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Technologies That Persist in Mathematics Education Instruction After Emergency Remote Teaching

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In this research study, the authors examined the responses of 63 mathematics teacher educators (MTEs) to see what digital technology tools they used during the COVID-19 pandemic that they continue to use in mathematics or mathematics education classes that support teacher preparation for undergraduate or graduate students. MTEs used mathematical action and conveyance technology, though not exclusively, to increase collaboration, assess their students, organize their course, engage students, record student work, among other purposes and were attracted to these technologies because of their ease of use. These changes have persisted because they positively influenced the teaching, cognitive, and social presence in the MTE's course or courses.

The COVID-19 pandemic caused most colleges and universities around the world to transition in-person instruction to online or hybrid instruction, even if faculty members felt unprepared to do so or had little to no interest in teaching online (Hechinger & Lorin, 2020; McMurtrie, 2020). Hodges et al. (2020) identified this shift of instruction as emergency remote teaching (ERT) or "a temporary shift of instructional delivery to an alternate delivery mode due to crisis circumstances." They further explained that "the primary objective in these circumstances is not to re-create a robust educational ecosystem but rather to provide temporary access to instruction and instructional supports in a manner that is quick to set up and is reliably available during an emergency or crisis" (Emergency Remote Teaching section, para. 1).

Mathematics teacher educators (MTEs) teaching classes that support the initial teacher preparation of undergraduate or graduate students were among the many faculty members grappling with this abrupt migration to ERT. Many MTEs relied on their technological pedagogical content knowledge (also known as technology, pedagogy, and content knowledge, or TPACK; Angeli & Valanides, 2005, 2009; Margerum-Leys & Marx, 2002; Mishra, 2019; Mishra & Koehler, 2006; Niess, 2005; Pierson, 2001; Zhao, 2003) to rethink, revise, and adapt their instructional strategies for engaging students during ERT (Driskell et al., 2023). Curious if MTEs continue to use technologies they adopted during ERT, the authors examined qualitative survey data for patterns of responses to the following research question: What technology-related instructional changes/revisions made during the onset of COVID-19 have persisted for MTEs, and why have these changes persisted?

Literature Review

Literature has focused on the influence COVID-19 has had on instruction, including digital tools for improved instruction (e.g., see Carey et al., 2020; Lee & Freas, 2020; Morgue, 2020). Carey et al. (2020) used a Twitter (now known as X) based community of practice (CoP) to help educators — in-service and preservice teachers and teacher educators — to collaborate about instructional changes during emergency remote teaching and learning. Chat participants talked about new teaching methods and resources for remote instruction during the pandemic. They reported that the Twitter chat alleviated feelings of isolation by fostering a virtual community of individuals with similar experiences during the school closures imposed by the pandemic.

Due to the transition to online schooling, field placement teaching opportunities were unavailable and, thus, stripped preservice teachers from opportunities to practice teaching within in-person K-12 classrooms. To fill this void, some preservice teachers used virtual simulations to conduct an inquiry-based lesson with a small group of avatar students (Lee & Freas, 2020). The simulations allowed those preservice teachers to enact the Five Practices (Stein et al., 2008) and use talk moves to facilitate the discussion among the avatar students.

During spring 2020, Morge (2020) taught a graduate course that met synchronously and asynchronously on alternate weeks and focused on rational numbers and learning trajectories for K-8 in-service and preservice teachers. The synchronous meetings aimed to clarify questions or misconceptions from the asynchronous work, address problem-solving strategies, and introduce new tasks and content. The use of breakout rooms, the whiteboard, emoticons, and the chat feature of the online platform facilitated meaningful discussions about problem-solving during those sessions, while also giving the instructor valuable insights into participants' understanding and needs.

Driskell et all. (2023) analyzed survey data to understand how the context of teaching during COVID-19, from in-person classes to online classes, interacted with MTE's TPACK. For 70% of the 209 MTE survey participants, their TPACK was specifically associated with in-person instruction prior to COVID-19; therefore, they had to create new pedagogy for online instruction when transitioning to ERT.

Although the MTE participants' reported changes in their aspects of teaching were more negative than positive, two positive changes were their use of general technology tools for students' learning (36% positive vs. 4% negative) and use of mathematical technology tools for students' learning (37% positive vs. 18% negative). One participant reported that using the Google Slides electronic slideshow "helped more students see each other's thinking even more than would have happened during class" (p. 16).

Since many of the MTE participants in the Driskell et al. (2023) survey research had been teaching in-person classes prior to COVID-19, they changed or created pedagogy for online instruction. The top two themes that emerged from the survey responses related to instruction and tools. About 64% of the participants reported that they needed to change their pedagogy to account for the online context. In the tools theme, MTEs noted challenges with technology issues, yet they also noted new learning experiences with virtual meeting tools, video tools, digital tools for instruction, and digital manipulatives.

Another influence on education since COVID-19 has been facilitating instructional change with faculty members. "Despite frequent calls for more student-active learning, studies find that teaching remains predominantly traditional and teacher-centered" (Borte et al., 2023, p. 597). Yet, when COVID-19 struck in spring 2020, "faculty at every career stage suddenly had to learn new instructional practices" (Rupnow et al., 2020, p. 2397).

