Teaching mathematics during COVID-19: Lessons learned and best practices

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ABSTRACT

The COVID-19 pandemic has been called an educational catastrophe. It caused massive disruptions in education, learning loss for students, and massive increases in teacher workloads, stress, and health-related issues. There were significant issues of student disengagement and rampant cheating on assessments. This paper looks not at the huge negative impacts of COVID-19 but seeks rather to identify teaching practices in mathematics that may have been effective during the pandemic and that may be maintained after the pandemic to benefit students. What was learned is that best practices in mathematics teaching, while certainly influenced by the pandemic, remain best practices going forward. One major change is the continuing use of technology in mathematics teaching, a change in which the necessary use during the pandemic may have served as exemplars for teachers who will then continue these practices after the pandemic. This study also emphasized that exemplary teachers remained exemplary teachers before, during, and after the pandemic had impacted the teaching of mathematics.

Keywords: COVID-19, mathematics teaching, assessment, effective practices

INTRODUCTION

Siddiquei and Kathpal (2021) identify six educational constituencies impacted by COVID-19: students, instructors, institutions, infrastructure, content, and motivational factors. They list challenges for students including readiness for technical skills to learn online, network and speed issues, identification, interaction, and participation. For instructors, challenges were identified as preparation, teaching style transitions to online teaching, and communication barriers related to online teaching. Institutional challenges were training for teachers and students, technical and multimedia support, technical troubleshooting, and online counseling sessions for teachers. For content, challenges were the development of new material, multimedia tools, regular assignments, checking assignments, and receiving regular feedback from students. Technological challenges were network stability and speed, device suitability, ease of use, and tools for conferencing for online teaching. Motivational factors for teachers were identified as a sense of job security, salary being on time, family support, mental and emotional support of peers, and support from higher authorities (Siddiquei & Kathpal, 2021). All of these factors were impacted by the pandemic. This paper will address only some of these factors, with a focus on classroom factors such as pedagogy and assessment.

The COVID-19 pandemic was an unprecedented, prolonged disruptive and traumatic event for education around the world. Schools in Ontario, Canada, were closed to in-person learning for a total of 29 weeks over the period from March 2020 to September 2022. This was longer than for any other Canadian province and most other education jurisdictions. The abrupt shift to emergency remote teaching (ERT) was not by choice for either students or teachers. Thus, the usual reasons for selecting online learning did not apply (Knopik & Domagała-Zyśk, 2022). Trust and Whalen (2020) found a significant number of teachers were ill-prepared for ERT due to lack of sufficient or current technology skills. This issue was echoed by Hamam (2022) who emphasized that teachers not only require up to date skills but must also motivate their students to learn, no matter what instructional environment exists. In addition, the shift to ERT may also have resulted in limiting student creativity and metacognitive growth (Maor et al., 2023; Patston et al., 2021), although these conclusions are unclear at this time. However, it appears that educators who are outstanding classroom teachers were able to continue supporting their students' growth despite the limitations of ERT (Maor et al., 2023).

The negative impacts of the pandemic are well known. For students, these included reduced engagement in their learning, the creation of significant learning gaps, lack of social-emotional growth and interactions, mental health concerns, reduced ethical behavior and rampant cheating during assessments, and negative impacts on student attitudes towards education.

For teachers, the pandemic resulted in dramatically increased workloads, stress, mental and physical health deterioration, reduced teaching self-efficacy and confidence, leaves of absence, and in some cases, teachers leaving the profession due to pandemic-related factors. Teachers of mathematics faced all these negative impacts. But were there any positive outcomes from the pandemic-related changes that were forced on educators? For example, were there instructional or assessment strategies implemented during the pandemic that teachers felt would be beneficial to their students even after the pandemic-related measures were reduced or eliminated? This paper examines the impact of the pandemic on teachers of mathematics in Ontario and identifies pedagogical and assessment changes enacted during the pandemic that teachers plan to continue in their future practice. The study also considers how these changes compare to known research-affirmed best practices in the teaching of mathematics.

Unsurprisingly, there is relatively little current educational research related to the impact of COVID-19, and any such research is from early in the pandemic. To date, no research on the impact of the pandemic on the teaching and learning of mathematics has been found. Therefore, this study serves as a first step in addressing the research gap related to mathematics education during COVID-19. Pandian (2020) has called teaching during the pandemic "the new normal" (p. 8063). While this may not be the case, there is no denying that the pandemic has fundamentally changed educational practices.

RESEARCH QUESTIONS

1. What are the characteristics of effective mathematics instruction and how were they implemented during the COVID-19 pandemic?
2. What pedagogical practices were most effective during the pandemic, and which of these practices are most likely to be continued or added to teachers' professional practice after the pandemic?
3. What assessment practices were most effective during the pandemic, and which of these practices are most likely to be continued or added to teachers' professional practice after the pandemic?
4. What can educational jurisdictions do to support and encourage these best practices in mathematics teaching?

LITERATURE REVIEW

As stated, there is relatively little published research on the impact of COVID-19 on education. In addition, most published research is related to the very early stages of the pandemic, and almost no published research examines the impact on teaching over the entire course of the pandemic. Therefore, this literature review examines available research on COVID-19 and education across various jurisdictions, as well as research-affirmed practices on the teaching and learning of mathematics. The literature review examines the overall impact of the pandemic on education, technological issues, curriculum, pedagogy, assessment, and professional development. Issues related to the impact of the pandemic on the mental health of teachers and students are discussed briefly, although it is clear that there has been a significant impact in these areas.

Educational Leadership

With the sudden onset of the pandemic, educational leaders were thrown into completely unfamiliar territory. There were no resources or prior information on which to fall back (Reimers, 2020). Indeed, "during this pandemic education systems were flying blind and that in many cases teachers were left to their own devices, without adequate support from leaders and administrators" (Reimers et al., 2021, p. 37). Leaders scrambled to meet immediate demands, often around technological issues (Barajas et al., 2021; Chadwick et al., 2021).

School Configurations

School timetables in Ontario were realigned several times based on safety concerns.

From March 2020 until June 2020, learning was entirely online. In September 2020, many schools began using the quadmester model: students took two courses per day, typically with one 3-hour class in the morning, and a second 3-hour class in a different subject in the afternoon. In-person classes were limited to 15 students, masked and socially distanced. The two courses ran for approximately 44 days, followed by two different courses for a similar 44-day time period. Many schools overlaid this format with a synchronous online presence for students who had opted to stay fully online. This model was called hybrid synchronous. A variation on this model had one cohort of 15 students attend in class on day one, followed by a different cohort in class on day two. Some school boards chose to run separate online schools for those students who were fully online. Some school districts ran a modified quadmester system, with students taking two subjects alternating weekly with a different two subjects.

Another model used by some school districts was the octomester. In this model, students took one course at a time, full school days of 5 or 5.5 hours, for approximately 22 days. The students then moved to a different subject for the next 22 days. Once again, in-class learning was limited to 15 students, socially distanced and masked, and the hybrid synchronous model was overlaid.

Both quadmester (3-hour classes) and octomester (5- or 5.5-hour classes) provided suboptimal learning environments for students, resulting in reduced student engagement and reduced persistence when students faced challenging work. In addition, the short timelines for each course resulted in reduced student understanding and retention of course concepts. This was particularly prevalent in subjects such as mathematics, which tend to be cumulative in nature.

In September 2022 most boards returned to a semester structure, although students could still choose to remain entirely online, and hybrid synchronous overlays were common. Among the challenges for all these structures was maintaining engagement for students, especially those who were fully online. Some teachers commented that some online students did not even turn on their cameras, so the teacher had no means of monitoring student understanding.

Technology

This area had the greatest impact during the pandemic as jurisdictions pivoted to forms of online learning, including hybrid synchronous and hybrid asynchronous, as well as fully online learning. Deficiencies were quickly identified, including insufficient or obsolete physical equipment, connectivity problems, and lack of teacher current technological capacity (Bell et al., 2021; Chadwick et al., 2021). While it is a generalization to suggest that more experienced teachers frequently had not remained current in their technological knowledge for teaching, it does appear that newer teachers were more often able to cope with the sudden pivot to online environments (Thohir et al., 2022). However, most teachers dealt with the sudden pivot and some even used the pivot to enact creative ways to support their students' learning (Rath et al., 2020). For some students, the shift to online learning platforms actually increased their motivation to study mathematics (Öztop, 2022), although there is a large body of anecdotal evidence that other students disengaged from their studies either wholly or substantially. Many jurisdictions made substantial investments in technological upgrades (Reimers, 2020). While these investments were made out of necessity, they did serve to dramatically increase technological capacity in those jurisdictions. This could be seen as providing the necessary infrastructure should the jurisdictions need to pivot again to online learning in the future.

