Examining How Emergency Remote Teaching Influenced Mathematics Teaching

Christie S. Martin¹ · Kristin Harbour¹ · Drew Polly²

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Abstract

The COVID-19 pandemic forced teachers worldwide to shift to emergency remote teaching (i.e., virtual teaching). As teachers return to their classrooms for in-person teaching, there is a need to examine how remote teaching influences teachers' instruction. This study examined teachers' use of digital technologies and specific mathematics activities both during remote teaching and during in-person teaching after returning to their classrooms. The study also examined how teacher participants reported how the pandemic influenced their mathematics teaching. Data analysis indicated statistically significant differences in the frequency of use of all digital technologies except for mathematics games, meaning that mathematics games are used now as much during in-person teaching as remote teaching. Teacher participants also reported that the largest influences of the pandemic and remote teaching have had on their in-person mathematics teaching was the use of general, non-mathematics specific technologies to support organization, the use of hands-on or virtual manipulatives, and the benefit of formative assessment. Implications for future research include the need to examine teachers' use of digital technologies and mathematics activities more closely during in-person teaching and leverage interviews as a possible way to more closely study teachers' experiences.

Keywords Mathematics education · Mathematics · Emergency remote teaching · Digital technologies · Virtual teaching · COVID-19

Transition to Emergency Remote Teaching

Teachers world-wide transitioned to emergency remote teaching modalities when the COVID-19 pandemic commandeered society in mid-March of 2020 (Hodges et al., 2020; Viner et al., 2020). States, districts, and schools responded to the crisis in various ways, with most schools in the U.S. transitioning to some form of emergency remote teaching (Diliberti & Kaufman, 2020). The transition to emergency remote teaching (also referred to by some as remote or virtual teaching) led many teachers to upend their ways of teaching and either relearn or learn how to design and facilitate learning experiences in new ways, including synchronous, asynchronous, or bichronous teaching methods

(Martin et al., 2020, 2021). Long-term school building closures also exacerbated differential opportunities for student engagement and learning (Van Lancker & Parolin, 2020).

Effective Teaching Strategies

Effective Online Teaching Strategies

Educational technology researchers who have conducted syntheses of research have noted that effective online teaching involves skills that are different from in-person skills (Graham, 2018; Pulham & Graham, 2018). For instance, Pulham and Graham (2018) found that some of the most effective online teaching strategies include flexible and personalized activities, mastery-based learning, using and interpreting student learning data, and managing the technologies of learning management systems and other software. While these strategies are supported by research, they are rather broad and not content-specific, resulting in the need to continue to determine how to relate these strategies within a specific content (e.g., mathematics) context.

✉ Drew Polly
drew.polly@uncc.edu

¹ University of South Carolina, Columbia, SC, USA

² University of North Carolina at Charlotte, Charlotte, NC, USA

Effective Mathematics Teaching Practices

Currently, research-based tenets of mathematics teaching and learning are described in the NCTM Principles to Actions (National Council of Teachers of Mathematics [NCTM], 2014). NCTM (2014) outlines eight tenets, or principles, for the effective teaching and learning of mathematics for all learners (see Table 1).

Effective Use of Technology in Mathematics

One essential element in the effective teaching and learning of mathematics is the use of appropriate technology and tools (NCTM, 2014; Polly & Orrill, 2016). The NCTM Technology Principle (2014) cites research that technology has many benefits to support teaching and learning. While the research base on virtual teaching and learning of mathematics in K-12 settings is limited, there are some published studies about how technology supports the mathematics practices described above from which to draw upon.

Technology has been a part of our classrooms for decades now, but the presence, use, and access vary across teachers. Ruberg et al. (1993) looked at the impact of digital technologies in the classroom. The layout of the classroom and size of computers at that time contribute to how teachers engaged with the technology. The teachers in the study used the computers for individual work and small group work primarily. The study shared teachers' perceptions of using technology and they noted the new modality was engaging, they enjoyed using a new medium, and thought that students needed to engage with technology to prepare for their future.

Currently, many programs and apps provide feedback and adjust activities for students immediately. In Ruberg et al. (1993) teachers shared that a benefit of having students using

computers at that time was gaining familiarity for the future. This idea is reflected in the Common Core State Standards as well as the Programme for International Student Assessment (PISA) framework. Digital technologies are familiar to students as they are surrounded by technology from a young age. Teachers continue to innovate based on their understanding of effective teaching practices and expertise with technology.

The effective use of technology has been shown to improve mathematics achievement for students (e.g., Polly, 2008). There are several studies that examine what effective use of technology means in greater specificity. Cheung and Slavin (2013) reviewed 45 studies and identified types of technology use in the mathematics classroom. The three types were labeled computer-managed learning, comprehensive models, and supplemental computer-assisted instruction (CAI) technology. They noted that all three had positive effects; however, the greatest positive effects were found with the use of computer-assisted instruction (CAI) technology. This conclusion was drawn from a rigorous review of 74 studies included in their analysis. The program category for CAI accounted for 70% of the studies reviewed. Walsh (2011) highlights immediate feedback as an advantage of CAI and that it requires the learner to be active rather than passive. At the conclusion of their review Cheung and Slavin suggest that incorporating supplemental programs using the guidelines of the providers may improve achievement but warns against complacency and promotes the constant evaluation of newer and better tools. The common thread of engagement, immediate and effective feedback, and looking toward the future are threads across research (Cheung & Slavin, 2013; Ruberg et al., 1993; Walsh, 2011).