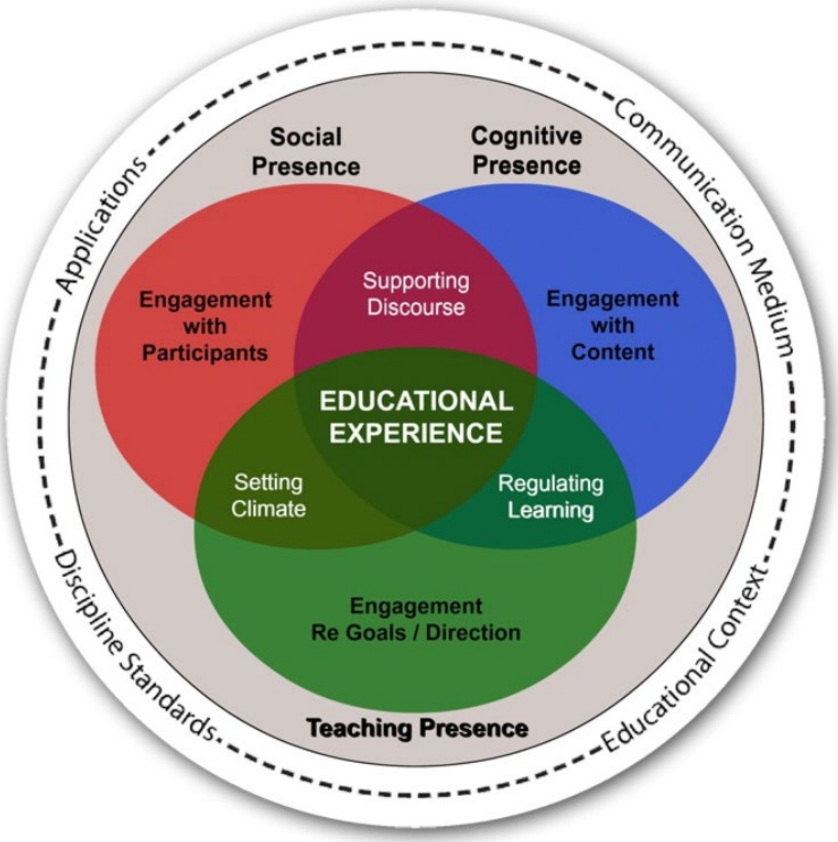
Rupnow et al. (2020) found that when faculty members were forced to use remote instruction, they either continued using former instructional practices or stopped old practices and developed new practices. Change was related to careers status, as professors who were close to retirement made the least amount of changes. The authors also described two levels of change. First order change included alterations to instruction that did not impact learning, such as moving resources from paper to online or making lectures available online. Second order changes were described as "transformative changes that reconsider existing goals and structures and seek to create new ones better aligned with stakeholders' needs" (p. 2405). These changes involved shifting instructional methods to prioritize student-driven meaning-making instead of relying solely on lectures.

Theoretical Framework

To frame this study, we used the ideas of conveyance technology and mathematical action technology described in the work of Dick and Hollebrands (2011), along with the Community of Inquiry (CoI) model (Garrison et al., 2000). Dick and Hollebrands described conveyance technology as allowing teachers and students "to present, communicate, and collaborate with each other" (p. xi) and is "not mathematics specific" (p. xii). On the other hand, mathematical action technology are technologies "that can perform mathematical tasks and/or respond to the user's actions in mathematically defined ways" (p. xii). Throughout our analysis and discussion, we refer to tools as being from either category.

Since the MTEs in this study transitioned their courses to online or blended learning experience during ERT, the CoI framework is an appropriate structure for making sense of their work. The CoI posits that learning takes place within the community by way of the interplay among three fundamental components: cognitive presence, social presence, and teaching presence (see Figure 1).

Figure 1
The Community of Inquiry Framework



Note: Image used with permission from the Community of Inquiry website and licensed under the CC-BY-SA International 4.0 licence (https://creativecommons.org/licenses/by-sa/4.0/). The original image is located at https://www.thecommunityofinquiry.org/framework

Cognitive presence is “the extent to which the participants in any particular configuration of a community of inquiry are able to construct meaning through sustained communication” (Garrison et al., 2000, p. 89). Having sustained communication with students, during the onset of the COVID-19 pandemic, changed for many teacher educators as they transitioned their in-person communication to online communication. COVID-19 also had an impact on the physical and mental health of many students and individuals, in general, leading to change in their ongoing communication. Therefore, COVID-19 influenced the cognitive presence of the education community, and teacher educators sought ways to adjust their instruction to help support students in constructing knowledge through continuous, purposeful communication.

Social presence is a person's ability to "project their personal characteristics into the community, thereby presenting themselves to the other participants as 'real people'" (Garrison et al., 2000, p. 89). Garrison et al. elaborated that social presence is also a person's ability to identify with or relate to the community, engage in purposeful communication within a trusting environment, and cultivate interpersonal relationships by expressing their unique personalities. The core of social presence is to support cognitive presence, indirectly fostering the critical thinking process within the learning community.

Teaching presence enhances and strengthens both social and cognitive presence to achieve educational outcomes. It serves two primary roles: designing and facilitating the learning experience. The design involves selecting, organizing, and presenting course content, along with creating and developing learning activities and assessments. The facilitation "may be shared among the teacher and some or all of the other participants or students" (p. 90). An effective teaching presence promotes active discussion and knowledge building while guiding conversations, identifying misunderstandings, and facilitating the negotiation of meaning.

Methodology

This qualitative study (Creswell, 2013) examined patterns to help us more fully understand MTEs' personal experiences with their adoption of technologies that persisted after ERT. The Technologies That Persist After Emergency Remote Teaching survey was designed specifically for this study based on previous research (Driskell et al., 2023; Harrington et al., 2022) to gather data about MTEs' mathematics education or mathematics content classes that support the initial teacher preparation for undergraduate and graduate students. Such classes included required courses with a mathematics focus for preservice and in-service intervention specialists, as well as elementary, middle, and secondary teachers. For any MTEs who provided their email at the end of the survey, we followed up with them if we had a question about their responses to triangulate the data.

Participants

The target population of this survey was mathematics teacher educators in the U.S. teaching classes that supported the initial teacher preparation of undergraduate or graduate students. Therefore, the survey targeted members of the Association of Mathematics Teacher Educators (AMTE), since it is the largest professional organization focused on enhancing mathematics teacher education.

Three different methods were used to reach the approximately 900 AMTE members. First, an email was sent to the leaders of the 24 AMTE state affiliates asking if they would forward to their members an email, which included a purpose of and link to the survey. Second, the survey was made accessible to attendees of the AMTE's national conference using a QR code directed to the survey that accompanied a brief description of the survey on a small slip of paper. Third, emails with the survey purpose and link were sent to mathematics educators using emails listed in the contact information section of the AMTE annual conference program.

The purpose of the survey was described in the initial Qualtrics survey page, explaining as follows: "This survey specifically addresses MTEs' classes that support mathematics teacher initial preparation for undergraduate and/or graduate students. Such classes include required courses with a mathematics focus for preservice and in-service intervention specialist and elementary, middle, and/or secondary teacher." The sample included 64 anonymous respondents, of which one was discarded because they were teaching neither undergraduate nor graduate courses with a mathematics focus for preservice or in-service teachers. Therefore, responses of 63 MTEs were analyzed.

The higher education teaching experiences of the 63 participants included 0-6 years (n = 17), 7-14 years (n = 21), 15+ years (n = 24), and retired (n = 1). The types of classes the participants taught were undergraduate courses with a mathematics focus for preservice teachers (n = 31), graduate courses with a mathematics focus for preservice teachers (n = 5), both undergraduate and graduate courses with a mathematics focus for preservice teachers (n = 24), and other (n = 3). The number of courses the participants typically teach included one class per semester (n = 3), two classes per semester (n = 24), three classes per semester (n = 15), four classes per semester (n = 14), five classes per semester (n = 3), two classes per quarter (n = 1), four classes per quarter (n = 1), three classes per year (n = 1), and other (n = 1).

