math, and math achievement were negatively correlated with MA, both before and during distance education' (1).
[43]	Doz et al. (2022)	Italy	Students (129)	High school	Quantitative	'students' grades during the quarantine period increased compared to their grades before the pandemic. However, students were more satisfied with their teachers' in-class teaching methods and believed that in-class teaching was more efficient' (5).
[44]	Drijvers et al. (2021)	Belgium, Germany, and the Netherlands	Teachers (1719)	Secondary school	Quantitative	'Further findings are that teachers' confidence in using digital technologies increased remarkably during the lockdown and that their experiences and beliefs only marginally impacted their distance learning practices' (35).
[45]	Enders and Kostewicz (2023)	United States	Teachers and SET teachers (31)	Secondary school	Quantitative	'Teachers reported increases in the variety of presentation and practice methods and the use of synchronous methods of feedback. Assessment and methods of providing feedback on assessments remained stable over time' (50).
[46]	Faggiano and Mennuni (2020)	Italy	Students (5)	High school	Qualitative	'the guidance of the teacher in conducting the discussion resulted to be important in order to give meanings to the properties of rotation; the digital tools, the DGE [dynamic geometry environment] GeoGebra, resulted to be fundamental in fostering students to endow rotation with its mathematical meaning' (168).
[47]	Fuchs et al. (2023)	United States	Students (157)	2nd grade	Quantitative	'Across the 2 years, declines (standard deviations below expected growth) were approximately 3 times larger than those reported for the general population and for students in high-poverty schools' (278).
[48]	Fujita et al. (2023)	Japan	Teachers (207)	Elementary and junior high schools	Mixed	'Most participants held relatively positive attitudes towards the use of online teaching of mathematics. Their sense of crisis was very high, and they were anxious about, (a) how to actually make their teaching interactive and (b) how to deal with unexpected technical issues' (2197).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[49]	Fütterer et al. (2023)	Germany	Students (729)	Secondary school	Quantitative	'Familiarity with face-to-face technology-enhanced teaching gained before the COVID-19 pandemic appeared to be less important for high-quality digital distance teaching. Thus, infrastructural measures, such as equipping schools with digital devices so that teachers and students can familiarise themselves with technology, do not seem to be decisive for high-quality digital (distance) teaching' (1).
[50]	Gasteiger et al. (2023)	Germany	Students (5108)	Elementary school	Quantitative	'There was a significant drop in performance overall. While the drop in the content domain Numbers & Operations was smaller than the overall drop in performance, the content domains Space & Shape and Data, Frequency, Probability were more affected' (1).
[51]	Ghobrini et al. (2022)	Algeria	Students (100)	High school	Mixed	'due to this high degree of personal contact with students, some of them point out that the main reason they attend the online class is the instructor herself who is adept at stimulating students' engagement' (10–11).
[52]	Goldhaber et al. (2023)	United States	Students (2.1 million)	3rd to 8th grades	Quantitative	'high-poverty districts that went remote in 2020–2021 will need to spend nearly all of their federal aid on helping students recover from pandemic-related academic achievement losses' (377).
[53]	Golding (2021)	United Kingdom	Students (179) and teachers (NR)	Year 13	Mixed	'A small number of participating students reported home-based study beneficial for their mathematics learning, and a bigger group identified some wider benefits that partly offset the challenges. Most participating 16–18-year-old students, though, reported finding remote learning of mathematics both demanding and limiting' (263).
[54]	Gore et al. (2021)	Australia	Students (3030)	Primary school	Quantitative	'our analysis found no significant differences between 2019 and 2020 in student achievement growth as measured by progressive achievement tests in mathematics or reading' (605).
[55]	Guillaume et al. (2022)	United States	Students (6546)	Middle and high schools	Quantitative	'Periods of exclusive at-home remote schooling were pervasive—reported by more than 60% of youths—and linked to a reduction in school enjoyment and time spent on reading, math, and science' (1).
[56]	Gunzenhauser et al. (2021)	Germany	Students (63) and parents (63)	Elementary school	Quantitative	'Children who received more need-oriented support from parents showed a more favourable development of arithmetic skills across the lockdown' (1).
[57]	Gülbağcı Dede et al. (2023)	Turkey	Instructional materials (85)	Elementary school	Qualitative	'the majority of the tasks were at low cognitive demand level, cognitive demand levels did not show a balanced distribution, and some tasks had mathematical errors' (1).
[58]	Haas et al. (2023)	Luxembourg	Students (8), teacher (3), parents (13), and school leader (1)	Elementary school	Qualitative	'During remote teaching, parents adopted a similar role as a teacher and employed different strategies to motivate and guide their children during their learning processes. They assisted their children to solve tasks, by asking questions, giving hints, or motivating them with various strategies' (12).