Additionally, Higgins et al. (2019) conducted a meta-analysis focused on how technology impacts three specific

Table 1 Effective Mathematics Teaching Practices Adapted from NCTM, (2014)

Effective Mathematics Teaching Practice	Explanation
Establish mathematics goals and focus learning	During planning, determine the mathematics goal(s) of the lesson and align all activities to the goal(s)
Implement tasks that promote reasoning and problem solving	Provide activities focused on cognitively-demanding tasks, mathematical reasoning, and ill-structured problems
Use connected mathematical representations	Provide opportunities for students to create their own representations/pictures and connect them through discussions
Facilitate meaningful mathematical discourse	Provide opportunities for discussions between teacher and students that support a deeper understanding of mathematics concepts
Pose purposeful questions	Pose questions that align to the goal(s) and help promote a deeper understanding of concepts
Build procedural fluency from conceptual understanding	Start by developing an understanding of concepts which will build a foundation for procedural fluency
Supporting productive struggle in learning mathematics	Provide opportunities for students to engage productively in determining how to start a task, what strategies to use, and how concepts related to each other
Elicit and use evidence of student thinking	Collect and use formative assessment data to make decisions about future activities and supports

characteristics: (a) student outcomes, (b) motivation to learn, and (c) attitude about learning. Their analysis of 24 studies showed technology had a significant impact on all three areas. They note their results support the meta-analysis of Cheung and Slavin (2013) and suggest the finding of the moderate effect technology has on students' attitudes and motivation is important, as research (Pierce et al., 2007; Roblyer & Davis, 2008) shows increase in motivation and positive attitude support learning outcomes. Additionally, Urbina and Polly (2017) explored teachers' integration of technology using technological pedagogical content knowledge (TPACK) as a guide. The four third-grade teacher participants were observed and interviewed. When asked to describe their use of technology, the response from one of the teachers mirrored the key points described above, specifically that technology was a vital part of education, needed to be adaptive to students' individual needs and that it provides experiences such as complex simulations. The research suggests that technology motivates and engages students when adapted to their needs (NCTM, 2014).

The Organization for Economic Co-operation and Development (OECD) provides the mathematical framework developed by the Programme for International Student Assessment (PISA). PISA 2022 "aims to consider mathematics in a rapidly changing world driven by new technologies and trends in which citizens are creative and engaged" their list of twenty-first century skills include systems thinking, research and inquiry, and information use. In the content knowledge related to quantity it includes a section devoted to computer simulations. The emphasis on technology is not necessarily new, as technology has been present in classrooms for over thirty years. However, technology is changing rapidly and how it is best used to support effective mathematics instruction continues to be examined.

Research on teachers' use of technology in mathematics also indicates that teachers sometimes are reluctant to use it, meaning that in cases like emergency remote teaching they will use it, but when given the choice of using or not using it, some teachers may be apt to not use digital technologies anymore in their classroom (Polly & Hannafin, 2010). While technology has potential to improve teaching and learning in mathematics it is unknown how teachers are using digital technologies when returning to in person mathematics teaching. There is a need to examine how teachers used technology to teach mathematics during emergency remote teaching and how they are using technology now that most teachers have returned to in-person teaching.

Purpose and Research Questions

Based on the recommendations for effective mathematics teaching and the research about effective online teaching, there is a need to examine how teachers transitioned to

remote teaching and back to in-person mathematics teaching. Specifically, there is a need to explore how emergency remote teaching influenced and still influences the types of mathematics activities that students are engaged in, as well as the digital technologies that students used and are using. As such, the current study was grounded in the following research questions:

- 1) How did the frequency that teachers reported using digital technologies while teaching mathematics virtually differ from the frequency, they use them currently while teaching in face-to-face settings?
- 2) How did the perceived usefulness that teachers reported using digital technologies while teaching mathematics virtually differ from the frequency, they use them now while teaching in face-to-face settings?
- 3) How did the perceived usefulness of specific mathematics activities while teaching virtually differ from the usefulness of those activities in face-to-face settings?
- 4) How did the resources that teachers use while teaching mathematics virtually differ from the resources they report now using in face-to-face settings?
- 5) How did participants report ways that teaching mathematics virtually influenced their teaching in face-to-face settings?

Methods

Participants

Participants were recruited via social media (e.g., Facebook and Twitter) and e-mail to alumni of our teacher preparation programs to complete an online survey. Participants who completed the survey included 68 elementary and secondary teachers, with grades taught ranging from first to ninth, and included general education elementary teachers, special education teachers, and secondary mathematics teachers. Table 2 describes the role of teacher participants while teaching mathematics virtually and their current role when data were collected.

Data Analysis

The survey included a combination of Likert scale items and open-ended questions (see Appendix for survey questions). For research questions 1–3, descriptive statistics and paired samples t-tests were conducted using SPSS 27 (IBM Corp, 2020) using the Likert scale items. Paired-samples t-tests were conducted to compare the means for digital technologies and mathematical activities between remote teaching and in-person teaching.

Table 2 Grade Levels of Teacher Participants

Grade level	Frequency during remote teaching	Frequency after returning to in person teaching
Kindergarten	8	10
Grade 1	4	4
Grade 2	6	5
Grade 3	4	7
Grade 4	17	14
Grade 5	8	7
Grade 6	11	12
Grade 7	4	3
Grade 8	2	3
Grade 9 and higher	4	3

For research questions 4 and 5, the open responses provided were analyzed using an open coding approach (Coffey & Atkinson, 1996). Qualitative data were first coded using an open coding approach to allow themes to emerge from the data. Following the identification of the themes, themes were then checked to verify their accuracy. In the results section, we provide quotes and a description of the themes that were most frequent in the data set. We elected to include data from all research questions in this paper based on the purpose to study both teachers' use, perceptions, and experiences of teaching mathematics in an emergency remote learning environment (i.e., virtual teaching) as well as their current practices now that teachers have returned to in-person teaching.