The choices of which conveyance technologies and mathematical action technologies to include in our survey was based on our prior research (Driskell et al., 2023) and feedback from outside reviewers. The conveyance technologies and mathematical action technologies listed on our survey are listed in Table 1. An "Other" category was included in the survey to allow MTE participants to share conveyance and/or mathematical action technologies not listed on the survey.

Survey

The Technologies That Persist After Emergency Remote Teaching survey was administered online, and participants could access it through a link sent to them via email. The intended use of the survey was to gather a qualitative snapshot of MTEs' continued use of technologies that they adopted during the COVID-19 pandemic. A survey was the preferred method of data collection because it allowed for collecting data from a large set of participants about perceptions of MTEs from a subset of the entire population of MTEs.

Table 1
Examples of Conveyance and Mathematical Action Technologies

Category	Application
Conveyance Technologies	
Collaborative Board Spaces	Jamboard, Padlet, Google Docs, Google Slides, White boards, other
Electronic discussion boards, learning management systems, presentation apps	Google Slides, Nearpod, other
Screencasting tools	Screencastify, other
Social annotation	Hypothesis, Perusall, other
Social media	Instagram, Twitter, other
Surveys	Google Forms, Poll Everywhere, other
Video conferencing apps	Zoom, other
Video-based discussion	Flip videos/Flip, other
Videos	3-Act Tasks, other
Mathematical Action Technologies	
Data analysis software	Fathom, Tinkerplots, CODAP, other
Dynamic algebra	GeoGebra, Desmos graphing calculator, CAS tools, graphing simulator, other
Dynamic geometry	GeoGebra, Geometer's Sketchpad, Desmos geometry, other
Simulations	PhET, Rossman Chance, other
Spreadsheets	Excel, Google Sheets, other
Virtual manipulatives	NCTM, Math Learning Center, other

Nine educators were solicited to establish the instrument's content validity to enhance the credibility and trustworthiness of the findings. These educators were solicited because of their level of expertise in higher education and their publication records in areas of mathematics education, preservice education, technology education, or survey research. Initially, four of these educators reviewed the survey instrument for its clarity, representativeness, technology relevance, and comprehensiveness to confirm that the survey questions would gather the data intended to answer the research question.

Overall, these educators suggested changes to the wording of questions to add clarity, suggested questions be removed since they were not necessary to measure the construct, suggested changes in the types of technologies listed in the survey, and suggested changes to the comprehensiveness of the survey. For example, a question was changed from, "Where are you in your career?" to, "Where are you in your career as a mathematics educator?" to clarify that the survey was gathering data about participants' mathematics education career.

Many changes were suggested for technology relevance. The original list of technologies was based on our prior research (Driskell et al., 2023) and is included on the right side of Figure 2. The list of technologies was revised to those on the left side of Figure 2. Many new categories were created to combine tools with similar features. For example, Collaborative Board Spaces was created to combine Jamboard, Padlet, Google Docs, Google Slides, and others. CODAP and TinkerPlots were combined into the category Data Analysis Software. Two new groups were created to show the diversity of Desmos, GeoGebra, and Geometeter's Sketchpad (or Web Sketchpad): Dynamic Algebra and Dynamic Geometry.

Figure 2
Original and Updated Type of Technology Tools

Updated Type of Technology Tool

- Collaborative board spaces (e.g., Jamboard, Padlet, Google Docs, Google Slides, White boards, Other)
- Data analysis software (e.g., Fathom, Tinkerplots, CODAP, Other)
- Dynamic algebra (e.g., GeoGebra, Desmos graphing calculator, CAS tools, graphing calculator simulator, Other)
- Dynamic geometry (e.g., GeoGebra, Geometer's Sketchpad, Desmos geometry, Other)
- Electronic Discussion Boards
- Learning Management System
- Presentation apps (e.g., Google Slides, Nearpod, Other)
- Screencasting tools (e.g., Screencastify, Other)
- Simulations (e.g., PhET, Rossman Chance, Other)
- Social annotation (e.g., Hypothesis, Perusall, Other)
- Social media (e.g., Instagram, Twitter, Other)
- Spreadsheet (e.g., Google Sheets, Other)
- Surveys (e.g., Google Forms, Poll Everywhere, Other)
- Video-based discussion (e.g., Flip videos/Flip, Other)
- Video conferencing apps (e.g., Zoom, Other)
- Videos (e.g., 3-Act Tasks, Other)
- Virtual manipulatives (e.g., Math Learning Center math apps, Polypod, Other)
- Other

Original Types of Technology Tools

- CODAP
- Desmos
- Electronic discussion boards
- Flipgrid
- GeoGebra
- Geometer's Sketchpad (or Web Sketchpad)
- Google Docs
- Google Forms
- Google Sheets
- Google Slides
- Jamboard
- Learning Management System
- Math Learning Center math apps
- Mathigon
- Nearpod
- Padlet
- PhET simulations
- Poll Everywhere
- Screencastify or other screencasting tools
- 3-Act Tasks videos
- TinkerPlots
- Toy Theater
- Video conferencing apps (i.e., Zoom)
- Other

After the educators who were solicited for feedback confirmed the changes in the survey, it was piloted a second time with five additional educators. Revisions proposed included adding social media and social annotation for additional types of technology tools. These tools were incorporated into the survey, and the educators who provided feedback were asked to review and confirm the updates. In December 2022, the final survey was sent to leaders of the 24 AMTE state affiliates, who then sent the survey to their AMTE members.

The final survey had eight items: six short answer and two free response items. The first item asked MTE participants if they were teaching undergraduate courses, graduate courses, or both, with a mathematics focus that preservice or in-service intervention specialist or preservice or in-service elementary, middle, or secondary teachers are required to take. The second question asked participants to indicate the number of years they had spent in their higher education careers as a mathematics teacher educator, with options including 0-6, 7-14, 15+, retired, and prefer not to answer. The third question asked MTE participants for the number of courses they taught per semester or quarter. The fourth question asked them to select from a list what technology tool or tools they started to use or use differently — and then decided to retain as a permanent part of that course's instruction — that has/have improved or enhanced their instruction.