However, the shelf life of technology is very short, and ongoing investments in technology will be needed to provide realistic student support going forward.

A study by Foulger et al. (2017) foreshadowed some of these issues, identifying 12 technological competencies necessary for all teachers and advocating that teacher education programs ensure that all beginning teachers by competent in all 12 areas, and that in-service teachers ensure that their technological competence be kept up to date. The pandemic appears to have simply emphasized these needs.

Curriculum

Most jurisdictions attempted to maintain their current curriculum, although many postponed high-stakes assessments associated with that curriculum (Cooker et al., 2022). Some jurisdictions, recognizing that it was not possible to maintain "business as usual," opted to prioritize curriculum to emphasize important content and big ideas (Mohajeri et al., 2021).

Ontario chose a different path. In both 2020 and 2021, the Ontario Ministry of Education (OME) produced new or revised curriculum policy documents for mathematics. In June 2020, the OME issued a revised mathematics curriculum for Grades 1 through 8, to be implemented in September 2020 (OME, 2020). The revised curriculum included new strands such as coding, mathematical modeling, and social-emotional learning, which had never been included in the elementary curriculum previously. Teachers, already attempting to cope with pandemic-related changes, were expected to implement these new strands without any professional learning materials being readily available.

In June 2021, the OME released a new destreamed (detracked) Grade 9 mathematics course. This new course also included the new strands of coding, mathematical modeling, and social-emotional learning (OME, 2021). Once again, no professional learning was available at that time, and teachers were required to implement the new course in September 2021. The OME enlisted the Ontario Association for Mathematics Education (OAME), the provincial mathematics teachers association, to produce online learning materials and sample lesson plans for both this new Grade 9 course and the revised Grades 1 through 8 mathematics curricula. None of the learning resources produced through OAME was related to how instruction had changed due to the pandemic. Monitoring by OAME indicated that there were over 1,000,000 visits to the new resource website by June 2022 (OAME, personal communication, May 27, 2022), although it is not known how many of these visits were unique visitors. However, a sampling of the learning resources on the site showed that many of the lesson plans were very long, some in excess of 20 pages. Some lessons for the elementary panel were actually folders with as many as seven or eight different files. For teachers scrambling to adjust to teaching during the pandemic as well as implementing new curricula, these excessively wordy and lengthy lesson plans were of limited value.

It appears that the OME was unaware that teaching mathematics during the pandemic could not be just "business as usual." One student teacher was told by his associate teacher to "Just take everything that you used to do with pencil and paper and put it online." Clearly there was a lack of direction from the OME.

Some researchers considered the pandemic to be an opportunity to rethink curriculum and education as a whole. Leask (2020) found the shift to ERT revealed and enhanced the global connectivity of education. The pandemic has highlighted how connected the world is and how important it is today and will be in the future—that all graduates are able to work together across national and cultural boundaries as professionals and citizens regardless of their ability to engage in mobility programs (Leask, 2020, p. 1390). Similarly, Cun Uei and Ho Vui Shing (2021) broadened this discussion to include not only education but also industry, commerce, and trade, recognizing that the shift to remote work will fundamentally change how work is conceived. However, both these papers appear to minimize the immediate effects of the pandemic and make no comments on the learning gaps that have been created for students. These learning gaps appear to be exacerbated in educational jurisdictions that began the pandemic with limited technological capacity (Bell et al., 2021).

Pedagogy

Pedagogies were significantly disrupted by the COVID-19 pandemic and the pivot to online teaching and learning. These disruptions were felt throughout education systems. University teaching was negatively impacted, often because instructors had not kept up with technology (Lin-Siegler et al., 2016; Martin et al., 2023; Maulyda et al., 2021; Meng & Zheng, 2022; Saileela & Lawrence, 2021; Verrecchia & McGlinchey, 2021). This lack of readiness for ERT appears to be pervasive, although one study (Saileela & Lawrence, 2021) claimed that there was a high level of readiness by university professors in India, but this appears to be an outlier in the research.

Medical schools were also negatively impacted (Das & Al Mushaiqri, 2021; Scott, 2020; Unnikrishnan et al., 2020), typically because of the difficulty of doing hands-on learning such as anatomy dissections. Often similar issues were raised by secondary school teachers (Chamberlain et al., 2020) although some teachers described the ERT as opportunities to revise their teaching practices for the better. Vilchez et al. (2021) in discussing teaching physical education online found that ERT resulted in more student choice, higher engagement, and the use of social media platforms as teaching tools; however, they also identified negatives of ERT, including impacts on student mental health, the need to redesign lessons, equitable access to technology, and also maintaining engagement for some students.

Mathematics Pedagogy

Over the last four decades, there has been a massive paradigm shift in mathematics pedagogy. Traditional pedagogy in mathematics involved a transmission model in which the teacher demonstrated various procedures and algorithms; students then practiced these procedures and reproduced them on assessments. However, this relatively one-dimensional view of mathematics knowledge was supplanted by the realization that students are multidimensional learners and that more than simple knowledge needed to be taught and assessed. These new instructional strategies may be referred to as reform mathematics or sometimes ambitious mathematics teaching.

Reform mathematics involves students taking an active part in their own learning. Such strategies involve hands-on activities, use of technology, manipulatives, and problem-based learning. Typically, these activities are carried out in groups, with students working cooperatively on real-world problems and explaining their thinking to other learners (Moyer et al., 2018; Van Steenbrugge & Ryve, 2018). These strategies have been found to have positive effects on both student achievement and other related variables such as engagement and attitude (Blazar &

Pollard, 2023; Irvine, 2020a; Moyer et al., 2018; Smith & Star, 2007). These activities may also involve student choice (Irvine, 2017) or problem-posing activities (Irvine, 2017).

In a mixed methods study involving 53 teachers and 829 students, Blazar and Pollard (2023) identified active mathematics teaching, where students had hands-on activities, peer interactions, and physical movement as being the most effective instructional strategy for both increasing student engagement and increasing student achievement.

Ambitious mathematics teaching is a related concept, whereby teachers focus on eliciting student thinking and providing useful feedback to each student to move that thinking forward (Anthony & Hunter, 2023; Anthony et al., 2015; Kinser-Traut & Turner, 2020; Tekkumru-Kisa et al., 2020). Ambitious teaching's aim is to create positive learning opportunities for each student and develop confident mathematics learners (Gibbons et al., 2023; Rawlins et al., 2020; Youngs et al., 2022). It is based on the concept of a growth mindset (Dweck, 2006) which posits that through effort and persistence, every student can develop their mathematical skills, knowledge, and self-concept. Typically, an ambitious mathematics teaching environment involves similar activities as in a reform mathematics classroom, with an emphasis on problem-solving, inquiry, and exposing student thinking.

More recently, Liljedahl (2021) has proposed a focus on student thinking in mathematics, called thinking classrooms. He identifies 14 research-affirmed classroom practices to enhance student thinking as the ultimate goal of mathematics teaching. These practices include visibly random grouping of students and vertical non-permanent working surfaces for groups. The United States National Research Council identified five strands of mathematical proficiency: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick et al., 2001). Pedagogy therefore needs to address all five strands in order to develop mathematically proficient students.

Teaching Styles

A number of different teaching styles have been identified: traditional styles include command, practice, and task assignment; styles enabling participation involve reciprocal teaching, small groups, and microteaching; styles promoting individualization include practices such as inclusion, self-evaluation, self-teaching, individualized programs, and learner-initiated tasks; cognitive-related styles feature problem-solving and guided discovery; and there are also social styles and styles favoring creativity (Fernandez-Rivas & Espada-Mateos, 2019).

Much of mathematics instruction has featured traditional styles such as command and practice. However, reform mathematics and ambitious mathematics requires shifting teaching styles to more participatory and cognitive-related styles such as small groups, problem-solving, and guided discovery. These styles involve significantly more teacher preparation as well as a markedly different lens on what constitutes mathematics teaching. There is some evidence that teaching during the pandemic resulted in a reversion to more traditional mathematics instruction for many teachers. However, some teachers were able to maintain a modified version of the styles that support reform mathematics and ambitious mathematics teaching.