Results

In the following section, we describe the results of participant responses on the survey to answer each of the five research questions.

RQ 1: Frequency of Use of Digital Technologies

Descriptive statistics for participants' frequency of use of digital technologies when teaching virtually and teaching face-to-face are provided in Table 3. Next, we present findings related to these frequencies, as well as a comparison among the two teaching modalities.

Virtual Teaching

During virtual teaching, the two most-used digital technologies, which were used either daily or a few times each week, were (a) digital technologies for teachers to assign work (95.59%; 65 participants) and (b) digital technologies used

Table 3 Descriptive Statistics of Frequency of Digital Technologies

Technology	Daily		A few times a week		A few times a month		Less than a few times a month		Never	
	Virtual	In person	Virtual	In person	Virtual	In person	Virtual	In person	Virtual	In person
Using a digital program to assign students math work	48 (70.59%)	22 (32.35%)	17 (25.00%)	16 (23.53%)	3 (4.41%)	8 (11.76%)	0 (0.00%)	11 (16.18%)	0 (0.00%)	11 (16.18%)
Using a digital program for students to turn in math work	48 (70.59%)	16 (23.53%)	14 (20.59%)	14 (20.59%)	2 (2.94%)	16 (23.53%)	3 (4.41%)	9 (13.24%)	1 (1.47%)	13 (19.12%)
Using digital programs to make videos of math concepts or strategies	27 (39.71%)	4 (5.88%)	19 (27.94%)	4 (5.88%)	12 (17.65%)	11 (16.18%)	4 (5.88%)	28 (41.18%)	6 (8.82%)	21 (30.88%)
Using videos made by others to help your students	24 (35.29%)	15 (22.06%)	19 (27.94%)	12 (17.65%)	18 (26.47%)	16 (23.53%)	4 (5.88%)	19 (27.94%)	3 (4.41%)	6 (8.82%)
Using virtual manipulatives to demonstrate a math concept or strategy	15 (22.06%)	3 (4.41%)	32 (47.06%)	14 (20.59%)	11 (16.18%)	23 (33.82%)	7 (10.29%)	15 (22.06%)	3 (4.41%)	13 (19.12%)
Using virtual manipulatives to allow students to explore a math concept or strategy	17 (25.00%)	2 (2.94%)	27 (39.71%)	11 (16.18%)	13 (19.12%)	24 (35.29%)	6 (8.82%)	16 (23.53%)	5 (7.35%)	15 (22.06%)
Using digital math games to allow students to practice strategies	25 (36.76%)	22 (32.35%)	23 (33.82%)	25 (36.76%)	11 (16.18%)	9 (13.24%)	7 (10.29%)	6 (8.82%)	2 (2.94%)	6 (8.82%)

by students to turn in work (91.18%; 62 participants). Following these two most frequently used digital technologies of assigning work and turning in work, there was a considerable decrease in frequency with the next most-used digital technology (i.e., Using digital programs to make videos of math concepts or strategies) being only used at least a few times a week in virtual teaching by 48 participants.

The additional five digital technologies options on the survey were used either daily or a few times a week by between 42 to 48 of the participants. The three least frequently used digital technologies in virtual teaching were: (a) using videos made by others to help your students (63.23%; 43 participants), (b) using virtual manipulatives to allow students to explore a math concept (64.71%; 44 participants), and (c) using digital programs to make videos of mathematics concepts (67.65%; 46 participants).

In-Person Teaching

The most frequently used digital technologies that participants reported using either daily or a few times a week during in-person teaching included: (a) digital math games for practice (69.11%; 7 participants), (b) using a program to assign students work (55.88%; 38 participants), and (c) using a program for students to turn in work (44.12%; 30 participants). The least frequently used digital technologies that participants reported using either daily or a few times a week during in-person teaching were: (a) using digital programs to make videos of mathematics concepts (11.76%; 8 participants), (b) using virtual manipulatives to allow students to explore a concept (19.12%; 13 participants), and (c) using virtual manipulatives to demonstrate a mathematics concept (25%; 17 participants).

Comparisons between Virtual and In-Person Teaching

Table 4 provides the means for each digital technology for both virtual and in-person teaching. To calculate the means for each of the Likert scale responses, the following coding was used: Daily- 1, A few times a week- 2, A few times a

month-3, Less than a few times a month- 4, Never- 5. Paired samples t-tests indicated statistically significant differences for the frequency of use of digital technologies between virtual teaching and in-person teaching for each of the various digital technologies except for digital games. Across the six digital technologies used in teaching in which the difference in teaching modality was significant (i.e., all technologies except for digital games), the technologies were used statistically significantly more frequently during virtual mathematics teaching compared to teaching mathematics in-person ($p < 0.001$).

As indicated, the only digital technology without a significant difference between virtual and in-person teaching was the use of digital games to allow students to practice strategies where there was a slight difference in the means (2.09 for virtual and 2.25 for in person; $p > 0.05$). While the means indicate a slightly higher frequency in the use of digital games to allow students to practice strategies during in-person teaching modality, the difference is not significant, indicating there was not a significant difference in their use between the two teaching modalities.