[59]	Hacatrjana (2022)	Latvia	Students (256)	9th grade	Quantitative	'diagnostic test results in Mathematics are best predicted by the parental education level, fluid nonverbal reasoning and verbal reasoning' (1).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[60]	Haelermans et al. (2022)	The Netherlands	Students (263,553)	Primary school	Quantitative	'The results show large inequalities in the learning loss based on parental education and parental income, on top of already existing inequalities' (1).
[61]	Haser et al. (2022)	Turkey	Teachers (28)	Middle school	Qualitative	'Students' lack of participation, teachers' limited use of methods to teach mathematics, the socio-economic status of families and their lack of collaboration with teachers were among the reasons for mathematics learning loss' (1).
[62]	Herman et al. (2023)	Indonesia	Students (324)	Primary school	Quantitative	'The sole factor that contributed to students' learning anxiety was how challenging it was for them to comprehend the mathematics material that their teacher was delivering online' (239).
[63]	Herrera and Nolasco (2023)	Philippines	Students (607)	Junior high school	Quantitative	'the extent of the quality of the printed modules of the students is high, based on their overall result (mean = 2.99) … Overall, they were highly satisfied with the quality of the module' (780).
[64]	Hofer et al. (2023)	Germany	Students (223)	Secondary school	Quantitative	'A supportive home learning environment—including a dedicated study place at home—can be considered an important protective factor compensating for missing routines and assistance during remote schooling' (355–356).
[65]	Hogue (2022)	United States	Pre-service teachers (230)	Kindergarten to 6th grades	Quantitative	'developing and embedding instructor-created videos into a learning management system has the potential to breathe life into asynchronous courses, while also offering the similar promise to courses using a synchronous format' (392).
[66]	Huang et al. (2022)	China	Teachers (2)	Primary school	Qualitative	'For the experienced teacher, students' mistakes in homework and her online teaching practice triggered her knowledge changes. For the young teacher, the online video lessons, relevant resources on the Internet and students' performance were her primary sources that triggered the changes of her knowledge for teaching' (359).
[67]	Huang et al. (2023)	China	Teachers (2)	Primary school	Qualitative	'teachers adaptively used online video lessons as important resources for their online synchronous lessons and virtual Teaching Research Groups as a teachers' collaboration mechanism supported them to develop online video lessons and address various technological constraints' (103).
[68]	Hunt et al. (2024)	United States	Teachers (5)	Elementary school	Qualitative	'Results yielded three themes related to the instructional design, barriers and challenges, and equity: (a) Goal-focused planning and delivery, (b) Centrality of discourse, and (c) Time' (1789).
[69]	Hunter et al. (2022)	New Zealand	Teachers and school leaders (20)	Primary school	Qualitative	'while focusing on mathematics, teachers and school leaders gained insights related to their students' funds of knowledge and saw opportunities for learning for students, parents, and the teachers themselves' (207).
[70]	Isnawan et al. (2022)	Indonesia	Parents (71)	Junior high school	Qualitative	'students did not learn the content well due to poor explanations by the teacher. Furthermore, they did not study well at home due to signal constraints and quota limitations' (873).

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[71]	Jacinto (2023)	Portugal	Students (12)	Middle school	Mixed	'The main results show the feasibility of adapting in-person, after-school math activities for an online setting, engaging middle grade students in mathematical problem-solving with technology by providing moderate mathematical challenges and promoting collaborative work' (1).
[72]	Jaekel et al. (2021)	Germany	Students (3159), teachers (277), and parents (1688)	5th to 10th grades	Quantitative	'Teaching methods enabling social connectedness (e.g., video meetings, learning videos created by the teacher) revealed the most consistent positive associations with students' and parents' teaching quality ratings and students' learning experiences' (1).
[73]	Jana and Adna (2021)	Indonesia	Students (50)	Class VII	Quantitative	'a computer-based drilling learning model would be effective if it was viewed from the perspective of students' mathematical reflective thinking ability' (54).
[74]	Jaudinez and Joaquin (2023)	Philippines	Students (71)	High school	Mixed	'EthnoSTEM-Based Mathematics Instruction (EMI) is an effective intervention to enhance Sama students' mathematical thinking, especially in knowing and applying amidst distance learning during the COVID-19 pandemic' (354).
[75]	Jeong et al. (2023)	South Korea	Students (4546)	High school	Quantitative	'The analysis revealed that the average score of Math and English classes fell in regions with low land prices during the first year of the pandemic (2020); whereas it increased in regions with high land prices compared to the level prior to the pandemic' (11).
[76]	Jia et al. (2023)	China	Students (284)	Primary and junior high schools	Quantitative	'The positive effect of the online learning supported by an ITS [intelligent tutoring system] was demonstrated by the quasi-experiment in the mathematics subject of a junior high school. The teacher's flipped-class design and the personalised assignment to all students contributed to the performance improvement' (340).
[77]	Jojo (2023)	South Africa	Teachers (3)	Primary school	Qualitative	'teachers benefited from technology informed collaborations with other teachers on WhatsApp groups and used those experiences to promote learning in their own environments' (abstract page).