The latter four items asked MTE participants to provide the name of a technology tool that most positively influenced their instruction, select from a list of choices the nature of the structure of the course or courses in which they started using this technology tool or started using it in a new way, describe how they used the tool, and tell more about why they continued to use this technology tool, including what they found most useful, helpful, and valuable. MTE participants were given the opportunity to complete the later four questions a second and third time, if desired.

Free responses were coded using the process of open coding as described by Corbin and Strauss (2008). Corbin and Strauss discussed the process of "breaking data apart and delineating concepts to stand for blocks of raw data" (p. 195). Two researchers conducted an initial round of open coding on all responses using the full set of data. This coding process involved dividing sections of sentence responses down to specific phrases that pertained to a certain concept, such as assessment or collaborative work. After completing the initial coding, the two researchers discussed their codes, noting any differences, which were then shared with the third author. Final coding involved 100% agreement by all authors. A discussion of the final codes can be found in the Findings section.

Ethical Considerations

Participants were informed that all information they provided would be confidential, no identifying information would be collected, and only the researchers would have access to the responses. The survey was in compliance with the first author's Institutional Review Board policy for the protection of human subjects in research.

Findings

The findings discuss the types of technology tools that MTE participants began using or used differently when they had to adapt their instructional methods due to the COVID-19 pandemic. MTEs later retained these technology tools as a permanent part of their courses because they improved or enhanced their instruction. Further information about the tool that most positively influenced their instruction is also shared. Details about this information are provided in the next sections.

Type of Technology Tools

To address the technology-related instructional changes made, participants were asked the following question:

When you were required to implement different instructional methods due to the COVID-19 pandemic, what technology tool(s) did you start to use or use differently–and then decided to retain as a permanent part of that course's instruction–in your mathematics education courses (content or pedagogy) that has/have improved or enhanced your instruction?

The MTE participants were then asked to select the technology tool or tools from a list of 18 choices, which included "Other" as a choice (see Table 2 choices column). Of these 17 types of technology tools, 11 are conveyance technologies and six are mathematical action technologies (see Table 2 column 2).

MTE participants were allowed to select as many technology tools as they wanted (see Table 2 column 3). Altogether, 309 types of technology tools were selected. The minimum number of tools an MTE selected was one (n = 11) and the maximum was 12 (n = 1). The average and mode for the number of technology tools MTEs selected were each five (n = 12). Both collaborative board spaces (conveyance technology) and virtual manipulatives (mathematical action technology) were selected by a majority of the MTE participants.

After selecting the type of technology tools, participants were asked to identify one of the types of technology tools they selected that most positively influenced their instruction. Of the 63 participants, 52 completed this question, with six participants sharing two different technology tools, and two sharing three different technology tools. Three of the counts are excluded from Table 3 because in three MTEs' responses it was unclear if Desmos was being used as a dynamic algebra or dynamic geometry tool.

Collaborative board spaces once again topped the list as the technology tool that most positively influenced MTEs' instruction. The specific types of collaborative board spaces mentioned were Google Slides (n = 9), Google Docs (n = 3), and Google Jamboards (n = 3). The seven presentation apps mentioned were Nearpod (n = 4) and Google Slides (n = 3). Of the seven times video conferencing apps were mentioned, Zoom was mentioned six times. Both Desmos (n = 3) and GeoGebra (n = 1) were specifically mentioned as dynamic geometry technology tools. Desmos was also used as a dynamic algebra technology tool.

Table 2
Overall Types of Technology Tools

Type of Technology Tool	Conveyance or Mathematical Action Technology	Count
Collaborative board spaces (e.g., Jamboard, Padlet, Google Docs, Google Slides, White boards, Other)	Conveyance	34
Virtual manipulatives (e.g., Math Learning Center math apps, Polypod, Other)	Mathematical Action	32
Video conferencing apps (e.g., Zoom, Other)	Conveyance	30
Learning Management System	Conveyance	29
Presentation apps (e.g., Google Slides, Nearpod, Other)	Conveyance	28
Surveys (e.g., Google Forms, Poll Everywhere, Other)	Conveyance	18
Dynamic algebra (e.g., GeoGebra, Desmos graphing calculator, CAS tools, graphing calculator simulator, Other)	Mathematical Action	18
Spreadsheet (e.g., Google Sheets, Other)	Mathematical Action	16
Electronic discussion boards	Conveyance	14
Screencasting tools (e.g., Screencastify, Other)	Conveyance	13
Videos (e.g., 3-Act Tasks, Other)	Conveyance	13
Video-based discussion (e.g., Flip videos/Flip, Other)	Conveyance	12
Data analysis software (e.g., Fathom, Tinkerplots, CODAP, Other)	Mathematical Action	12
Dynamic geometry (e.g., GeoGebra, Geometer's Sketchpad, Desmos geometry, Other)	Mathematical Action	10
Social media (e.g., Instagram, Twitter, Other)	Conveyance	8
Other		4
Simulations (e.g., PhET, Rossman Chance, Other)	Mathematical Action	3
Social annotation (e.g., Hypothesis, Perusall, Other)	Conveyance	3

Table 3
Technology Tool That Most Positively Influenced Instruction

Type of Technology Tool	Conveyance or Mathematical Action Technology	Count
Collaborative board spaces (e.g., Jamboard, Padlet, Google Docs, Google Slides, White boards, Other)	Conveyance	15
Presentation apps (e.g., Google Slides, Nearpod, Other)	Conveyance	7
Video conferencing apps (e.g., Zoom, Other)	Conveyance	7
Dynamic Geometry (e.g., GeoGebra, Geometer's Sketchpad, Desmos geometry, Other)	Mathematical Action	5
Learning Management System	Conveyance	5
Data Analysis Software (e.g., Fathom, Tinkerplots, CODAP, Other)	Mathematical Action	3
Video-based discussion (e.g., Flip videos/Flip, Other)	Conveyance	3
Virtual manipulatives (e.g., Math Learning Center math apps, Polypod, Other)	Mathematical Action	3
Videos (e.g., 3-Act Tasks, Other)	Conveyance	2
Other		2
Electronic Discussion Boards	Conveyance	1
Dynamic Algebra (e.g., GeoGebra, Desmos graphing calculator, CAS tools, graphing calculator simulator, Other)	Mathematical Action	1
Simulations (e.g., PhET, Rossman Chance, Other)	Mathematical Action	1
Social Annotation (e.g., Hypothesis, Perusall, Other)	Conveyance	1
Spreadsheet (e.g., Google Sheets, Other)	Mathematical Action	1
Surveys (e.g., Google Forms, Poll Everywhere, Other)	Conveyance	1

Combining these four incidents of Desmos being mentioned, along with the three times it was unclear if Desmos was being used as a dynamic algebra or geometry tool, Desmos was the second most common technology tool (n = 7), following Google Slides (n = 9), that most positively influenced MTEs' instruction. The three data analysis software apps mentioned were CODAP (n = 2) and Fathom (n = 1). The two technology tools coded as "Other" were Mursion and OneNote. Other Specific technology tools mentioned once were Flip, GoReact, Padlet, PhET, Perusall, and Yellowdig.