RQ 2: Perceived Usefulness of Digital Technologies

In addition to the frequency of use of digital technologies (i.e., RQ 1), participants also rated each digital technology based on their perceived usefulness in virtual and in-person teaching. Table 5 provides the descriptive statistics for this Likert-scaled item. Next, we present findings related to these perceptions within a virtual setting and an in-person setting, as well as a comparison among these two teaching modalities.

Virtual Teaching

The three highest-rated digital technologies participants perceived as useful (either very useful or useful) when teaching virtually were: (a) using a digital program to assign students' work (86.77%; 59 participants), (b) using a digital program for students to use to turn work

Table 4 Comparisons of Frequency of Use of Digital Technologies

	Virtual	In Person	Difference
Using a digital program to assign students math work	1.34	2.60	-1.26***
Using a digital program for students to turn in math work	1.46	2.84	-1.38***
Using digital programs to make videos of math concepts or strategies	2.16	3.85	-1.69***
Using videos made by others to help your students	2.16	2.84	-0.58***
Using virtual manipulatives to demonstrate a math concept or strategy	2.28	3.31	-1.03***
Using virtual manipulatives to allow students to explore a math concept or strategy	2.34	3.46	-1.12***
Using digital math games to allow students to practice strategies	2.09	2.25	-0.16

* $p < .05$; ** $p < .01$, *** $p < .001$

Table 5 Descriptive Statistics of Perceived Usefulness of Digital Technologies

	Very useful		Useful		Somewhat useful		Not useful		Did not use	
	Virtual	In person	Virtual	In person	virtual	In person	Virtual	In person	Virtual	In person
Using a digital program to assign students math work	47 (69.12%)	23 (33.82%)	12 (17.65%)	13 (19.12%)	8 (11.76%)	12 (17.65%)	0 (0.00%)	10 (14.71%)	1 (1.47%)	10 (14.71%)
Using a digital program for students to turn in math work	47 (69.12%)	19 (27.94%)	9 (13.24%)	14 (20.59%)	8 (11.76%)	13 (19.12%)	1 (1.47%)	10 (14.71%)	3 (4.41%)	12 (17.65%)
Using digital programs to make videos of math concepts or strategies	33 (48.53%)	11 (16.18%)	18 (26.47%)	15 (22.06%)	10 (14.71%)	17 (25.00%)	2 (2.94%)	4 (5.88%)	5 (7.35%)	21 (30.88%)
Using videos made by others to help your students	36 (52.94%)	19 (27.94%)	19 (27.94%)	23 (33.82%)	7 (10.29%)	17 (25.00%)	3 (4.41%)	3 (4.41%)	3 (4.41%)	6 (8.82%)
Using virtual manipulatives to demonstrate a math concept or strategy	27 (39.71%)	7 (10.29%)	20 (29.41%)	25 (36.76%)	16 (23.53%)	19 (27.94%)	2 (2.94%)	5 (7.35%)	3 (4.41%)	12 (17.65%)
Using virtual manipulatives to allow students to explore a math concept or strategy	24 (35.29%)	7 (10.29%)	16 (23.53%)	19 (27.94%)	23 (33.82%)	24 (35.29%)	2 (2.94%)	6 (8.82%)	3 (4.41%)	12 (17.65%)
Using digital math games to allow students to practice strategies	30 (44.12%)	27 (39.71%)	23 (33.82%)	24 (35.29%)	10 (14.71%)	10 (14.71%)	1 (1.47%)	1 (1.47%)	4 (5.88%)	6 (8.82%)

in (82.36%; 56 participants), and (c) using videos made by others to help students (80.88%; 55 participants). The three lowest-rated digital technologies participants perceived as useful (either very useful or useful) were: (a) using virtual manipulatives to allow students to explore a concept (58.82%; 40 participants), (b) using virtual manipulatives to demonstrate a math concept (69.12%; 47 participants), and (c) using digital programs to make videos of math concepts or strategies (75.0%; 51 participants).

In-Person Teaching

The three highest-rated digital technologies participants found very useful or useful when teaching in-person included: (a) digital math games for practice (75.0%; 51 participants), (b) using videos made by others to help students (61.76%; 42 participants), and (c) digital programs for students to assign work (52.94%; 36 participants). The three lowest-rated digital technologies participants found very useful or useful when teaching in-person included: (a) using virtual manipulatives to allow students to explore a concept (38.23%; 26 participants), (b) using digital programs to make videos of mathematics strategies (38.23%; 26 participants), and (c) using virtual manipulatives to demonstrate a math concept (47.05%; 34 participants).

Comparing Perceived Usefulness between Virtual and In-Person Teaching

Similar to determining if a significant difference between teaching modalities existed in the frequency of use of various digital technologies, paired samples t-tests were used to determine if a significant difference arose between the perceived usefulness of these technologies. Results indicated statistically significant differences between virtual and in-person teaching for all digital technologies ($p < 0.001$) except for using digital math games to allow students to practice strategies ($p > 0.05$). Table 6 provides the means and differences in means for participants' perceived usefulness of each of the seven surveyed digital technologies. The largest differences between virtual and in-person teaching were between the use of digital programs to make videos of math concepts or strategies, the use of a digital program to turn in math work, and the use of a digital program to assign students math work. As stated, before the negative number means that participants found the technology to be more useful during virtual teaching than in-person teaching. The smallest differences were for games to provide practice and using videos made by others to help students.