[78]	Joshi et al. (2022)	Nepal	Teachers (402)	Secondary school	Quantitative	'the level of behavioural, social, emotional, and cognitive engagement of students was found to be high in the online mode of instruction. Additionally, cognitive engagement has significant highest impact on social, behaviour, and emotional engagement' (1).
[79]	Joshi et al. (2023)	Nepal	Teachers (456)	Secondary school	Quantitative	'sharing and integrating digital resources in mathematics instruction significantly affects student assessment, whereas developing and sharing digital resources impacted the integration of such resources in student assessment' (1).
[80]	Jukic Matic (2021)	Croatia	Teachers (6)	Lower secondary school	Qualitative	'social parameters were prominent factors in the decision-making of many teachers regarding teaching remotely. For example, the teachers always put students' needs first: they were accessible almost all day to their students, they tried not to overload students and provided daily feedback on their work' (361).

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[81]	Kalogeropoulos et al. (2021)	Australia	Students (37) and teachers (2)	Primary school	Mixed	'teachers were concerned about effectively catering for all students and assessing student progress and engagement with the tasks. Survey data revealed most students displayed positive engagement with remote learning experiences, except for the lack of opportunity to learn mathematics with and from their peers' (1).
[82]	Keldgord and Ching (2022)	United States	Teachers (103)	Elementary, middle, and high schools	Mixed	'educators feel that VM [virtual manipulatives] are a valid and feasible support of mathematics instruction when physical manipulatives are not available' (957).
[83]	Khadka et al. (2023)	Nepal	Students (2226)	Basic and secondary schools; and university	Quantitative	'access to the internet, grades/levels, and availability of digital devices are significant in the practice of the humanistic role of teachers and students' learning achievement' (1).
[84]	Khalil (2022)	Saudi Arabia	Teachers (130)	Primary school	Mixed	'the beliefs of mathematics teachers about teaching in virtual classrooms in the following order of importance: teaching competence; mathematical achievement; employing the philosophy of active learning' (1765).
[85]	Khanal et al. (2022)	Nepal	Teachers (454)	Basic and secondary schools	Quantitative	'the technical skills and digital resources with the learners and teaching figures and curves were major challenges of mathematics teachers in online mode of instruction' (237).
[86]	Kleinke and Cross (2022a)	United States	Students (904)	Kindergarten to 8th grades	Quantitative	'Student achievements in the remote group (R) exceeded those in the hybrid one (H) in both subject areas (math and ELA [English language]) considered' (189).
[87]	Kleinke and Cross (2022b)	United States	Students (904)	Kindergarten to 8th grades	Quantitative	'Findings revealed significant group differences in grade levels at or below 6th grade. In the majority of analysed comparisons, learner achievement in the hybrid group was significantly lower than those in either the remote or the classroom group, or both' (259).
[88]	Klemer et al. (2023)	Israel	Teachers (104)	Elementary, middle, and high schools	Quantitative	'The results indicate an increase in teachers' knowledge regarding the e-learning environments available at their schools... most teachers experienced difficulties emanating from lack of preparation time, technological knowledge, and/or technical conditions' (1).
[89]	Knopik and Oszwa (2021)	Poland	Students (104) and teachers (6)	Primary school	Quantitative	'The students have shown a high level of mathematical performance (84.8%), a significant increase of the relatedness to the group and a significant decrease in the sense of situational fear. The results also indicate a high level of students' sense of competence and satisfaction associated with implementing mathematical projects' (1).
[90]	Krzywacki et al. (2023)	Finland and United States	Teachers (15)	Elementary school	Qualitative	'Finnish teachers, for example, relied on and leveraged their commitment to fostering student autonomy and self regulation, during ERT [emergency remote teaching], despite its other limitations. U.S. teachers, in contrast, struggled to realise their obligation to providing close monitoring and support for students as they completed mathematics work' (9).

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[91]	Lalduhawma et al. (2022)	India	Students (356) and teachers (60)	Secondary and higher secondary schools	Quantitative	'most of the students and teachers were not quite ready to shift to online learning platforms. Bad internet connectivity, low data limits, slow data speed, demand for costly devices such as smart phones and related software and connectivity were problems faced in conducting online classes' (175).
[92]	Lambert and Schuck (2021)	United States	SEN teacher (1)	Elementary school	Qualitative	'Challenges included supporting students with productive struggle when not physically present with them and supporting student self-regulation during mathematical problem-solving' (289).
[93]	Lavidas et al. (2022)	Greece	Teachers (16)	Preschool	Qualitative	'mathematical activities such as Numbers and Operations, Geometry, and Measurement occurred during distance learning in digital preschool classrooms. They [Participating teachers] made little reference to activities related to Algebra, while they did not refer to Data Analysis and Probability' (1).