Analysis of Free Responses Survey Items

In two open-ended questions, participants were asked to describe how they used the technology tool that had the most positive influence on their instruction and to explain why they continued to use it, including what aspects they found most useful, helpful, or valuable. Of N = 63 MTE participants, 49 (~78%) completed these free response items.

From our coding of the data, we found 17 unique codes that appeared more than once (see Table 4). Further details about the six codes that appeared most often are shared in the subsequent sections.

Collaborative Work

The code Collaborative Work was uniquely shared 19 times in 17 participant responses (~35% of the 49 MTEs participants who completed the free response questions), where two participants each shared two different responses that supported collaborative work. In all of these responses, collaborative work reflected both the social and cognitive presence of the CoI framework.

Specific technologies these participants mentioned included Google Slides (n = 7), Google Jamboards (n = 4), Google Docs (n = 2), Zoom breakout rooms (n = 2), along with Desmos, Nearpod, Padlet, and OneNote (each, n = 1). Of the eight specific technologies mentioned, seven are conveyance technologies. It is unclear if the eighth technology, Desmos, was being used as a mathematical action or conveyance technology. For Desmos to be considered a mathematical action technology, the MTE would have been using either the Desmos graphing calculator or an activity within Desmos Classroom that included one of the Desmos math tools (i.e., graphing calculator, dynamic geometry, polypad).

For Desmos to be considered a conveyance technology, the MTE would have created or used an activity within Desmos Classroom that did not include one of the Desmos math tools or any dynamic mathematical object. These uses of Desmos were not clear in Participant 20's response:

> I did not know much about Desmos before the pandemic and had never used it in my instruction. I used it primarily in a content course for elementary teachers after the onset of the pandemic. I used it for both asynchronous and synchronous activities to facilitate discussion about different mathematical topics related to measurement and geometry. … I found the individual but also collaborative capabilities of the tool. I liked the ability to pace students during synchronous instruction. Further in asynchronous instruction, I was able to make available responses from other students so that even in asynchronous instruction there was still an ability to learn from one another. I liked how the formats could vary so there was some novelty in interacting with

it for the students, while still within the confines of an organized and structured space.

Table 4
Data Codes and Their Frequency, Meaning, and CoI Component

Codes	Freq	Meaning	CoI Framework Components
Collaborative work	19	Students work together in a shared virtual space.	Social & Cognitive Presence: Social Discourse
Assessment	13	MTE discusses assessment.	Teaching Presence
Course organization	13	MTE discusses course schedule, links for class, handouts, answer keys, assignments, post videos, etc.	Teaching Presence
Ease of use	10	MTE discusses a digital tool as being easy to use.	Teaching & Cognitive Presence: Selecting content
Engagement	8	Students are engaged with content.	Social & Teaching Presence: Setting climate
Record of student work	8	MTE keeps student work for future use.	Teaching Presence
Dynamic tool	5	MTE discusses choice of tools (e.g., GeoGebra, Desmos, virtual manipulatives, etc.)	Teaching & Cognitive: Selecting content
Recording lecture	5	MTE records lectures for future use.	Teaching Presence
Convenience	3	MTE discusses tools that focus on convenience (e.g., Zoom is convenient instead of coming in-person, especially when students need to miss class).	Teaching Presence
Practice Teaching	3	Students are given an opportunity to teach; sometimes used instead of student teaching due to issues with K-12 classroom access.	Teaching Presence
Reflection	3	Students reflect on their work or assignment on their own.	Cognitive Presence
Student feedback	3	Students are given feedback.	Teaching Presence
Pace students	2	MTE discusses utilization of a specific digital tool, such as Desmos, because of its use of pacing in class.	Teaching Presence
Peer feedback	2	Student peers give each other feedback.	Social & Cognitive Presence: Social Discourse

Codes	Freq	Meaning	CoI Framework Components
Time	2	MTE mentions being able to save time.	Teaching Presence
Voice in class	2	MTE discusses teaching so the student's voice is heard.	Social & Teaching Presence: Setting climate
Share explanations	2	Students share explanations with class.	Social & Cognitive Presence: Social Discourse

It is clear, however, from Participant 20's response that they appreciated the collaborative capabilities within Desmos.

Of the 17 participant responses, 11 were similar to Participant 3's feedback about how Google Jamboards and Google Docs, both conveyance technologies, "allows multiple students to contribute to the document at the same time." Participant 18 specifically noted — and Participant 26 shared a similar comment — that Google Docs "allowed groups to work together even when not in the same physical space."

Participant 18 also noted that when using Google Docs, students "enjoy being able to compare what they were thinking to other groups, which is hard to do on paper." Participant 57 stated, "I find that the interactive Google Slides help to engage some of my students who are less likely to participate verbally, helping to make their ideas public." These subthemes of allowing multiple students to contribute, different physical spaces, comparing work, and making ideas public allowed students to collaborate more effectively.

The following quotations demonstrate how participants used multiple forms of collaboration:

> When teaching synchronously on Zoom, I would prepare my class slides using Google Slides. Whenever I planned a breakout discussion, I premade a slide for each breakout room that had directions, space for answers, etc. As they worked in rooms, I could monitor their thinking by watching the Google slides, visit a breakout room when desirable, and plan our post-discussion. I could also do this with Jamboard. … I continue to often use this now that we are fully in-person because it is a great formative assessment tool. Evidence of each group's thinking gets captured in real time. They can compare/contrast their ideas with other groups, and when I facilitate the post-discussion, I can use and project the evidence gathered in a variety of ways. (Participant 21)

> I previously used PowerPoint slides for my classes. I switched to Google Slides to allow for more active student participation in the synchronous format. Students were asked to add solutions, ideas, and information to selected slides. Sometimes this was done independently. Sometimes this was done with a team of peers in virtual breakout rooms. Even when we returned to in-person instruction, I decided to continue using Google Slides because I

> felt students were more engaged in the lesson when they had opportunities to contribute to the notes. I think students feel more ownership when they are given edit rights to the slides. They also like the chance to be creative when they populate the slides. (Participant 25)

These examples of MTEs' statements are evidence that these technologies helped MTEs facilitate and improve collaboration and communication among the students and between the students and instructor. These tools empowered students and faculty members to work together, regardless of their physical barriers, and promoted knowledge sharing, innovation, and teamwork that contributed to improved student learning.