Table 6 Comparisons of Perceived Usefulness of Digital Technologies

	Virtual	In Person	Difference
Using a digital program to assign students math work	1.47	2.57	-1.10***
Using a digital program for students to turn in math work	1.59	2.74	-1.15***
Using digital programs to make videos of math concepts or strategies	1.94	3.13	-1.19***
Using videos made by others to help your students	1.79	2.32	-0.53***
Using virtual manipulatives to demonstrate a math concept or strategy	2.03	2.85	-0.82***
Using virtual manipulatives to allow students to explore a math concept or strategy	2.18	2.96	-0.78***
Using digital math games to allow students to practice strategies	1.91	2.04	-0.13

* $p < .05$; ** $p < .01$, *** $p < .001$

RQ 3: Perceived Usefulness of Mathematics Activities

To focus more on mathematics teaching and learning, another Likert scale survey item allowed participants to share their perceived usefulness of specific mathematics activities that are common in mathematics classrooms and aligned to the NCTM *Principles to Action* (NCTM, 2014). Table 7 shows the descriptive statistics for virtual and in-person teaching. Next, we present findings related to these perceptions within a virtual setting and an in-person setting, followed by a comparison among these two teaching modalities.

Virtual Teaching

The three highest-rated mathematics activities participants rated either very useful or useful in virtual teaching were: (a) directly modeling a specific strategy (86.6%; 59 participants), (b) working with students together on solving a problem where you equally share responsibility for solving the problem (76.4%; 52 participants), and (c) posing a word problem and letting students explore the task (72%; 49 participants). The two lowest-rated mathematics activities participants indicated as very useful or useful in virtual teaching were: (a) letting students explore a problem with no support (47.06%; 32 participants) and (b) having students work independently on math activities and problems (50%; 34 participants).

In-Person Teaching

Nearly every mathematics activity provided on the survey related to perceived usefulness of mathematics activities was rated very useful or useful by a majority of the participants; the highest-rated mathematics activity was found very useful or useful by 62 participants (91.17%) and the lowest rated item was found very useful or useful by 52 participants (76.47%), indicating a high perceived usefulness of all the surveyed mathematics activities. Specifically,

the highest-rated mathematics activity based on perceived usefulness (very useful or useful) for in-person teaching were: (a) letting students solve word problems where you provide support with questions (91.17%; 62 participants), (b) facilitating a number talk or math routine (85.29%; 58 participants), and (c) directly modeling a strategy or series of steps (83.82%; 57 participants). The three lowest-rated mathematics activity based on perceived usefulness (very useful or useful) for in-person teaching were: (a) letting students explore a math problem where you provide no support (76.47%; 52 participants), (b) playing a math game as a group or a class (77.94%; 53 participants), (c) and having students work independently on mathematics activities and problems (77.94%; 53 participants).

Differences between Virtual and In-Person Teaching

Table 8 provides the means and differences in the means between participants' perceived usefulness of seven various mathematics activities for virtual and in-person teaching. As stated earlier, a negative difference indicates participants perceived the mathematics activity was more useful while teaching virtually, while a positive difference means that participants perceived the mathematics activity was more useful while teaching in-person. The means of only mathematics activity, direct modeling, was perceived as more useful in a virtual setting versus an in-person setting (-0.08); however, a paired sample t-test indicated that the difference was not statistically significant ($p > 0.05$), indicating the perception of usefulness of direct modeling of a specific strategy or series of steps was the same across the two teaching modalities. Four surveyed mathematics activities were rated higher for perceived usefulness during in-person teaching compared to virtual teaching. All four of these differences indicated statistical significance when analyzed using a paired samples t-test. The mathematics activities where a statistically significant differences on perceived usefulness during in-person versus virtual teaching were found include: (a) posing a word problem and letting students explore the task where you provide no support (0.84; $p < 0.001$), (b)

Table 7 Descriptive Statistics of Perceived Usefulness of Mathematics Activities

	Very useful		Useful		Somewhat useful		Not useful		Did not use	
	Virtual	In person	Virtual	In person	virtual	In person	Virtual	In person	Virtual	In person
Facilitating a number talk or math routine	23 (33.82%)	38 (55.88%)	17 (25.00%)	20 (29.41%)	18 (26.47%)	6 (8.82%)	3 (4.41%)	1 (1.47%)	7 (10.29%)	3 (4.41%)
Posing a word problem and letting students explore the task where you provide no support	14 (20.59%)	30 (44.12%)	18 (26.47%)	22 (32.35%)	14 (20.59%)	12 (17.65%)	18 (26.47%)	3 (4.41%)	4 (5.88%)	1 (1.47%)
Directly modeling a specific strategy or series of steps	41 (60.29%)	42 (61.76%)	18 (26.47%)	15 (22.06%)	6 (8.82%)	6 (8.82%)	3 (4.41%)	3 (4.41%)	0 (0.00%)	2 (2.94%)
Working with students together on solving a problem where you equally share responsibility for solving the problem	30 (44.12%)	36 (52.94%)	22 (32.35%)	19 (27.94%)	10 (14.71%)	11 (16.18%)	4 (5.88%)	0 (0.00%)	2 (2.94%)	2 (2.94%)
Posing a word problem and letting students explore the task where you provide support with questions	33 (48.53%)	41 (60.29%)	16 (23.53%)	21 (30.88%)	15 (22.06%)	2 (2.94%)	2 (2.94%)	0 (0.00%)	2 (2.94%)	4 (5.88%)
Playing a math game as a group or class	16 (23.53%)	30 (44.12%)	25 (36.76%)	23 (33.82%)	14 (20.59%)	12 (17.65%)	5 (7.35%)	0 (0.00%)	8 (11.76%)	3 (4.41%)
Having students work independently on math activities and problems	15 (22.06%)	27 (39.71%)	19 (27.94%)	26 (38.24%)	28 (41.18%)	12 (17.65%)	6 (8.82%)	1 (1.47%)	0 (0.00%)	2 (2.94%)