Affective Considerations in Mathematics Teaching and Learning

Hativa et al. (2001) studied university-level teaching, and their four dimensions of effective teaching—interest, clarity, organization, and positive classroom climate—apply as well to elementary and secondary teaching. Devlin and Samarawickrema (2022) emphasize that the motivation of students is a key criterion for effective teaching.

Beyond cognitive considerations, there is a large body of research indicating that successful mathematics teaching must consider other dimensions of students, such as engagement, attitudes, beliefs, and emotions. Shernoff et al. (2003) found that mathematics classes required high cognitive intensity, but that students were typically not engaged in their learning. They found that students were less engaged and more negative about their learning in mathematics than in any other subject. There are significant correlations between engagement and achievement in mathematics (Bodovski & Farkas, 2007; Moller et al., 2014).

Engagement is also a key dimension of successful student learning. There are multiple correlations between engagement and educational factors such as perceptions of mathematics (Fung et al., 2018); attitudes toward mathematics (Bodovski & Farkas, 2007); student agency in mathematics (Collie & Martin, 2017); and student graduation rates as well as students pursuing higher education (Bodovski & Farkas, 2007).

Interest

In addition, student interest must be considered. Sun and Rueda (2012) identified interest as a key criterion for successful distance learning, along with student self-efficacy and self-regulation. Thus, students who are uninterested in the material may disengage and may also feel reduced self-efficacy, thus reducing self-confidence and achievement.

Hidi and Renninger (2007) identify four phases of student interest. Initial interest is triggered by a situation or topic (Triggered Situational Interest); if interest in the topic is sustained (Maintained Situational Interest), the student becomes more focused and persistent in their study of the topic; if the student independently re-engages with the topic and asks self-generated questions, they build their own knowledge base about the topic (Emerging Individual Interest). The final stage, Well-Developed Individual Interest, is characterized by willing re-engagement with the topic, positive feelings toward the topic, and self-regulation whereby the student generates questions and seeks answers, persevering and asking for feedback to grow their knowledge base. Teachers need to recognize these stages of interest and endeavor to trigger situational interest whenever possible, with the ultimate goal of moving students towards well-developed individual interests when possible.

Real-World Situations

One way of triggering student interest is to embed mathematics in real-world situations. Providing such context should not only generate interest but also encourage engagement and persistence. It is important that the context is real to the student. Irvine (2015) provides a list of what constitutes the real world to a student: (a) students could use the mathematics immediately, for example, in their part-time jobs, budgeting, or sports; (b) students could use the mathematics in another subject, in the near term, such as in science, geography, technical shops, family studies; (c) someone close to the student could or did use the math content, such as a family member, relative, adult acquaintance; (d) there were examples in the real world of people using the mathematics; and (e) the mathematics flowed from an investigation, experiment, or model in which the students were involved (p. 109).

As much as possible, teachers of mathematics need to embed the mathematics in students' real worlds. This can also be done by attaching the mathematics to some external event in the news (Irvine, 2022). By attaching the mathematics to a real-world situation that is currently unfolding in the news, there is a clear link to the utility of the mathematics, and student interest and engagement are heightened.

Assessment

Assessment in Ontario schools is governed by the policy document *Growing Success: Assessment, Evaluation and Reporting in Ontario Schools* (OME, 2010). This document mandates that students be assessed across four categories: knowledge, application, communication, and thinking/inquiry/problem-solving. It also emphasizes that assessment is a process, not an event; that students be given multiple opportunities to demonstrate their understanding; and that students be given opportunities to demonstrate their understanding in multiple ways. These ways could include examinations, tests, quizzes, assignments, presentations, portfolios, models, and other ways. This requires teachers to broaden their assessment strategies to include interviews, peer and self-assessment, rubrics, performance tasks, problem-posing, and problem-solving.

It is important that assessments be congruent with instructional strategies. Thus, in reform mathematics classrooms, assessments need to reflect the attributes of instructional strategies that support reform mathematics principles. This means that assessments need to be authentic (i.e., grounded in real-world situations, contextualized to place the mathematics in context) and problematized, illustrating that the mathematics can be used to solve an actual problem or meet a real need (Villarroel et al., 2018).

Growing Success (OME, 2010) identifies three types of assessment: assessment for learning, assessment of learning, and assessment as learning. Assessment for learning (formative assessment) is ongoing throughout the learning process and identifies for the teacher the stages of learning of each student on each topic or task; the teacher then provides descriptive feedback for the next steps in the learner's progress. Assessment of learning (summative assessment) may be closer to the traditional concept of assessment and may be used for evaluation as well. Summative assessments provide opportunities for students to demonstrate their learning. Assessment as learning is the metacognitive dimension of a student's learning, with students identifying their personal learning processes and building upon those to move towards self-regulated learning.

The *Growing Success* document states that overall expectations of the curriculum policy documents must be assessed. This is frequently accomplished by assessing specific expectations related to the overall expectation and then making inferences regarding the student's understanding of the overall expectation.

Of the five strands of mathematical proficiency identified by the United States National Research Council (Kilpatrick et al., 2001), procedural fluency appears to be the most frequently assessed strand, perhaps due to teachers' familiarity with this strand and the relative ease of assessing this strand compared to the others, even though all five strands are important in assessing a student's mathematical proficiency.

IMPACT OF THE COVID-19 PANDEMIC

In Ontario, schools closed to in-person learning on March 20, 2020, teachers were given little time to prepare for this shift, and classes began in April. For the remainder of that school year, online instruction was the only option. Online instruction was asynchronous and required a minimum of 3 hours per week in each subject. No professional learning was available to teachers on how to teach in an online environment. Access to technology was a major issue. This was the beginning of a total of 29 weeks of online learning, occurring at various times over the next 2 school years.

In the school district under study, beginning in September 2020 secondary schools ran a quadmester system, with a hybrid synchronous overlay. In-person classes were limited to 15 students and the cohort stayed together, with social distancing in classes. In February 2021 there was a change to a modified quadmester, with students taking two subjects per week on alternate weeks. Synchronous hybrid was still employed, with some students attending in-person classes and others only online. This system continued until February 2022, when a change to a four-subject semester system was reinstituted, although still with social distancing for in-person learning and synchronous hybrid to accommodate fully online students. In September 2022, the hybrid option was eliminated, although students could still choose fully online learning and the school district accommodated those choices. In some school districts, this was accommodated through the creation of online schools, but not in the school district under study.

The following section provides information on student and teacher issues related to the pandemic and is not specific to the school district under study.

Student Engagement, Learning, and Mental Health

This study does not focus on the negative impacts of the pandemic on student learning, which are becoming well-known and the subject of continuing research. For students, these included reduced engagement in their learning (Martin et al., 2023) and the creation of significant learning gaps (Doreleyers & Knighton, 2020; Klosky et al., 2022; Tranjan et al., 2022). In addition, students lacked social-emotional growth and interactions (Houghton et al., 2021) and also experienced mental health concerns (Houghton et al., 2022; Iqbal et al., 2022; Seah, 2022). An additional major issue was reduced ethical behavior and rampant cheating during assessments. All these factors had a negative impact on student attitudes towards education (Gute et al., 2019).

Teacher Issues

The pandemic resulted in dramatically increased workloads for teachers, stress (Casacchia et al., 2021), and frustrations related to technology and the lack of suitable resources. This resulted in issues related to mental and physical health deterioration (Pressley, 2021) and increases in leaves of absence and early retirements (Bintliff, 2020). The reduced teaching self-efficacy and teacher confidence continued to contribute to these negative impacts, even after the end of pandemic-related modifications to the education system (Pressley, 2021). There is some evidence that there was a differential impact of these factors, with early-stage teachers demonstrating less impact than later-stage teachers, especially teachers who had not maintained their technological currency (Moorhouse, 2021).