Assessment

Participants also frequently referred to assessment in the survey. Desmos, Google Docs, and Google Slides were three tools — of the 10 tools mentioned for assessment — MTEs used to monitor and provide feedback to individuals or groups. These applications enabled instructors to evaluate students' understanding both during and after an activity for formative assessment.

For example, Participant 6 described how they utilized activities within the Desmos Classroom to both assess students' mathematical knowledge and teach pedagogy. Since the activities included one of the Desmos math tools, like creating graphs to model a story, their use of Desmos was as a mathematical action technology.

> I love how Desmos has incorporated features that allow for the 5 practices, which is what I use (model) and what our program teaches. For certain tasks I think Desmos is better than pencil paper, and it allows for quick sharing (like an Elmo would in class) of student work, but it's better because it can be anonymous! Also, I love their quick check-in screens. It gives me a pulse of the class that I can review very quickly and return to later.

Participant 31 shared how they used Google Docs to monitor student work and used the version history to determine each student's level of contribution:

> I use Google Docs to do collaborative lesson planning. Students draft in the document together and I can monitor group work in real time. I track what they are writing and intervene before work is submitted. I also use the Version History to confirm the contributions of each member. I give feedback using the Comment and Suggesting tools. When the students revise their work, I can click on "See all changes" and quickly skim for the edits I requested. I don't have to reread the entire lesson and I can see if they are actually attending to my feedback.

Video tools like Flip allowed Participant 32's students to explain their homework solutions, while their peers could view and respond to the videos:

> Instead of going over homework in class, each student selects a homework problem that they will present on Flip and submit for a grade. I approve the video before posting it and other students can view and comment/ask questions. This saves/saved time in class since I no longer have to go over many homework questions.

Participant 23 used autograde in their LMS for quizzes to help with assessment by offering students practice, immediate feedback, and multiple attempts to complete the quizzes.

> I created auto-graded daily "Study Quizzes" to push students to more regularly and more immediately review and study their notes from each day's lesson, and to give feedback on their understanding of assigned practice problems. The practice problems were never collected and graded, so they weren't "homework," in that sense. However, practice with the skills and concepts is necessary for students to internalize the content, and I used D2L to give some opportunity for students to test themselves about some skills and concepts. I allowed unlimited attempts on each Study Quiz until students maximized their score — up until the Due Date. Questions came from a question pool, so that each Study Quiz attempt could end up having different questions than a previous attempt. Each Study Quiz has around 8 questions.

Overall, assessment reflected the teaching presence of the CoI framework and was done using both mathematical action technology (n = 1, Desmos) and conveyance technologies, including Google Slides (n = 3), LMS (n = 2), as well as Flip, Google Classroom, Google Docs, Google Jamboards, Nearpod, OneNote, and Yellowdig (each, n = 1).

Course Organization

Under the code Course Organization, 13 MTEs described their experiences with conveyance and mathematical action technologies that offered organization and structure for their classes, thereby addressing teaching presence within the CoI framework. The types of technologies these participants mentioned included Google Classroom (n = 2), Google Docs (n = 2), and LMS (n = 2), along with Desmos, GeoGebra, Google Slides, Google Jamboards, Nearpod, OneNote, and Zoom (each, n = 1). The idea of archiving data in the form of lectures with conveyance technology like Zoom or taking class notes with Google Docs were useful.

The idea of sequencing course activities was also a common subtheme. Although it is unclear from Participant 20's response if they were using an activity within Desmos Classroom that included one of the Desmos math tools, it is evident that they used Desmos to structure their class, as they referenced using it to manage pacing students and sharing student work:

> I liked the ability to pace students during synchronous instruction. Further in asynchronous instruction, I was able to make available responses from other students so that even in asynchronous instruction there was still an ability to learn from one another. I liked how the formats could vary so there was some novelty in

> interacting with it for the students, while still within the confines of an organized and structured space.

Participant 19 also structured their class using technology — in this case GeoGebra — and created a “class” in GeoGebra:

> I created a “class” associated with this tool. I was able to create required constructions for students to complete as a part of the class. A nice feature was the ability to adjust the tools available to students which could make some constructions much more like hands-on compass and straightedge constructions.

By creating a class in GeoGebra, Participant 19 could streamline the teaching process and invite students to join the class, and then share constructions that their students could manipulate and interact with as they explored mathematical relationships in an engaging environment. Thus, this MTE utilized GeoGebra as both a mathematical action technology, allowing students to create constructions, and as a conveyance technology, since the necessary constructions were provided within the GeoGebra class.

Ease of Use

With the Ease of Use code, MTEs commented about various technologies that helped them in teaching their courses, thereby addressing teaching presence within the CoI framework. Although the responses for conveyance technologies varied, one MTE explained that they used their LMS to provide course structure and simplify their classes into a one-stop-shop for students to access all course materials through Google technologies. Overall MTEs’ references to Google technologies for Ease of Use included Google Classroom (n = 2), Google Docs (n = 2), Google Jamboards (n = 1), and Google Slides (n = 1).

The primary advantage of these Google technologies, as MTEs mentioned, was their collaborative shared spaces, which allowed students to work together on group projects either in class or individually from home. Other technologies MTEs discussed included CODAP, Fathom, Nearpod, and Zoom (each, n = 1).

One MTE, Participant 15, utilized Google Docs as their LMS because of how easy it was to use:

> I use a Google Doc consistently now as my LMS because I create a course schedule and post links to handouts, assignments, answers, and extra practice. I can easily update course materials as the semester progresses if needed. I continue to use a Google Doc because it is easier than Canvas to use and it also lets me and students quickly see the course schedule as well as links to all course materials concisely in a two-page document. I also have continued to use this because it is easy to give students access to course materials if they miss class.

Mathematical action technologies were also discussed in the Ease of Use code. For example, Participant 30 remarked how they utilized Fathom to have students "visualize the problem and simplify the difficulty of abstract content." Another MTE, Participant 33, used CODAP to "explore statistical phenomena and dynamics through graphical means." These tools were making it easier for teachers to convey content, which in turn made instruction easier.