facilitating a number talk or routine ($0.63; p < 0.001$), (c) playing a math game as a group or class ($0.6; p < 0.001$), and (d) having students work independently on math activities and problems ($0.47; p < 0.01$). Two additional mathematics activities, along with direct modeling of a specific strategy or series of steps, indicate no statistically significant difference ($p > 0.05$) in their perceived usefulness between the two teaching modalities: (a) working with students together solving a problem where you equally share responsibility for solving the problem and (b) posing a word problem and letting students explore the task where you provide support with questions.

RQ 4: Differences in Mathematics Resources Used

Participants noted differences in the mathematics resources used between virtual mathematics teaching and in-person mathematics teaching. Table 9 shows the resources that were mentioned most frequently for the open-ended survey about resources used to teach mathematics virtually.

Participants wrote a variety of responses when asked if they were using any resources now that they have returned to in person teaching compared to resources, they used last year. Eight participants mentioned that their district had purchased a commercial curriculum, so they were using that as their primary resource. Seven teachers commented that they were using a lot more manipulatives as a tool to support their students' mathematics learning during in person classes. Additionally, five teachers mentioned that they were still using digital mathematics programs (e.g., iReady, Dreambox, etc.) and two teachers mentioned that their districts had just purchased new digital mathematics programs that they were required to use.

RQ 5: Influences of Virtual Teaching on Face-to-Face Teaching

One of the open-ended survey items asked participants to explain how virtual teaching influences their current in person teaching. The responses included a variety of responses but a majority of them focused on three themes: organization, their use of technology, and the use of manipulatives (hands-on mathematics tools).

Organization

Multiple participants reported that teaching mathematics virtually influenced the way that they organize aspects of their classroom now that they are teaching in person. Participants reported that their use of non-mathematics specific digital technologies such as Peardeck, Seesaw, Google applications, edPuzzle, and other programs were used during virtual mathematics teaching and kept as part of their

Table 8 Comparisons of Perceived Usefulness of Mathematics Activities

	Virtual	In Person	Difference
Facilitating a number talk or math routine	2.32	1.69	0.63***
Posing a word problem and letting students explore the task where you provide no support	2.71	1.87	0.84***
Directly modeling a specific strategy or series of steps	1.57	1.65	-0.08
Working with students together on solving a problem where you equally share responsibility for solving the problem	1.91	1.72	0.19
Posing a word problem and letting students explore the task where you provide support with questions	1.88	1.60	0.28
Playing a math game as a group or class	2.47	1.87	0.60***
Having students work independently on math activities and problems	2.37	1.90	0.47**

* $p < .05$; ** $p < .01$; *** $p < .001$ **Table 9** Teacher Reported Resources Used During Virtual Teaching

Resource mentioned	Number of participants	Percentage of participants
Digital math program or website (iready, dreambox, reflex, ixl)	37	54.41%
Non-math specific digital tools (jamboard, nearpod, seesaw)	31	45.59%
Virtual manipulatives	14	20.59%
Teacher-created resources	12	17.65%
District-created videos	8	11.76%
Open educational resources	8	11.76%
Mathematics games	7	10.29%
Hardware (e.g., monitors, document camera)	4	5.88%
District resources	3	4.41%

mathematics classroom when they returned to in person teaching.

One teacher wrote that one of the ways virtual mathematics teaching influenced her current in person teaching was, “Having a digital platform where learners turn in work digitally each day. It helps in the event we have to pivot to virtual; they are already aware of the routines and procedures of submitting work.” Two other respondents specifically talked about Canvas, their district’s Learning Management System (LMS). The use of the LMS allowed teachers to be more efficient with aspects of lesson planning, assigning work, and communicating with parents; therefore, freeing up more time for working with students. One teacher wrote,

“I keep all of my notes and assignments and our learning management system allows students to turn them in through the learning management system. This reduces the amount of paper I handle increases my time to give feedback and actually help students.”

Two other respondents also commented that teaching virtually influenced the way they communicate with parents. A teacher commented that they became very aware of the importance of parent relationships while teaching mathematics in a virtual setting, which they have tried to continue

after returning to in person teaching. “Students’ independent completion of virtual math activities and assessments almost entirely was dependent on your relationship with the parents. If you did not have a strong relationship, most likely the student did not work independently.”

Use of Manipulatives

While teachers reported that teaching virtually has influenced the variety of technology-rich tools that they are using after returning to in person mathematics teaching, one common comment by many teachers is that teaching virtually reminded them that students need and require opportunities to engage in hands-on manipulatives while exploring and learning about mathematics concepts. One teacher commented that by teaching virtually they “realized even more that manipulatives and concrete learning needed to happen before abstract, algorithm learning.” Another teacher commented that now she “uses manipulatives even more than I did before, because I see the need for them when students didn’t have access to them.”

In some cases, teachers reported that they are using a combination of hands-on manipulatives as well as the online virtual manipulatives that they learned about and

used while teaching mathematics virtually. One teacher reported that the virtual manipulatives made it “easier to model and show a concept” and provided opportunities for students to represent a concept during independent work or centers.