METHODOLOGY

This research utilized a mixed methods methodology (Teddlie & Tashakkori, 2009), employing both qualitative and quantitative dimensions. One aspect of the study employed narrative (Savin-Baden & Howell Major, 2013). Three narratives were provided by teachers who taught mathematics during the pandemic; one of these teachers also functioned as an instructional resource teacher for the district for a portion of the pandemic. In addition, a 20-question survey involving both Likert-scale and open-ended response questions was analyzed. Respondents for the survey were recruited in two ways. A convenience sample was recruited through two advertisements placed in the *Ontario Mathematics Gazette*, the provincial professional journal for mathematics teachers in Ontario, at 3-month intervals. In addition, a snowball sample based on mathematics teachers known to the four authors as well as survey respondents, was solicited through personal emails. The survey focused on two aspects of teaching mathematics: pedagogy and assessment practices.

Teacher Narratives

The teacher narratives provided thick personalized descriptions of teaching during the pandemic and humanized the perceptions of teachers involved in very difficult situations. The narratives allowed the three teachers to convey their failures and successes and graphically illustrate their feelings and emotions over the almost 2.5 years that the pandemic impacted their teaching. The three narratives were analyzed using content analysis (Krippendorff, 2013) to identify common themes as well as to identify individual differences among the authors.

Three exemplary mathematics teachers (coauthors of this paper) responded to question prompts about teaching mathematics during the pandemic. All three were identified as outstanding teachers by their peers. All are very proficient with teaching with technology, which allowed them to avoid some of the difficulties experienced by some other teachers when the abrupt pivot to online learning occurred in March 2020.

Amanda Cloutier has taught mathematics and French as a Second Language for 6 years. A recent provincial teacher of the year award winner, Amanda is the founder of FSLDisrupt, an organization dedicated to empowering French teachers to diversify the texts used in their classrooms. She has been a conference presenter, coach, and staff sponsor for multiple clubs, including a STEM club that she ran during the pandemic.

Paul Alves has taught for 26 years and is twice past president of the Ontario Association for Mathematics Education (OAME), the provincial professional association for Ontario teachers of mathematics. Paul is a National Instructor for Texas Instruments and a frequent conference presenter at provincial, national, and international conferences. Paul has been a department head in four schools and is currently a district instructional coach in mathematics.

Wendy Telford has 22 years of teaching experience. She has been a provincial mathematics coach as well as district coordinator for the Math GAINS provincial mathematics coaching program. The Math GAINS Co-Teaching Initiative was an OME-funded professional development initiative that provided job-embedded professional learning opportunities for Grades 7 to 12 mathematics teachers. Over a 3-year period, Wendy led a team of instructional coaches supporting teachers in 49 schools through co-planning, co-teaching, and co-debriefing of mathematics lessons. An avid sports coach as well, Wendy recently retired from teaching in June 2022. The three coauthors were asked to respond to question prompts concerning teaching mathematics during COVID-19. See Table 1 (Appendix).

The narratives were quite wide-ranging and dealt with a number of teaching-related factors. This paper focused on the pedagogy and assessment aspects of the narratives.

Teacher Survey

The teacher survey focused on two factors: pedagogy and assessment. The Likert-style survey questions were analyzed using descriptive statistics. Likert responses were coded using 1=Strongly Agree, 2=Agree, 3=Neither Agree nor Disagree, 4=Disagree, 5=Strongly Disagree. Therefore, a lower mean response score indicated agreement (e.g., I feel that many of my students developed learning gaps; M=1.44 indicated strong agreement) while a larger mean response score indicated disagreement (e.g., I assessed students the way I usually do; M=4.18 indicated strong disagreement). The open-ended survey questions were analyzed using content analysis to identify best practices that teachers indicated they planned to continue after the pandemic and to analyze why these practices were effective.

RESULTS

In the following, themes from the narratives are presented, followed where appropriate by survey responses. The two major foci of the survey (pedagogy, and assessment) echoed the teacher narratives to a large extent. The survey also asked respondents to identify strategies that they planned to continue in their teaching practice after pandemic-related restrictions were eased and to provide descriptions of lessons or activities that they felt worked well for their students. Most insightful were the reasons provided for why these lessons or activities were effective for their students' learning.

Survey Responses

There were 55 responses to the survey. A large majority of respondents (92.73%) were secondary school teachers of mathematics, with most of the remainder being middle school mathematics teachers. The mean number of years of experience of the responders was 13 with a standard deviation of 5.14. Figure 1 (Appendix) shows the types of teaching that were in use during the pandemic. The wide variety in Figure 1 is due to two factors: different teaching modalities were used during different times due to lockdowns or other mandates, and different school districts enacted differing strategies during the various periods of the pandemic—there was no single strategy mandated by the Ontario Ministry of Education.

Over 76% of survey respondents indicated that mathematics could not be taught in the usual way during the pandemic, and over 90% felt that mathematics content could not be taught with the usual depth of understanding. Similar to other early pandemic research, over 90% of respondents identified learning gaps in students' mathematical knowledge (M=1.44, SD=0.81). While not a focus of our research, issues with technology featured significantly in teachers' responses: lack of adequate technology at school or at home, outdated technology in schools, connectivity issues that sometimes resulted in abbreviated or even canceled sessions, inadequate technology support, and lack of professional development related to teaching with technology.

Pedagogy

Figure 2 (Appendix) illustrates teachers' responses concerning how the pandemic impacted instructional strategies. In Figure 2, the top bar represents "Easier to teach than pre-pandemic"; the second bar is "Same as pre-pandemic"; the third bar is "Harder to teach than pre-pandemic"; and the fourth bar is "Could not do during pandemic." Unsurprisingly, responses to all facets of instruction that were surveyed were found to be more difficult to teach. Harder to teach than pre-pandemic responses ranged from 47.27% (assigning homework) to 81.48% for problem-solving. Even Socratic lessons were found to be more difficult to teach (68.63%) or impossible to teach (5.88%). More traditional strategies such as practicing procedures were somewhat less impacted although while 30.91% of respondents indicated that these could be taught at the same level as pre-pandemic, 67.27% said it was more difficult, and 1.82% said practicing procedures could not be taught during the pandemic.

Of major concern were the responses for instructional strategies congruent with reform mathematics or ambitious mathematics teaching. 65.45% of respondents stated that group work was more difficult to implement, and 30.91% stated that group work could not be done during the pandemic. Similarly, for cooperative learning, 72.22% said this was more difficult, and 25.93% said cooperative learning could not be implemented. Thus, only 1.85% of responding teachers said that cooperative learning could be implemented at the same level as pre-pandemic instruction.

Similar results were found for investigations (74.55% harder, 14.55% impossible) and problem-solving (81.48% harder, 3.70% impossible). So, the key strategies related to reform mathematics, which are strongly supported by research evidence as being optimal for the learning of mathematics, were found to be much more difficult or impossible to implement during the pandemic. As a consequence, teachers who followed the philosophy of reform mathematics were faced with very difficult and labor-intensive circumstances.

Of the teachers surveyed, 76.36% stated that they incorporated new ways of teaching (M=2.18, SD=0.64), and half (50.1%, M=2.65, SD=1.44) stated that using technology made them more creative teachers.

Assessment

Over 87% of teachers indicated that they could not assess students' progress in the usual ways (M=4.15, SD=0.80); 72% stated that they needed to learn and employ new ways of assessing students (M=1.69, SD=.0.77) There was concern expressed by over 96% of teachers that their assessments did not accurately reflect their students' learning (M=3.96, SD=0.89). Three factors were proposed as reasons for this lack of accurate assessment. One factor related to the difficulty of assessing students online is that in some cases students did not engage or even turn on their computer cameras. Teachers were unable to read students' facial expressions or body language, which in face-to-face settings are frequently used to formatively assess students' understanding. This dramatically inhibited teachers' ability to provide useful feedback, which has been shown to be key to students' understanding and progress (Hattie, 2003, 2009; Hattie & Timperley, 2007), and thus negatively impacted students' learning.

A second factor related to students cheating on assessments. Sites like Photomath® or Wolfram Alpha® can be used by students working remotely to obtain solutions to most mathematics problems without the students demonstrating their own understanding. This factor mandated that teachers change their assessment practices, and 92% of teachers agreed that they needed to change their assessment practices during the pandemic (M=4.15, SD=0.80). For example, replacing the usual written test with individualized assignments (e.g., Irvine, 2020b) and open-ended questions so that there were no standard responses. In addition, student-posed problems could be utilized (Irvine, 2017).