[94]	Leite et al. (2024)	United States	Students (10,590) and teachers (213)	Middle and high schools	Quantitative	'teachers made several changes to teacher strategies due to school closures, including allowing students more time to complete assignments. Multilevel modelling showed that teacher orchestration activities, particularly those related to regulation/management and awareness/assessment, were positively related to student achievement' (95).
[95]	Lo et al. (2022)	Hong Kong	Teachers (13)	Primary school	Qualitative	'They [Participating teachers] used OERs [open educational resources] to introduce mathematics and to facilitate class interactions in online lessons. However, not all schools had policies and guidelines on the use of OERs in place. Some teachers also encountered challenges when using OERs' (1).
[96]	Lo et al. (2023)	Hong Kong	Teachers (34)	Secondary school	Mixed	'The findings of this study reveal the concerns of and requests from our teacher participants, such as providing more detailed guidelines, advanced questions, and interactive quizzes. The findings also reflect the substantial need for open access flipped learning resources in secondary schools' (4787).
[97]	Lomos et al. (2024)	Luxembourg	Teachers (811)	Primary school	Quantitative	'we find a large variation between teachers in terms of time spent online during the remote education weeks, ranging from teachers who spent no time to those who spent hours online' (3174).
[98]	Maarif et al. (2022)	Indonesia	Students (9)	Senior high school	Qualitative	'Male students are superior in accepting explanations from teachers, accepting differences of opinion, and mathematical insight. Meanwhile, female student excels in only one indicator (the effectiveness of mathematics)' (1673).
[99]	Machado et al. (2023)	Portugal	Students (29)	9th grade	Mixed	'It is considered that the use of the Desmos platform, for the construction of a didactic sequence on the volume of geometric solids, had the desired effect' (388).
[100]	Magat (2023)	Philippines	Teachers (12), IT practitioners (5), and math experts (5)	Senior high school	Mixed	'The qualitative data analysis through content analysis highlights the need for improving the user interface, usability, user experience design, user control, flexibility in interaction, data quality, reliability, and user privacy of the developed app' (160).

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[101]	Mailizar et al. (2020)	Indonesia	Teachers (159)	Lower and upper secondary schools	Quantitative	'student level barrier had the highest impact on e-learning use. In addition, the student level barrier showed strong positive correlation with the school level barrier and curriculum level barrier' (1).
[102]	Mamolo (2022)	Philippines	Students (31)	Senior high school	Mixed	'Students' anxiety remained "High" before and after the implementation, indicating fear and uncertainty of the new normal in instruction' (1).
[103]	Maras (2022)	Croatia	Students (456)	High school	Quantitative	'The research shows a higher prevalence of cheating in favour of female students, which can potentially be explained by the more honest response of female respondents, but also by their reluctance towards technology and virtually organised Math teaching' (65).
[104]	Marfuah et al. (2022)	Indonesia	Teachers (57)	High school	Qualitative	'Moodle was used as the Learning Management System, and GeoGebra Classroom was used as the Task Response System' (69).
[105]	Martin et al. (2021)	Australia	Students (1548)	High school	Quantitative	'beyond the effects of online learning demands, online and parental learning support, and background attributes, adaptability was significantly associated with higher levels of online learning self-efficacy and with gains in later achievement' (1).
[106]	Maurer et al. (2021)	Germany	SEN teachers (96)	Special and inclusive schools	Quantitative	'the support of students with difficulties in mathematics was perceived as being significant more challenging than the identification of difficulties in mathematics. TSE [Teachers' self-efficacy] in distance learning was rather low' (1).
[107]	McLaren et al. (2022)	United States	Students (277)	Middle school	Quantitative	'On the delayed posttest, students in the No-Hint condition [of a digital learning game] did significantly better in the classroom, while there was no significant difference between conditions at home. In addition, students in the Hint condition used significantly more hints in the classroom than they did at home' (1).
[108]	McLeod (2023)	United States	Students (516)	Kindergarten to 8th grades	Quantitative	'the distance education program resulted in growth comparable to or exceeding benchmark growth norms. Grades 3, 4, 7 and 8 surpassed national growth benchmarks in mathematics' (1).
[109]	Mertasari et al. (2023)	Indonesia	Students (218)	High school	Quantitative	'the intrinsic and extrinsic dimensions of students' learning motivation tend to be parallel, with the intrinsic dimension being higher than the extrinsic dimension' (129).
[110]	Mire et al. (2023)	United States	SEN students (5)	Elementary school	Mixed	'remotely administered CBM [curriculum-based measurement] is feasible for some students with autism: all participants completed the study tasks with minimal behavioural difficulties, and assessor ratings of acceptability were high' (345).
[111]	Moldavan et al. (2022)	United States	Teachers (10)	Secondary school	Qualitative	'These frontline experiences recognise technology-associated systemic inequities in marginalised, urban communities and the need to strategize ways to implement equity-oriented technology integration that benefits all learners, especially urban youth' (277).