Formative Assessment

Multiple participants commented that teaching mathematics virtually influenced their opinions of the importance of formative assessment with their students. The technologies (or digital resources) that they wrote about focus largely on formative assessment or activity-based programs such as Blooket, Kahoot, edPuzzle, and others. One teacher wrote, “I became very comfortable with programs such as showbie and go formative as a way to have students show their work to me in a digital format.”

Another teacher reported that using more digital assignments now that they have returned to in person teaching has freed up more time to give feedback on student work. They wrote that they “give more feedback on assignments as it is easier to grade digitally.” Other teachers wrote that during in-person teaching now they are pre-testing more and using that data to influence the activities and support that they give their students.

Discussion

This study has multiple findings that warrant further discussion, including the frequency digital technologies were used across teaching modalities and how various digital technologies are perceived as useful by elementary and secondary mathematics teachers. Patterns in the data help to reveal the similarities and differences between teachers’ enactment of effective mathematics instruction and how they use technology to support their students’ learning. Below, we discuss the similarities and differences that emerged in teachers’ use of and perceptions of usefulness for digital technologies in relation to effective teaching and learning of mathematics.

Differences and Similarities Between Virtual and In-Person Digital Technologies

The use of digital technologies for virtual and in-person teaching overlapped in some ways and diverged in others. Digital technologies that addressed logistical or organizational needs in the classroom were prevalent in the data versus digital technologies that were mathematics specific (i.e., content-specific) in their use.

Non-Mathematics Specific Digital Technologies

Findings indicated that non-mathematics specific digital technologies were used most frequently and were perceived as highly useful in the virtual and in-person teaching. Teachers identified digital technologies used to assign and collect work in their top three as far as frequency of use and usefulness. These organizational technologies, (i.e., Peardeck, Google application, Seesaw) were essential in the virtual classroom since work done with paper and pencil was inaccessible; interestingly, the use of organizational technologies continued upon return to in-person teaching. These findings parallel results from Pulham and Graham (2018) who found that use of software and learning management systems were central to effective virtual teaching.

The open-ended survey responses indicated that after returning to in-person teaching teachers continued to use these organizational technologies as they were efficient in collecting and keeping track of student work; this efficiency allowed more time to engage with students and provide feedback. Research indicates computer assisted instruction (CAI) had the greatest positive impact on student learning (Cheung & Slavin, 2013), linking engagement and feedback to the impact (Walsh, 2011). The use of organizational technologies is only tangentially linked to the research as they relate to creating more time for the teacher to provide feedback, suggesting that technology in general may be beneficial in providing the space and time for feedback rather than the content of said feedback.

Mathematics Specific Technologies

Digital technologies designed specifically for mathematics instruction had similar frequencies of use and perceived usefulness in both virtual and in-person teaching. One notable difference was that digital math games were identified as used most frequently and found to be highly useful for in-person learning, but used less, not statistically significantly less, in the virtual classroom. It may be that social interaction supports higher engagement when using math games, which may have been challenging to create in the virtual setting. The remaining list of technology applications related specifically to mathematics were used less frequently and perceived as less useful in both settings. The usage and perceptions suggest teachers may need support in using mathematics specific technologies. Eyyam and Yaratani (2014) stress the importance of using technology tools to directly support and improve learning outcomes. Additionally, research suggests successful implementation of technology is based in students’ needs (Chen et al., 2018), ensures technology-based tasks are considered valuable by the students (Johnson & Sinatra, 2013), connects to the effective mathematics practices (NCTM, 2014), and prepares students

for the expectations described in the PISA framework. Coupling this information with our findings, may indicate that there are areas of support and growth in the use of digital technologies to enhance effective mathematics instruction that need further research and development.

Differences Between Virtual and In Person Mathematics Practices

Findings indicated that the teacher's abrupt transition to remote teaching and possible limited exposure to navigating the virtual space caused a teacher-centered approach to become prevalent during mathematics instruction. Data revealed direct modeling of a specific strategy to be the highest rated activity for virtual learning, whereas the lowest rated mathematics activities were letting students explore a problem with no support and having students work independently on mathematics activities. The ranking of mathematical activities in the virtual classroom followed a trajectory of highest rating being the direct instruction or most control by the teacher to the lowest rating being those that released control to the students. Importantly, this pattern shifted when teachers returned to in-person teaching in their classrooms. The data for in-person teaching showed the two most highly rated mathematics activities were letting students solve word problems with support and facilitating a number talk, respectively. These two activities are a shift toward a student-centered approach of instruction, aligning more with research supported practices for effective teaching and learning of mathematics (e.g., NCTM, 2014); however, the third most highly rated activity for in-person teaching was direct modeling of a strategy. Teachers continued to find exploring problems with no support and students working independently as least useful in both settings.

Direct modeling of how to solve problems runs counter to the NCTM (2014) principles of effective mathematics teaching and learning and limits students' access and equity to high-quality mathematics teaching (Martin et al., 2021; Polly et al., 2022). When returning to in-person teaching, teachers reported they shifted to supported problem solving as the most useful practice. In the virtual classroom, teachers may have engaged more heavily in the direct modeling strategy due to being unprepared for such an abrupt transition to virtual teaching or a perception that they needed to provide more direct support to students. Even though teachers quickly returned to more sound mathematical activities when in person, direct instruction persists as a highly rated activity. Common Core Standards for Mathematics (CCSSI, 2010) and the PISA 2022 framework address the importance of technology in the classroom to support learning outcomes and for students to be familiar with the skills needed for the twenty-first century. Myers highlights that effective use of technology increases achievement, but it is important to

emphasize effective technology and effective mathematical instructional practices need to be aligned to support student learning and achievement.