A third factor hindering assessment was that some school boards, as well as the Ontario Ministry of Education, mandated that during specific times of the pandemic, students could not receive lower marks than they had prior to the start of pandemic restrictions and that final examinations either could not be administered or were optional—students could choose to write them if they wished, but would not be penalized if they chose not to write exams.

All of these factors acted to mitigate the accuracy of assessments of student understanding in mathematics. There was also discouragement expressed by teachers (as well as more conscientious students) that inflated student grades were used for other purposes such as university admissions and scholarships.

Addressing these assessment issues occurred in two ways. The first was to invent strategies to reduce cheating. These strategies included creating multiple versions of assessments, randomly assigned questions, open-ended questions, and student-posed questions. Cloutier described a unique strategy whereby each student chose a set of their own numbers to be used on assessments. These numbers were then substituted as parameters in questions so that each student's question was unique to them. Cloutier provided this description: For example, students would be given the question: Solve $Ax-B4x+C>0$, and their first step would be to substitute A, B, and C for their personal and unique numbers. This guaranteed that everyone's assignment in the class would be different, but they still needed to demonstrate the same skill. Students had to submit their rough work and for three assignments over the course of the year (student choice), they needed to submit a video explanation of their work. Cloutier later extended this concept using DeltaMath® so that test questions were unique to each student.

A far more important shift in assessment was the extended use of interviews and student video explanations. This allowed for a focus on student understanding and exposed students' thinking during problem-solving, resulting in students demonstrating deep learning about concepts. 67% of teachers who responded to the survey indicated that they planned to continue or expand the use of interviews as assessment tools after the pandemic.

Best Practices and What Will Be Retained by Teachers Going Forward

Teachers were asked about three aspects of their teaching practice that may or will change moving forward: use of technology, pedagogical changes, and assessment changes.

Technology

76% of survey respondents indicated that they will continue to use or begin to use more technology in their classes. These responses can be divided into two areas: learning management systems and mathematics-specific technologies. Teachers indicated that they will continue to use learning management systems such as Brightspace® and various Google applications as well as virtual classroom tools and videos. Also mentioned were some social media applications such as WhatsApp®.

In the mathematics-specific technologies, the most frequently mentioned were Desmos®, DeltaMath®, and Geogebra®. It was unclear whether some of these teachers had previously used these applications. Also identified were more general applications that can be applied to mathematics, such as Disrupt® and Kahoot®.

Pedagogy

59% of respondents indicated that they will make changes to their pedagogy. These changes included more group work and cooperative learning, attention to learning styles and modalities, investigations and problem-solving (with or without technology), better chunking of curriculum, and better incorporation of technology into their teaching. 20% of the strategies mentioned are elements of reform mathematics. An additional 12% of respondents explicitly identified thinking classrooms as a goal of their revised practice. As with the technology responses, it was unclear to what extent teachers had been incorporating these practices prior to the pandemic. Teachers were in slight agreement (50.1%) that using technology made them more creative teachers (M=2.69, SD=1.14) and only 31.9% felt that they were more creative teachers as a result of teaching during the pandemic (M=3.27, SD=1.13). However, a large majority (72.73%) incorporated new ways of teaching (M=2.18, SD=0.84), and 74.54% incorporated multimedia into their lessons (M=2.16, SD=0.90).

Assessment

Responses in this area were heavily influenced by the problems around cheating that arose during the pandemic. 30% of respondents indicated that they will return to pre-pandemic assessment methods because of concerns about cheating and the desire to have valid data about student achievement. However, there were multiple references to more authentic assessment practices, including conferencing, student interviews, student video demonstrations, open-ended problems, student problem posing, journals, and peer assessment. Several teachers indicated that their assessment practices had changed significantly and would continue to do so moving forward. "I've moved away from tests and quizzes (not completely, but mostly). That will probably never return at the level I used to use them" (survey respondent #44).

What was striking about these responses was the adherence to a focus on serving their students to the best of their abilities. There is no claim that these survey responses are representative of mathematics teachers as a whole. Certainly, the three coauthors of this paper are recognized as outstanding teachers of mathematics. However, the responses to our teacher survey do indicate that effective teachers will continue to overcome adversity and remain focused on student success; they will seek out and implement best practices to optimize opportunities for students to learn mathematics at a deep level.

DISCUSSION

There is no question that the COVID-19 pandemic caused massive disruptions to education. These disruptions will result in lingering learning gaps for some students that will continue to damage their learning and their attitudes toward learning, possibly for decades to come.

The three coauthors of this paper were in the classroom during the pandemic. They faced all the frustrations and obstacles that all teachers coped with, such as technological issues, lack of student engagement, assessment issues, and pedagogical limitations. However, what stood out in all their narratives was their attitude. They remained focused on student success. All of them learned new technologies to better serve their students. When district professional development proved inadequate, the three coauthors sought out other sources, such as social media professional groups and online resources, or they engaged in individual professional learning. This occurred despite the hugely increased workload that the pandemic caused.

All three coauthors adapted lessons to fit the new limitations of remote teaching (see Appendix for examples). Throughout the pandemic disruptions, they endeavored to remain true to the sound principles of mathematics teaching that gave their students the best opportunities to succeed. Thus, their students used appropriate technological tools to engage in ambitious mathematics that focused on real-world problem-solving, problem-posing, investigations, and deep learning. Other tools such as manipulatives were adapted to utilize whatever materials could be found in the students' own environments. Cooperative and group learning was modified to use online forums. Ways to expose student thinking were created to ensure that students' understanding was maximized.

Affective Dimensions

Di Martino and Zan (2010) found that virtually all students begin school with high levels of intrinsic motivation. They found that for mathematics most students have a turning point, a triggering event that turns their intrinsic motivation into dislike, fear, or anxiety about mathematics. It is possible that the COVID-19 pandemic represents such a turning point for some students. The issues around lack of student engagement and possibly the regression of teachers' styles to more traditional styles such as command and practice may mitigate students' attitudes towards mathematics. This may have far-reaching effects not only on those students' careers in mathematics but also on their entire educational progress. It is imperative that teachers find ways to address not only the content learning gaps that have occurred but also the impacts on engagement, attitude, and motivation of students to return these students' academic careers to appropriate levels.

Technology

The SAMR taxonomy derived from Puentedura (2006) identifies four levels of applications of technology. See Figure 3 (Appendix).

The SAMR taxonomy is bottom-up based on the role of technology. The bottom level is substitution, in which new technology is used to perform the same task as was previously done, either with or without technology. For example, a learning task previously done face-to-face would now be done online, but the task remains the same. In the second level, augmentation, the new technology is a direct substitute for old technology, but with functional improvement. An example could be the use of Google Jamboard® to replace and possibly enhance face-to-face brainstorming. At the modification level, the new technology allows for significant redesign of tasks. Here an example might be the use of instructional videos to create a virtual learning environment. Finally, at the top level, redefinition, the technology allows for the creation of new tasks that would not have been possible without the technological advance. During the pandemic, creative teachers developed numerous tasks that enhanced student learning. This often required the teachers to learn new technologies themselves. Cloutier (fourth author) created an award-winning application of Disrupt®, despite facing all the stress and pressures of teaching mathematics during the pandemic.

Rogers et al. (2005) identified levels of innovation adoption: innovators, early adopters,

adopters, late adopters, and resistors. The pivot to emergency remote teaching (ERT) due to COVID-19 removed any choice for teachers to adopt technological solutions. However, it is clear that some teachers made this pivot reluctantly, often because they had not kept their own technological capacity up to date.

It is interesting to note that teachers who had been innovators in technology prior to the pandemic continued to be innovators during and after the pandemic. Cloutier (fourth author) is an excellent example of such a teacher, as are the other coauthors. All of these exemplary teachers continued to learn and implement new technologies throughout the pandemic. They all went beyond what was required to cope with ERT to utilize technologies that enhanced the learning of their students.

One of the consequences of teaching mathematics during COVID-19 was an increased use of technologies to support and enhance student learning. This is something that will continue in mathematics classrooms, as teachers have been shown the utility of employing technology to generate student interest, increase engagement, and develop richer learning tasks for students. 76% of teachers indicated that they will continue to use technologies in their mathematics classrooms after the pandemic. The forced shift to technology during the pandemic demonstrated to mathematics teachers the benefits of incorporating technology into their instructional practice.

Research Questions

Research Question 1

RQ1 asked: What are the characteristics of effective mathematics instruction and how were they implemented during COVID?