[112]	Moliner and Alegre (2022)	Spain	Students (368)	High school	Mixed	'An overall negative effect size of −2.32 was reported for those students with COVID-19 restrictions. Mathematics achievement scores were 9.90% lower for the group with restrictions' (1).

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[113]	Moliner et al. (2021)	Spain	Students (68)	High school	Mixed	'Results showed a continuous decrease in the number of students who preferred the first option, switching progressively from online live classes to pre-recorded classes as the weeks passed' (179).
[114]	Molnár and Hermann (2023)	Hungary	Students (~55,000)	Kindergarten, lower, and upper primary schools	Quantitative	'kindergarten children and 1st–4th-grade students were significantly negatively affected by COVID restrictions compared to their older peers. This difference was extremely large in schools with a high share of disadvantaged students' (1).
[115]	Mukuka et al. (2021)	Zambia	Students (367)	Secondary school	Mixed	'more than 56% of the respondents did not have sufficient access to Information and Communication Technologies (ICT), electricity, and internet services. Most of these respondents also held a belief that mathematics is a subject that is best learned with face-to-face interactions between the teacher and students, and among students' (1).
[116]	Murphy et al. (2023)	Australia	Parents (8)	Primary school	Qualitative	'Analysis identified three categories of parental engagement: monitors, facilitators, and enhancers. Parents in each category responded to their role in at-home learning differently, and accessed and activated different capital to support their child's at-home learning in mathematics' (1).
[117]	Mustafa et al. (2023)	Jordan	SEN teachers (16)	Elementary school	Quantitative	'teachers' attitude towards the game [an assistive 3D instructional tool] was positive, and they intended to use the game in the learning process in the future' (527).
[118]	Nasir et al. (2022)	Malaysia	Teachers (4)	Secondary school	Qualitative	'the teachers had in-depth knowledge of teaching delivery methods and devices such as gadgets. Additionally, the teachers had a positive attitude in terms of their perception and acceptance of online teaching' (80).
[119]	Negara et al. (2022)	Indonesia	Students (70)	High school	Quantitative	'students who studied with Geo-SCL [GeoGebra-assisted social cognitive learning] obtained a higher increase in mathematical reasoning abilities than students who studied with Geo-PBL [GeoGebra-assisted problem-based learning]' (118).
[120]	Nikolopoulou (2022)	Greece	Teachers (14)	Preschool and primary school	Qualitative	'Disadvantages of online education, as experienced by teachers, mainly regarded technical problems, followed by limited resources/support for children at home, and limited training in online methodology. Teachers' positive experiences regarded children's familiarisation with the technology and maintenance of contact with the school environment, while the role of the parents was revealed as essential' (1).
[121]	Ober et al. (2022)	United States	Teachers (7)	High school	Qualitative	'The three most extensively discussed themes appeared to be assessment (19.11%), communication methods (12.23%), and use of online instructional approaches (11.90%)' (342).
[122]	Ober et al. (2023)	United States	Students (681)	High school	Quantitative	'Students enrolled during the pandemic-affected year reported a greater decrease in their anticipated AP [advanced placement] exam scores and received lower scores on a practice exam aligned with the AP exam compared to a prior year' (1).

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[123]	Oostdam et al. (2024)	The Netherlands	Students (5125)	Primary school	Quantitative	'students in grades 1 through 3 had significant learning delays after the first lockdown. However, results after the second lockdown showed that most students were able to catch up, compared to students from corresponding grades of cohorts before COVID-19' (1).
[124]	Orbach et al. (2023)	Germany	Students (484)	Elementary school	Quantitative	'The data revealed risk factors such as not having a tablet/laptop, lack of access to the internet, or a learning environment with siblings without an adult family member present. A negative association was found between multiple risk factors (at-risk levels) in home learning and basic number skills' (1).
[125]	Pandango et al. (2023)	Indonesia	Students (44)	Elementary school	Quantitative	'Overall, academic performance decreased near the end of online learning as compared to the beginning of online learning (87 ± 5.8 vs. 84.7 ± 6.2; p-value $= 0.043$)' (1362).
[126]	Pirrone et al. (2022)	Italy	Students (405)	Middle school	Quantitative	'The results showed a minor state of anxiety experienced during distance learning. However, the students who preferred to learn mathematics in person revealed less mathematics anxiety and better mental states and metacognitive awareness' (1).
[127]	Pourdavood and Song (2021)	United States	Teachers and pre-service teachers (48)	Preschool to 5th grades	Qualitative	'factors, like interactions, communication, and peer support impact the pre-service and the in-service mathematics teachers' beliefs and practices towards online teaching and learning' (96).
[128]	Pulungan et al. (2022)	Indonesia	Students (20)	High school	Qualitative	'Mathematics is a difficult subject especially when learning online, but students can still try to adapt starting from how to use the platform together and do repetition to understand mathematics' (162).