Limitations and Future Directions

Findings from this study contribute to the field regarding how the COVID-19 pandemic and virtual teaching influenced how mathematics was taught, what digital technologies were used, and how mathematics is taught now that teachers have returned to in-person mathematics teaching; however, as with much research, there are limitations that bring to light the need for future inquiry.

First, the sample was a convenient sample completed by 68 grade 1–9 mathematics teachers from the southeastern United States. Recruitment was completed via social media and e-mail lists that included teachers the researchers had previously worked in various capacities (i.e., grant projects, pre-service teacher preparation). Since this sample was not purposefully collected and included teachers ranging from Grade 1 through Grade 9, there is a need to consider future survey studies in which data are collected from various settings as well as larger groups of mathematics teachers.

Further, the data suggested teachers found digital technologies that supported the organization and logistics of the class in the virtual setting to be just as useful for in-person teaching. These organizational technologies were consistently the most frequently used and rated the most useful; however, previous research, standards, and PISA mathematics framework promote a use of technology that extends beyond classroom procedures (e.g., Cheung & Slavin, 2013; CCSSI, 2010; NCTM, 2014). Cheung and Slavin (2013) conclude their meta-analysis with a recommendation that teachers continually evaluate technology as more effective tools continue to be designed. The ability to evaluate tools and decide what makes an application better at meeting learning goals for twenty-first century learners should be part of professional development and teacher preparation. In addition, the study suggests there may be a benefit to researchers, educators, and mathematics technology developers collaborating. Through collaboration, potential resources, guidelines, and professional development opportunities for effective technology integration into all teaching modalities could occur, with the ultimate goal of supporting and advancing students' mathematical understanding.

Lastly, there is a need to more intensively study individuals or small groups of teachers through focus groups or interviews to examine their use of digital technologies during in-person instruction and to examine how remote mathematics teaching influenced their current instructional decisions more closely. These studies ideally would include multi- or mixed methods where data would be collected about teachers' actions as well as their students' learning to

make connections between teachers' pedagogical decisions around technology integration and students' mathematics learning. Even when thrust into an extremely challenging and daunting situation, findings indicated that teachers were resilient and used new technologies during the pandemic, which in turn positively influenced their in-person teaching after returning to schools. As teachers continue with in-person instruction, it is critical to continue to conduct meaningful research that examines how to best support all students' mathematics learning with the effective use of digital technologies.

Appendix

Survey

1. How frequently did you use each of these while teaching virtually?

- Using a digital program to assign students math work
- Using a digital program for students to turn in math work
- Using digital programs to make videos of math concepts or strategies
- Using videos made by others to help your students
- Using virtual manipulatives to demonstrate a math concept or strategy
- Using virtual manipulatives to allow students to explore a math concept or strategy
- Using digital math games to allow students to practice strategies

Scale: Daily, A few times a week, A few times a month, Less than a few times a month, never.

2. How frequently did you use each of these while now teaching in face-to-face settings?

- Using a digital program to assign students math work
- Using a digital program for students to turn in math work
- Using digital programs to make videos of math concepts or strategies
- Using videos made by others to help your students
- Using virtual manipulatives to demonstrate a math concept or strategy
- Using virtual manipulatives to allow students to explore a math concept or strategy
- Using digital math games to allow students to practice strategies

Scale: Daily, A few times a week, A few times a month, Less than a few times a month, never.

3. How useful was each of these while teaching virtually?

- Using a digital program to assign students math work
- Using a digital program for students to turn in math work
- Using digital programs to make videos of math concepts or strategies
- Using videos made by others to help your students
- Using virtual manipulatives to demonstrate a math concept or strategy
- Using virtual manipulatives to allow students to explore a math concept or strategy
- Using digital math games to allow students to practice strategies

Scale: Very useful, useful, somewhat useful, not useful, did not use.

4. How useful is each of these while now teaching in face-to-face settings?

- Using a digital program to assign students math work
- Using a digital program for students to turn in math work
- Using digital programs to make videos of math concepts or strategies
- Using videos made by others to help your students
- Using virtual manipulatives to demonstrate a math concept or strategy
- Using virtual manipulatives to allow students to explore a math concept or strategy
- Using digital math games to allow students to practice strategies

Scale: Very useful, useful, somewhat useful, not useful, did not use.

5. How did teaching math virtually influence the way you teach math in face-to-face settings? E.g.- what strategies and tools do you now use as a result of your experience?

6. What other comments do you have about teaching math virtually and its influence on you as an educator?

7. What was your role while teaching mathematics virtually?

Selections: Kindergarten, Grade 1, Grade 2, Grade 3, Grade 4, Grade 5, Grade 6, Grade 7,

Grade 8, Exceptional children/special education, AIG/Gifted.

8. What is your role this year?

Selections: Kindergarten, Grade 1, Grade 2, Grade 3, Grade 4, Grade 5, Grade 6, Grade 7, Grade 8, Exceptional children/special education, AIG/Gifted.

9. Describe the resources and supports that you used while teaching virtually (e.g., textbooks, websites, videos from specific sites, district supports, etc.).
10. If you are now using any resources not included above now that you are teaching in person describe or list them here.

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