Marshall et al. (2009) identified key characteristics of effective teaching, not specifically mathematics instruction. They identified active student engagement as critical to effective instruction; that digital technology can play a role in active engagement, by empowering students to engage in their own learning, through online research and the use of digital tools; and that students need to have some level of autonomy in their learning through being given some choice in what and how they learn and how they demonstrate their understanding; that learning has to extend beyond the classroom and have connections to the real world; and that engaging students must begin early in the students' academic lives.

Mathematics instruction must reflect the tenets of reform mathematics and focus on student thinking and understanding. Mathematics learning must be active, connected to the real world, involve hands-on through using manipulatives and other modeling activities, feature open-ended problems and student problem posing, and give students choices. Appropriate use of technology allows students to better investigate real-world issues that generate student interest and promote heightened engagement.

Research Question 2

RQ2 asked: What pedagogical practices were most effective during the pandemic, and which of these practices are most likely to be continued or added to teachers' professional practice after the pandemic?

Instructional practices that continued to focus on student success were most effective. These reflected the characteristics of reform mathematics, as outlined above. While activities required modification due to the impact of the pandemic on instruction, effective teachers were able to modify activities to continue to engage students in their own learning. Maintaining student engagement during remote instruction was clearly an issue, but by utilizing resources readily available in the students' homes, teachers were able to keep most students engaged in the learning of mathematics.

Research Question 3

RQ3 asked: What assessment practices were most effective during the pandemic, and which of these practices are most likely to be continued or added to teachers' professional practice after the pandemic?

Assessment was clearly an issue during the pandemic. Teachers who attempted to continue traditional assessment practices such as tests and quizzes were frustrated by rampant student cheating. 96% of teachers felt that their assessments did not accurately reflect student understanding. Successful assessment practices focused on student understanding and provided ways for students to demonstrate that understanding, through the use of interviews, conferences, video presentations, and asking students to provide their rough work and explain their thinking.

Research Question 4

RQ4 asked: What can educational jurisdictions do to support and encourage these best practices in mathematics teaching?

There are a number of ways that educational jurisdictions can support their teaching staffs, not necessarily in anticipation of another catastrophic event such as COVID-19, but to provide required support for any unanticipated event. Certainly, teachers need to be encouraged to maintain their technological expertise. This is difficult due to the rapid changes in technology, but a fundamental base of technological competence is now a prerequisite in today's classrooms. The three coauthors of this paper, while very strong in technology prior to the pandemic, all learned new technologies as required for them to adequately support their students. It is also important that jurisdictions maintain up-to-date technological hardware and software so that a shift to remote learning is possible in as seamless a manner as possible.

Educational jurisdictions also need to identify the big ideas and enduring understandings for each course. During the pandemic, individual teachers were left to prioritize curriculum for each of their courses, without centralized support. If the OME had identified curriculum priorities for mathematics courses (see Figure 4, Appendix), teachers would not only would have had additional time to focus on student instruction but there would have been more consistent curriculum coverage. Curriculum prioritization is useful not only for unexpected catastrophes but also for ordinary school years. By identifying big ideas and enduring understandings, teachers could then focus on ensuring that these topics received significant treatment, moving student learning forward on the big ideas of mathematics.

It is also clear that during a pandemic is not the time to introduce course revisions or completely new courses. This is particularly true when professional learning on these new curricula is lacking or non-existent, but it is certainly true that new content introduced during a crisis will receive relatively less attention and implementation than if such curricula were introduced during normal school functioning, and introduced with adequate implementation lead time so that teachers could become familiar with the new content and determine optimal ways of teaching it.

Educational jurisdictions need to provide prompt and timely professional development opportunities to ensure that all teachers are versed in research-affirmed instructional strategies as well as appropriate assessment strategies. Over 12% of teachers surveyed indicated that they planned to implement thinking classroom strategies after the pandemic. These teachers have already moved beyond reform mathematics and ambitious teaching to incorporate the latest research evidence into their professional practices. Jurisdictions need to support those innovator teachers with appropriate professional learning opportunities while at the same time moving later-adopter teachers into reform mathematics principles of instruction. Informing teachers of the most recent research-affirmed strategies and providing ways to implement these strategies is a key function of every educational jurisdiction.

In the same way, the pandemic exposed the inadequacies of "traditional" assessment strategies such as reliance on tests and quizzes. Research has already identified disconnects between these types of assessments and actual measures of student understanding (Irvine, 2019b). Support for more in-depth assessment strategies such as conferences, interviews, portfolios, and student video presentations is the responsibility of all jurisdictions. Teachers are often willing to consider implementing new strategies, but they need to know about them and understand the strengths and weaknesses of the strategies.

Teachers also need to be made aware of paradigm-shifting assessment strategies such as ipsative assessments (Hughes, 2014). Ipsative assessments advocate the assessment of students' progress (e.g., "personal bests"); these strategies measure individual student's progress toward their personal goals, rather than simply norm-referenced or criterion-referenced assessments.

Every educational jurisdiction needs to provide its teachers with the knowledge and resources to not only cope with a crisis in education but also to provide students with the best possible educational opportunities on an ongoing basis.

CONCLUSION

The COVID-19 pandemic was a catastrophe for education. Massive learning loss for students, inequitable educational opportunities, huge workloads and stress for teachers, and rampant cheating during assessments have all been documented. This paper chose to examine what could be taken from this pandemic time as positive and worth maintaining going forward. In mathematics teaching, it is clear that outstanding teachers continued to be outstanding teachers, focusing on student success despite the crushing workload that that entailed. Post-pandemic, there will be much more extensive use of technology in many mathematics classrooms; reform mathematics, ambitious mathematics teaching, and thinking classrooms are on the rise, and will proliferate going forward; most teachers will see the benefit of maintaining their technological knowledge for teaching at an up-to-date status; assessment and evaluation strategies focused on assessing student understanding will continue to grow.

Hopefully, educational jurisdictions will recognize the need to support teachers' professional learning in all these areas, as well as provide sufficient time and guidance when new initiatives are introduced. There is also a need to recognize the huge learning loss that students face, and educational jurisdictions need to introduce programs to address this loss.

As someone not in the high school classrooms during the pandemic, I (lead author) was amazed and humbled by the stories provided by my three coauthors. They are marvelous examples of what outstanding mathematics teachers look like and I have been honoured to work with them.

LIMITATIONS

There are several limitations to this study. First, the selection of the three coauthors was purposeful and is not meant to be representative of all teachers of mathematics in Ontario. The co-authors were selected based on their high levels of effectiveness, motivation, care, self-efficacy, and dispositions. Pre-pandemic they had demonstrated that they were recognized as outstanding teachers by their students, peers, and administrators.

Secondly, the sampling methods for survey respondents in all likelihood resulted in an upwardly biased sample. Respondents were recruited through advertisements in the provincial professional journal for mathematics teachers, the *Ontario Mathematics Gazette*. Subscribers to the Gazette tend to exhibit higher levels of professionalism and dedication to professional learning than is typical of all mathematics teachers. The snowball sampling method is likely to also have resulted in the recruitment of more dedicated professional educators. Further, teachers who had very negative attitudes towards teaching during the pandemic or who felt that their teaching during this time was substandard, were less likely to respond to the survey invitation.

Finally, the survey sample size (55 responses) is relatively small, and thus results are not generalizable based on sample size. Also, the sample was limited to mathematics teachers in Ontario and so results may not be generalizable outside the province.

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APPENDIX

Table 1
Teacher narrative prompts

Your pandemic math story:

This is your chance to describe in narrative form how you taught during the pandemic; your feelings; your successes; your failures; what you changed; what you didn't change; what stresses you faced and how you dealt with them; how your students coped with the pandemic and its impact on their education.

Was the pandemic a threat or an opportunity (or both)?