[129]	Purnomo et al. (2021)	Indonesia	Students (251)	Elementary school	Quantitative	'This study's findings indicated a significant relationship between parental involvement and student engagement in the online mathematics learning' (120).
[130]	Purnomo, Ainun, et al. (2022)	Indonesia	Parents (8)	Elementary school	Qualitative	'Aside from technical constraints such as the availability of internet networks and infrastructure, the findings of this study show that technological literacy and parental involvement in cognitive, emotional, social, and pedagogical aspects are still lacking' (130).
[131]	Purnomo et al. (2022b)	Indonesia	Students (56)	Elementary school	Quantitative	'parental involvement, both in terms of support and control aspects, has a significant influence on mathematics performance. On the other hand, mathematics self-concept and performance positively influence each other' (110).
[132]	Rakes et al. (2022)	United States	Pre-service teachers (17)	Secondary school	Mixed	'Growth in TPACK [technological pedagogical content knowledge] was not significant. A relationship between TPACK and MCOP^2 [mathematics classroom observation protocol for practices] was not evident, indicating a potential need for explicit focus on using technology for mathematics conceptual understanding' (1).
[133]	Roberts and Olarte (2023)	United States	Pre-service teacher (1)	Secondary school	Qualitative	'she [The pre-service teacher] navigated the remote teaching context and engaged sample students in all of the multilingual learner core practices despite the challenges of the COVID-19 pandemic, providing an example of what these practices may look like in remote instruction' (1).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[134]	Ruef et al. (2022)	United States	Teachers (9)	Secondary school	Qualitative	'our participants experienced concerns for students and families struggling to effectively engage with and access online education, and shared the practices and online tools they found most and least helpful in enacting equitable instruction' (1).
[135]	Russo et al. (2021)	Australia	Teachers (82)	Primary school	Mixed	'teachers were more positive about the value of student struggle in classroom-based settings compared with remote learning settings' (1).
[136]	Rutherford et al. (2022)	United States	Students (5453)	3rd to 4th grades	Quantitative	'Leveraging data from a mathematics learning software as a substitute assessment, we found that students had lower engagement with the software during the pandemic, but students who did engage had increased performance' (S94).
[137]	Saadati et al. (2021)	Chile	Teachers (423)	Appeared to be primary and secondary schools	Quantitative	'The results show teachers' high self-efficacy levels regarding the personal use of technology, but moderate self-efficacy in integrating technology in teaching. Moreover, teachers see a much more active role for themselves than for students in online activities' (1).
[138]	Sahın Dogruer (2023)	Turkey	Students (33)	Elementary school	Mixed	'ODL [Online distance learning] does not cause any change in students' attitudes towards geometry lessons; moreover, students commonly prefer face-to-face education over ODL' (220).
[139]	Santos et al. (2022)	Philippines	Students (650)	High school	Quantitative	'Time management correlates positively with success in science and mathematics. Achievement in science and mathematics is the highest among students with good time management. Procrastination negatively affects achievement' (142).
[140]	Saputro et al. (2023)	Indonesia	Students (48)	Elementary school	Quantitative	'Students who get asynchronous learning get a higher influence when compared to students who learn synchronously' (2996).
[141]	Schueler and Rodriguez-Segura (2023)	Kenya	Students (8319)	Primary school	Quantitative	'Although [phone] calls increased perceptions that teachers cared, accountability checks had no effect on math performance four months later and tutoring decreased achievement among students who returned to their schools after reopening' (442).
[142]	Schult et al. (2022a)	Germany	Students (> 80,000 each year)	Elementary school	Quantitative	'Regarding mathematics, low-achieving students seem to have a learning backlog that deserves attention in future education.' (544).
[143]	Schult et al. (2022b)	Germany	Students (> 80,000 each year)	Primary school	Quantitative	'Longer periods of school closures were associated with larger learning losses. Additional analyses showed larger learning losses for the group of low-achieving students and for schools with less socio-cultural capital' (1).
[144]	Sengil Akar and Kurtoglu Erden (2021)	Turkey	Teachers (15)	Secondary school	Qualitative	'the teachers stated that they had difficulty in establishing mathematical communication with students especially in the live lesson process in distance education' (6).
[145]	Spitzer and Moeller (2023)	Austria	Students (168)	4th to 12th grades	Quantitative	'students' performance increased in mathematics in the intelligent tutoring system during the period of school closures compared to the same period in previous years' (1).

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[146]	Spitzer and Musslick (2021)	Germany	Students (13,249)	4th to 10th grades	Quantitative	'the shutdown of schools in 2020 had a positive impact on the performance of students in an online learning environment [Bettermarks] for mathematics, relative to the year before' (13).
[147]	Spitzer et al. (2021)	Germany	Students (~300,000)	Classes 4 to 10	Quantitative	'the total number of students who registered increased considerably during and after school closures compared to the previous three years. Importantly, however, the proportion of students engaged also decreased more rapidly over time' (1).