In general, the Ease of Use code was evident in both conveyance and mathematical action technologies and varied from using an LMS or Google Docs to provide structure for a course to using Fathom to help simplify abstract mathematical content.

Engagement

Pertaining to the Engagement code, MTE participants mentioned using technology tools to encourage active engagement. These technology tools included Nearpod (n = 2) and Google Slides (n = 2), along with Perusall, PhET, virtual manipulatives, and Yellowdig (each, n = 1). As quoted earlier, Participant 25 wrote that when students added their solutions or ideas to Google Slides, students were more engaged. Students appeared to feel "more ownership when they are given edit rights to the slides," and they "like the chance to be creative when they populate the slides."

Participant 57 used Google Slides similarly and said,

> I find that the interactive google slides help to engage some of my students who are less likely to participate verbally, helping to make their ideas public. The slides also capture artifacts of our discussions and students' learning in each class session. I *hope* they serve as a reference for students as they work on their independent assignments for the course, and potentially in their field work.

Participant 61 also used a conveyance technology, Nearpod, and said:

> I used Nearpod while teaching online to try and increase the engagement of my students. Every few slides I embedded a quick check for understanding or graph or some type of data collection to keep students on task and engaged.

Participant 35 also used Nearpod to engage students in learning as it "enable[s] students to participate in teaching with virtual reality, 3D objects, PhET simulations, etc." They continued to write that "Nearpod enhances students' voice through open-ended questions, voting, quizzes, collaboration boards and more!" The use of the exclamation mark suggests that Participant 35 was enthusiastic about the numerous options available in Nearpod, many of which help enhance student engagement in learning.

When using the mathematical action technology PhET, Participant 34 mentioned that students were engaged in building mathematical models:

> I usually let students build their own mathematical models, or I build models for students to answer. ... In my opinion, the biggest advantage of PhET is that it allows students to fully participate in the class. Interesting dynamic simulation will greatly arouse

> students' interest. Secondly, it can realize interactive teaching and make students become the main body of the class.

Participant 63 also used a mathematical action technology, virtual manipulatives, to engage their students because the “action of using the virtual manipulatives can help students more deeply understand the mathematics content.” Two MTEs (Participants 27 and 32) used discussion boards — one used Perusall and the other Yellowdig — so that students could discuss the readings outside of class and the MTEs could read their peers’ discussions.

Overall, the code Engagement emerged from MTEs data in various ways, including encouraging students to add solutions or ideas to Google Slides; embedding quick checks in Nearpod; embedding virtual reality, 3D objects, PhET simulations, voting, quizzes, and collaboration boards in Nearpod; engaging students to build mathematical models in PhET; and engaging students in deeper mathematical learning through virtual manipulatives. When these methods of using technology facilitated discourse, they contributed to the intersection of social and cognitive presence within the CoI framework. Additionally, when these methods helped students construct meaning, they supported the cognitive presence of the CoI framework. Last, employing technology for student assessment contributed to the teaching presence within the CoI framework.

Record of Student Work

When examining the Record of Student Work code, MTEs indicated that collaborative boards spaces were particularly useful for them as they provided a record of student work. The technologies the eight MTE mentioned — two MTEs mentioned two different technologies — included Jamboards (n = 4), Google Slides (n = 4), and Google Docs (n = 2). MTEs noted that recorded data was helpful for planning a sequenced presentation of student work during subsequent whole-group discussions. The idea of selecting content exists at the intersection of cognitive presence and teaching presence within the CoI framework. For example, Participant 18 stated various benefits of having work recorded in Google Docs:

Having the collaborative space that could be shared among groups and also accessed as a reference later has been a nice bonus that I’ve continued to take advantage of even in in-person classes. First, students all know how to use it. Formatting templates with internal and external links (sometimes called a hyperdoc) has made them interactive and more than just a word processing tool. The collaboration aspect is flexible, since one person can type or multiple people can type simultaneously. Since they don’t get stuffed in a folder never to be seen again (and I link them to course materials), students refer to them more than they ever referred to their personal paper notes. They also enjoy being able to compare what they were thinking to other groups, which is hard to do on paper.

Participant 3 also mentioned using Google Docs, as “it eliminates paper waste and provides a record of students’ work during class.”

When using Google Slides and Jamboards, Participant 21 explained that their students "can compare/contrast their ideas with other groups, and when I facilitate the post-discussion, I can use and project the evidence gathered in a variety of ways." Participant 57 mentioned that they were hopeful students would use the recorded work in their future work:

> The slides also capture artifacts of our discussions and students' learning in each class session. I *hope* they serve as a reference for students as they work on their independent assignments for the course, and potentially in their field work.

Participant 26 mentioned how Google Slides replaced poster boards:

> When studying the 8 SMPs, each group developed its own poster and presented to the whole class. As such, we developed and studied each SMP. The posters were also able to be saved by the PST for later use as the posters created were all virtual in a shared ppt. I find that these items are more efficiently studied and found for further course use by PSTs.

Similarly, Participant 31 appreciated how Jamboards replaced poster boards:

> We would be able to see everyone's work and I could also archive it for later discussion. ... I like having the work archived. It isn't on poster paper anymore, and we can come back to it. I've also been able to more easily use work from one class when doing discussion in another class.

Overall, these eight MTEs found Jamboards, Google Docs, and Google Slides beneficial beyond the presentation tool to a collaborative space that could be archived for various educational purposes.

Discussion

This study investigated MTEs' instructional changes and revisions made during the onset of COVID-19 that persisted and why these changes persisted. The common themes that MTEs expressed for why the instructional changes made during COVID-19 persisted were that the technologies were easy to use and could be used to encourage collaborative work and as a record of student work, as well as for assessment, course organization, and engagement. These changes have persisted because they positively influenced the teaching, cognitive, and social presence — all components of the CoI framework — in the MTEs' courses.

MTEs intentionally created collaborative spaces — teaching presence — through numerous technologies, including Google Slides, Google Docs, Jamboards, Zoom breakout rooms, Desmos, Nearpod, Padlet, and OneNote. These technologies were used to facilitate and improve collaboration and communication among students and between MTEs and their students, thus supporting discourse, which exists at the intersection of social presence and cognitive presence within the CoI framework. They provided a space for students to work together, share ideas, share their creativity, discuss different strategies, provide feedback, and learn diverse perspectives from peers leading to deeper understanding and increased sense of inclusivity, thus enhancing both social and cognitive presence.