Specifically, talk about:

- Pedagogy—what you changed and why.
- Assessment—what you changed and why; was this a chance to modify the assessment for the better or just deal with assessment issues like online cheating; how accurately did your assessments reflect your students' learning?
- Curriculum—did you change anything; how did you cope with new courses/new strands; were you able to cover all expectations to the depth that you usually do?
- PD—did you get any/enough; did you have the time and energy to engage in PD?
- Student engagement—how did you engage your students in the new reality?
- Stress and workload—how did you cope with the demands of teaching in the new paradigm? Talk about the workload—same, more, less than usual.
- Student stress and mental health—what did you notice and what did you do about it?
- Technology—how did you cope with the vagaries of technology and its impact on your teaching?
- Colleagues and collaboration—was there more collaboration/less collaboration; how did your colleagues deal with teaching math during the pandemic?
- What did you learn—what worked, what didn't work?
- What will you take away from teaching in the pandemic and what will you continue going forward?
- Your feelings—talk about how you felt at the beginning of the pandemic, during, and after (now).

Figure 1
Types of teaching situations faced during the pandemic

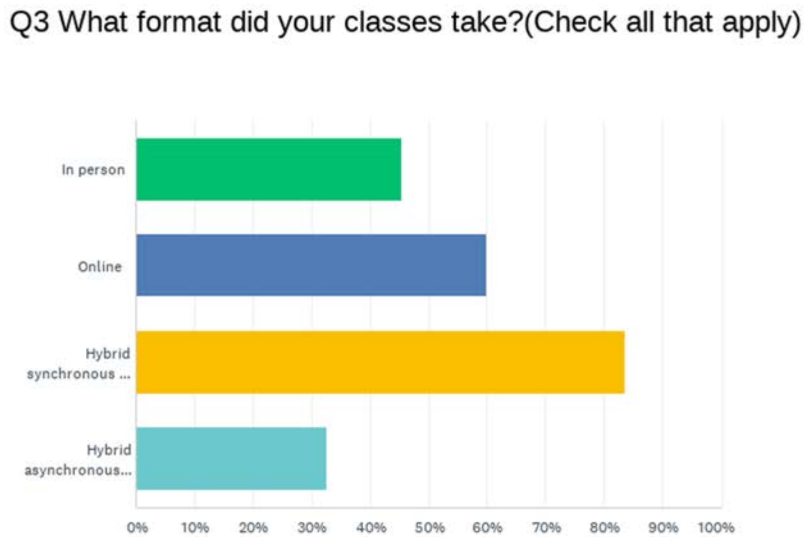


Figure 2

Degree of difficulty in implementing instructional strategies during the pandemic

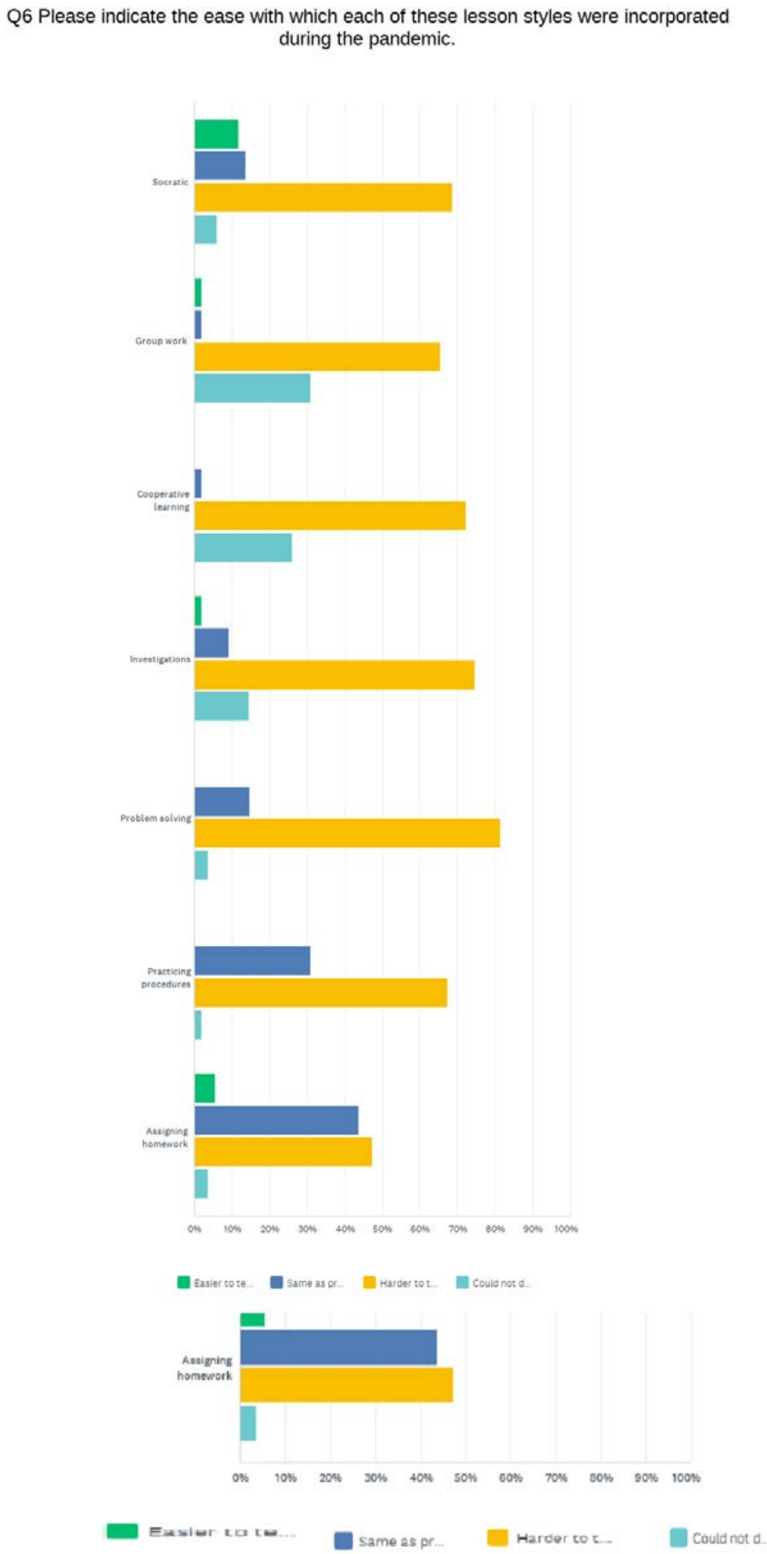


Figure 3
SAMR taxonomy (Puentedura, 2006)

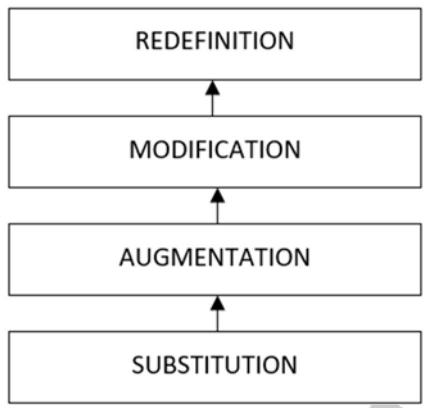
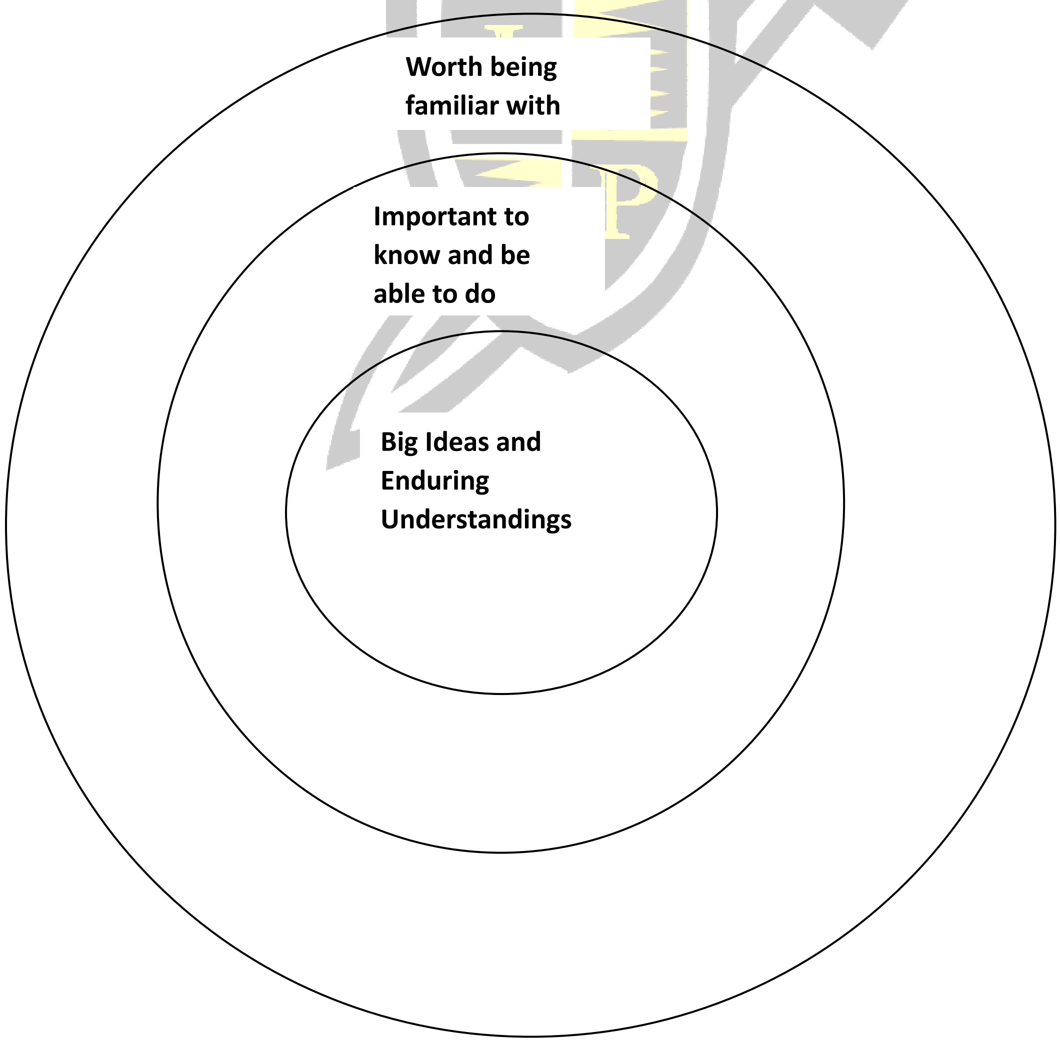