[148]	Spitzer et al. (2023)	Germany	Students (~16,000)	4th to 10th grades	Quantitative	'if teachers repeatedly assigned single problem sets (i.e., a small chunk of on average eight mathematical problems) to their class, students' performance increased significantly during both periods of school closures compared to the same periods in the previous year (without school closures)' (1).
[149]	Sunzuma et al. (2022)	Zimbabwe	Pre-service teachers (13)	Secondary school	Qualitative	'The pre-service teachers faced several challenges during peer teaching using WhatsApp such as lack of smartphones, a flood of messages, human interruption, unavailability of electricity and internet and the nature of mathematics concepts' (225).
[150]	Suparman et al. (2020)	Indonesia	Teachers (21)	Junior high school	Quantitative	'the results of the paired sample t-test show that teacher's ability to develop LMS [learning management system]-based SSP [subject specific pedagogy] improved after training' (6134).
[151]	Suripah and Susanti (2022)	Indonesia	Students (25)	Junior high school	Quantitative	'many students agreed with the use of websites as alternative learning media during this pandemic and students' high motivation to learn mathematics when using the website with an average percentage of 66.3%' (17).
[152]	Sutarto et al. (2022)	Indonesia	Students (30)	Elementary school	Mixed	'the ethnomathematics-based- e-Module was valid, practical, and effective for improving students' metacognitive abilities on spatial material' (32).
[153]	Tadeo and Yoo (2022)	South Korea	Students (70)	High school	Qualitative	'students needed teacher support on the content and supportive pedagogy. Supportive pedagogy needs may include test goals, schedule, content, and procedures, reviewing the test solutions and answers, and providing necessary test accommodations' (1).
[154]	Tanujaya et al. (2021)	Indonesia	Students (9), teachers (10), and lecturers (2)	Junior and Senior high school; and university	Qualitative	'The results showed two main problems in implementing the online mathematics learning system in West Papua, namely accessibility to Information Communications Technology (ICT) equipment and the ability to use ICT equipment in carrying out mathematics learning online' (3).
[155]	Tanujaya et al. (2023)	Indonesia	Students (93)	Senior high school; and university	Qualitative	'The findings revealed that students' thinking skills developed, indicating they were more interested than in the previous teaching and learning process. The learning process was more exciting and enhanced conceptual comprehension' (169).
[156]	Tarusu et al. (2022)	Indonesia	Students (NR) and teachers (NR)	Elementary school	Qualitative	'students formed through online mathematics learning during the coronavirus pandemic were honest, disciplined, and responsible' (2811).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[157]	Tashtoush et al. (2023)	Oman	Teachers (46)	Middle school	Quantitative	'the degree of teachers' assessment of the learning loss experience came to a high degree' (161).
[158]	Tay et al. (2021)	Singapore	Teachers (8)	Elementary and secondary schools	Qualitative	'Theme 1 unpacks teachers' considerations for HBL [home-based learning] relating to their: (a) design preparations and implementations and (b) professional learning as a community. Theme 2 illustrates students' factors for HBL in the form of teachers' descriptions of: (a) students' HBL engagement and (b) readiness' (303).
[159]	Taylor et al. (2024)	United Kingdom	Teachers (66)	Secondary school	Mixed	'inequitable distribution of engaged time, mathematical content and quality teaching has disproportionately negatively affected lower-attaining and disadvantaged pupils and is likely to have contributed to a widened attainment gap' (971).
[160]	Tesfamicael (2022)	Norway	Teacher educators (3)	Middle and lower secondary schools	Qualitative	'The prospective teachers' self-regulated learning, engagement in solving tasks, and participation in productive discourse were positively surprising, showing the cognitive presence of the learners during virtual teaching' (1).
[161]	Thurm et al. (2023)	Belgium, Germany, and the Netherlands	Students (2126) and teachers (323)	Secondary school	Quantitative	'High student appreciation of mathematics, good home environment, and more synchronous delivery of ERT [emergency remote teaching] were related to ERT experiences and more positive beliefs concerning digital mathematics education' (1).
[162]	Tsai et al. (2023)	Peru	Students (883)	Secondary school	Quantitative	'COVID-19 has further compounded decreases in subjective and objective indices of school engagement and performance that are typically observed in early adolescence' (1).
[163]	Tunç-Pekkan and Taylan (2024)	Turkey	Students (110), parents (80), and pre-service teachers (25)	Middle school	Qualitative	'we [the researchers] were able to build a unique and virtual learning community. While pre-service teachers and middle school students benefited the most, university supervisors also reported improving their skills on when and how to give feedback' (1831).
[164]	Tunç-Pekkan et al. (2023)	Turkey	Pre-service teachers (43)	Middle school	Mixed	'PSTs [Pre-service teachers] had mathematics teaching anxiety from "a little" to "a moderate amount" before the OLS [online laboratory school] and their teaching anxiety did not significantly change during the OLS period of 8 weeks' (5739).