These technologies enabled students to work together regardless of their physical barriers, leading to increased engagement. Some of these technologies allowed multiple students to collaborate simultaneously on documents while adding their solutions, work, comments, ideas, and creativity, allowing for all voices to be heard. Students could also comment on or edit each other's work, which promoted knowledge sharing, innovation, and effective teamwork, contributing to improved learning — cognitive presence — and enhanced social presence. Therefore, the teaching presence of many MTEs in integrating collaborative board spaces into their instruction influenced both cognitive and social presence, resulting in a comprehensive educational experience for their students that represents the intersection of cognitive, social, and teaching presence within the CoI framework.

MTEs in this research also shared how they implemented mathematical action technologies and conveyance technologies, including adopting new technology or using technology tools in new ways, and retained some of these new instructional methods as a permanent part of their course's instruction. Three MTEs were using mathematical action technology in creative ways resulting in some blurring of the lines of mathematical action technology and conveyance technology.

These MTEs used GeoGebra or Desmos to create dynamic tasks for their students to explore mathematical relationships while also using the tools to organize their class using either the GeoGebra Classroom or Desmos Classroom. Therefore, they used these two technologies as both a mathematical action technology and a conveyance technology. McCulloch and Lovett (2023) identified the GeoGebra Classroom and Desmos Activity Builder as activity builders or "the conveyance and collaboration spaces in which math action technologies can be embedded" (p. 41). Embedding these mathematical action technologies into a conveyance technology helped support course organization for these MTEs. Students could easily access the activities in the GeoGebra or Desmos Classroom, and the MTE either paced their students through an activity or had their students complete the activities at their own pace.

Using the GeoGebra or Desmos Classroom features, MTEs were able to monitor student work — which provided a record of student work — and share student work among the class. MTEs valued the high level of engagement among their students, as the students could interact with one another both in person and asynchronously. Through sharing student work, students were able to analyze their peers' work, which encouraged them to reflect on their own thinking and analyze different problem-solving strategies. These interactions might help students understand and learn from their mistakes, foster a growth mindset, and enhance their TPACK. Such interactions may also help prepare preservice teachers for future instructional practices with Desmos, which some teachers have used to teach the concept of functions (Chechan, et al., 2023; Dy, 2024; Ebert, 2014).

In addition to blurring the intersection of conveyance technologies and mathematical action technologies, MTEs were creative and used conveyance technologies beyond the initial intended purpose. MTEs' epistemology, again, evolved as they leaned on their creativity to utilize technologies in innovative ways (as described by Girod & Cavanaugh, 2001). For example, one MTE mentioned using Google Docs as their LMS because it was easier than Canvas. They used it to create a course schedule and post links to handouts, assignments, answers, and extra practice. They believed it was easier to update course materials as the semester progressed and was easier to see the course schedule as well as links to all course materials concisely in a two-page document.

Other MTEs mentioned using Google Docs, Google Slides, and Jamboards as an assessment tool and pedagogical tool as they monitored student work and contributions — watching them record their thinking in real time — and selected and sequenced work for discussion. Students were able to easily access everyone's work during discussions or during later discussions since their work was archived and easily accessible.

MTEs also used Google Slides beyond its initial intended purpose and used it as both a presentation and collaboration program. MTEs mentioned that Google Slides provided a space for students to participate actively in learning as they created content in collaboration and added solutions, ideas, and information to slides. MTEs were able to monitor students' thinking as students populated the Google Slides. MTEs felt students were more engaged in the lesson because they were given the opportunity to contribute and edit the slides, which helped some students feel more ownership in the class. Google Slides also provided space for some students to be creative with sharing their ideas and provided a record of their work.

Uniquely using Google tools, in general, was a common theme for MTEs. The Google tools were effective options for MTEs in managing learning activities for their preservice teachers. The technology tools MTEs felt were most useful and persisted as technology for them in the classroom should be technologies that we, who teach preservice teachers, should strongly consider including in our mathematics content and methods courses. Research conducted in classrooms has demonstrated the effectiveness of technologies like Pear Deck, Google Slides, and Jamboards in high schools (Olarte & Roberts, 2023), as well as Google Slides and Jamboards in PK-2 settings (Sugimoto & Meister, 2022).

Because of their *ease of use*, including access, sharing, and organization, collaborative board spaces can be used by MTEs in their course organization to structure lessons. These tools encourage simultaneous collaborative work and real-time editing, increase engagement, and provide a record of student work, immediate feedback, and assessment. Google tools also offer voice typing and other accommodating features for students. Google tools integrate seamlessly with Google Classroom, which many K-12 teachers are using as a cost-effective, streamlined platform for digital learning. Introducing preservice teachers to these Google tools during their teacher preparation program will help develop their TPACK and provide them with the knowledge, skills, and attitudes they will need to integrate technology effectively into their classrooms to support both instruction and student learning.

In conclusion, MTEs — not technology — were the key to change (as also asserted by Girod & Cavanaugh, 2001) in the ways they enacted creative uses of technology to enhance and transform teaching and learning to meet both their pedagogical needs and students' needs. MTEs expressed various ways to use technologies to increase collaboration, assess their students, organize their courses, engage students, record student work, among others, and were attracted to these technologies because of their ease of use. They were creative in using technologies beyond their intended purpose.

Similar to Girod and Cavanaugh (2001), with the blurring of the purposes of certain technologies, we suggest that MTEs were pushing "new boundaries of . . . resources" (p. 42), as their epistemology evolved while enacting new methods for effectively using technology to enhance learning. Their creative uses of technology indicated that conveyance technologies and mathematical action technologies are not mutually exclusive. As LMSs evolved and MTEs became more comfortable using them, they may have sought more specialized functionalities that would enable them to tailor GeoGebra and Desmos to their specific needs or customize these tools to better align with their unique pedagogical approaches and learners' needs. These customizations may have included adding new features to GeoGebra and Desmos that were not initially apparent, such as creating a classroom and sharing student work, thus increasing these technologies' versatility and usability.

For some MTEs in our survey, these features were easy to use and helped improve their course organization and assessment, increased collaboration and engagement among students, and provided a record of student work. These uses of technology provided students opportunities to communicate and share their strategies, leading potentially to deeper understanding of the content, exposure to diverse perspectives, and fostering a sense of community and inclusivity — thus, creating an overall collaborative educational experience, the heart of the CoI framework. With the evolution of these technologies, there is an overlap between conveyance technologies and mathematical action technologies with activity builders falling within this overlap. Further research is required to explore the intersection of conveyance technologies and mathematical action technologies as our tech-driven educational landscape evolves alongside our digital technology savvy society.

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