Figure 4
Curriculum prioritization

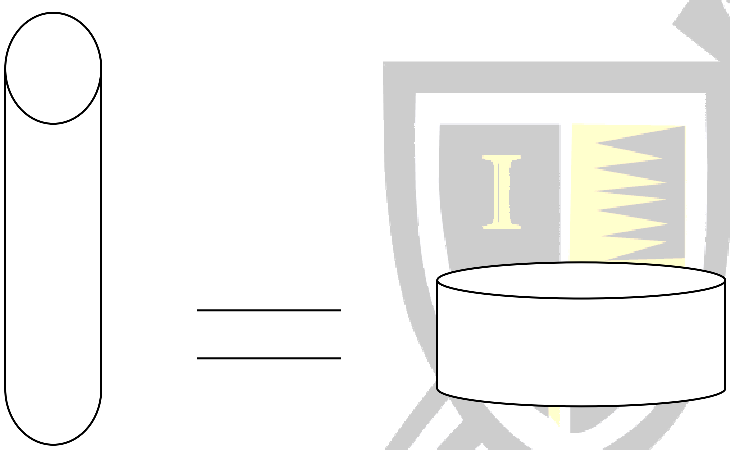


Appendix: Sample Modified Lessons

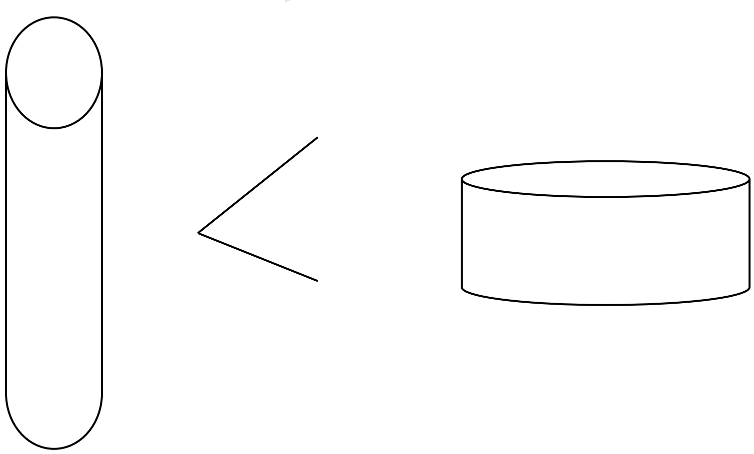
In the examples below, Classroom Lesson describes how the lesson would typically be taught if all students were in the classroom. Modified Lesson is the lesson as delivered during the pandemic, with all or some students online. Discussion compares the two treatments.

Example One: Volumes of differently shaped cylinders with same surface area.
Classroom Lesson: The objective is to have student consider cases involving volumes for a fixed surface area. Student groups are given two blank pieces of paper of the same size and tape and are asked to construct two different cylinders (without overlapping the paper). The corners are labeled as shown in the diagram. Students choose a corner, and each corner group devises a method for proving their corner's position. They then carry out the solution and compare to other corner groups (Irvine, 2019).

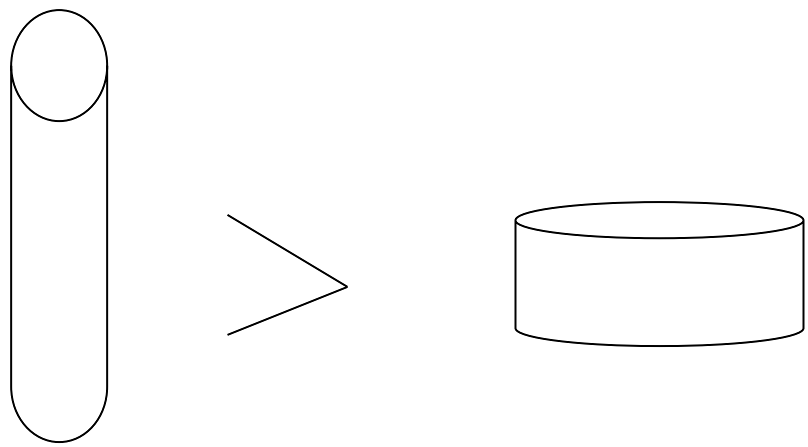
Corner #1



Corner #2



Corner #3



Modified Lesson: Each student, using two blank pieces of paper of the same size and tape and is asked to construct two different cylinders (without overlapping the paper). They are then asked about the volumes of the two cylinders and have three choices: Volume of cylinder #1 is greater than volume of cylinder #2; volume of cylinder #1 is less than volume of cylinder #2; volumes of the two cylinders are equal. Students choose a hypothesis from the three choices. They are then asked to make a plan to test their hypothesis. They may require hints or scaffolding questions about volume. The typical plan involves filling the cylinders with rice or some other available material. Some students chose materials such as cereal. After the investigation, students shared their findings and the teacher conducted a while-class online consolidation, emphasizing the relationship for two cylinders with the same surface area.

Discussion: The modified lesson did not involve student groups or the kinesthetic choice of moving to a corner of the room. In making the plan, students did not have the support of other group members. Some students required significant scaffolding in order to make and carry out their plans. Whole-class consolidation was similar for both the modified and the classroom lessons.

Both Telford and Cloutier (coauthors) provided Math Survival Kits for their students. The kits contained items such as tape, scissors, ruler, string, paper, and other items that could be used at home by students to carry out investigations. Without access to the math survival kits, some students would not have been able to carry out this investigation and would have been relegated to being spectators for this lesson.

Example Two: Nutritional Value of Foods

Classroom Lesson: Groups of students were given either pictures of various food labels or actual food packaging with nutritional labels. Groups then analyzed the nutritional value per serving or per package, including calories, vitamins, etc. Information may be graphed or used in activities involving ratio and proportion.

Modified Lesson: This lesson was a better version because I could send kids to THEIR FRIDGE during the lesson to get samples of food THEY EAT to use as the basis for our discussion… they thoroughly enjoyed analyzing the content of their fridge… I imagine parents came home to food all over the counter, because they probably forgot to put it all back!

I was able to personalize the lessons to the students.

Discussion: This lesson illustrated the importance of student engagement. By asking students to do mathematics with their own food in their own homes the lesson clearly connected the mathematics to the students' real lives. While students did not have the opportunity to engage in group discourse, the clear connections to reality elevated the activity for the students, who did not have to ask "When are we ever going to use this?"