[165]	Umbara et al. (2021)	Indonesia	Students (80)	Junior high school	Quantitative	'the domino algebra developed was feasible to be mass-produced and used in mathematics learning based on expert validity tests, user practicality tests, and effectiveness tests on students' mathematical communication skills' (483).
[166]	Uthappa et al. (2023)	United States	Students (704,929)	Elementary and middle schools	Quantitative	'Compared to 2018 to 2019, there was a 12.1% decrease (95% confidence interval [CI]: 16.8–19.3) in mathematics and an 18.1% decrease (95% CI: 10.8–13.4) in reading proficiency across the state at the end of 2020 to 2021' (S1).
[167]	Vahle et al. (2023)	United States	Teachers (11)	8th to 9th grades	Qualitative	'Findings highlight the interconnected nature of norms and reveal differences in teachers' responses to the breach of norms. We found administrative policies, particularly around grading, significantly impact teachers' decisions during ERT [emergency remote teaching]' (1).

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[168]	Vale and Graven (2023)	South Africa	Teachers (25)	Primary school	Qualitative	'WhatsApp, a free internet-based messaging service, was the most frequently used communication app across all types of schools for both messaging parents and sending instructional material and support in the form of videos, pictures and text messages' (163).
[169]	Vit (2023)	Hungary	Students (8448)	6th, 8th, and 10th grades	Quantitative	'educational units were less likely to inhibit learning losses during the COVID-19-affected two-year period. Educational units with less advantaged student SES composition were more susceptible to a decrease in their average mathematics test scores than the most advantaged institutions' (1).
[170]	Voievoda et al. (2022)	Ukraine	Teachers (103)	Primary, secondary, and senior secondary schools	Quantitative	'the growing interest of Ukrainian mathematics teachers in computer mathematical games was noted after long-term online learning during quarantine measures on COVID-19' (467).
[171]	Wang and Walkington (2023)	United States	Students (35) and teacher (17)	High school	Mixed	'the math walks program is an effective approach to informal mathematics learning. The program was successful in helping students develop problem-posing skills and connect mathematical concepts to the world around them' (1).
[172]	Wellberg (2023)	United States	Teachers (7)	High school	Qualitative	'During distance learning, most sample teachers maintained their use of these [computational] items by collecting students' written work via uploaded photographs or a "whiteboard" feature in a paid assessment system' (379).
[173]	Widjaja et al. (2021)	Australia	Pre-service teachers (56)	Primary school	Qualitative	'While there was a low level of engagement with pre-recorded lectures, there was a high level of engagement and participation in the online synchronous seminars, together with a marked increase in overall satisfaction with the unit' (230).
[174]	Wijaya (2021)	China	Students (408) and parents (NR)	Elementary and junior high schools	Mixed	'there is a good student learning attitude towards the learning video. Students feel that the learning video is very interesting yet effective as they were able to understand the concept taught' (1).
[175]	Wijaya and Weinhandl (2022)	Indonesia	Students (321)	High school	Quantitative	'effort expectancy (EE) and hedonic motivation (HM) had a significant effect on attitudes, whose correlation with habit also influenced the continuous intention during this post-pandemic period' (1).
[176]	Xie et al. (2021)	China	Students (132,740)	Primary school	Quantitative	'the introduction, interaction, summary and consolidation, curriculum characteristics, and goal achievement parts of the NCPM [Chinese New Century Primary School Mathematics Textbook] micro classes have received high approval from students' (65).
[177]	Yaniawati et al. (2023)	Indonesia	Students (26) and teachers (3)	Secondary school	Mixed	'augmented reality was useful as an alternative didactic and pedagogical source of learning geometry during the COVID-19 pandemic' (4).
[178]	Yılmaz et al. (2021)	Turkey	Teachers (9)	Primary, middle, and high schools	Qualitative	'There were salient factors in this study that supported or hindered equitable mathematics instruction, such as teachers' beliefs, expectations for students, access to resources, students' socioeconomic status, and language barriers" (307).

No	Authors (year)	Regions	Subjects (*n*)	School contexts	Methods	Statements of key findings
[179]	Zhan et al. (2022)	Philippines	Students (90)	Junior high school	Quantitative	'students who preferred graded assessment seem to have a shared belief that they can gauge their understanding of Mathematics through graded evaluations. On the other hand, students who chose non-graded reviews may have experienced a certain degree of pressure and stress from Mathematics, and ungraded assessments give them more confidence and lessen their fear of committing mistakes' (23).
[180]	Zhang et al. (2024)	Hong Kong	Teachers (109)	Primary and secondary schools	Qualitative	'despite the multitude of digital teaching tools, the implementation of most mathematical educational values was more restricted in distance teaching. Rationalism and Control were prioritised, reflecting the challenges of assessing student progress remotely' (871).

Abbreviation: NR, not reported.