J. Korean Soc. Math. Ed. Ser. D. (2024) 27(3), 253–265 ISSN 1226-6191
https://doi.org/10.7468/jksmed.2024.27.3.253 Online ISSN 2287-9943

EDITORIAL

Advancing teaching and learning of mathematics through transformative technology

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Abstract

This editorial explores the transformative potential of technology in advancing equitable teaching and learning in mathematics education. The COVID-19 pandemic has underscored the need for innovative approaches to education, particularly in leveraging technology to create more inclusive and effective learning environments. This special issue focuses on how emerging technologies can deepen students' mathematical proficiencies, shape students' identities, and promote equitable teaching practices. The EqT-tech framework is introduced, highlighting six key dimensions that enhance equitable mathematics education through technology: inquiry-based learning, mathematical identity and agency, formative assessment, collaborative learning, amplification of cognitive processes, and insights into social justice issues. Through a review of seven manuscripts, three recurring themes are identified: the use of technology to develop students' mathematical identity and agency, the role of collaborative platforms in enhancing collective learning, and the expanding nature of emergent technology to increase mathematical rigor as well as awareness for teaching mathematics for social justice exploring inequities within our communities. These studies imply an emphasis on the importance of task design and teacher knowledge in implementing equitable teaching practices, suggesting that technology, when used thoughtfully, can significantly advance equity in mathematics education.

Keywords: equity, technology, positioning, social justice, technology-enhanced

mathematics tasks

I. INTRODUCTION

The motivation for this special issue was to elevate the role that technology can play to make math classrooms and instruction more equitable. The pandemic disrupted all the ways of knowing, being, teaching and learning. In fact, educators will often qualify their instruction with the distinction of pre covid and post covid. Even in our personal lives we can mark how our daily lives have been impacted and differ pre covid versus post covid. So what have we learned about technology in recent years? How have we advanced in our ways of thinking about the role of technology in teaching and learning? More importantly, how can technology be a lever for equity? What studies inform us about how technology can advance equity, in what ways, for whom and under what conditions?

This special issue focuses on better understanding how emerging technology has transformative potential in deepening student mathematical proficiencies (NRC, 2001), shaping mathematics identity and student agency (Schoenfeld, 2016; Aguirre et al., 2013) as well as using technology to focus on equitable mathematics teaching practices (NCTM, 2020; AMTE 2022). Some of the digital tools with differing potential include dynamic and graphical tools that amplify mathematics by supporting students' reasoning and problem solving, as well as conveyance tools that facilitate communication, assessment, presentation, and collaboration (Dick & Hollebrands, 2011). Several of our mathematics education researchers have a keen interest in seeing how these differing digital tools like adaptive and collaborative platforms play a role in advancing the teaching and learning of mathematics through collaboration and differentiation. In addition, we sought studies that examined how these specific technologies supported the development of students' mathematical proficiency and empower students to develop a strong sense of agency and fostering positive mathematical identities.

When considering technologically-enhanced tasks and interventions that develop mathematical explorers, we imagined the transformative ways technology-

- offers student-centered learning experiences: exploration, discovery, collaboration and facilitating discourse (McCulloch & Lovett, 2023)
- advances equitable teaching practices (Gutiérrez, 2009)
- provides access to rigorous mathematics that connect to society helping students better understand problems and model real world issues that arise in everyday life, in the workplace and larger society (Byun et al., 2023; Suh et al., 2024).
- allows for ease of differentiation and useful formative assessment to support teaching and learning (Wills, 2020).

Two recent position statements from AMTE (2022) and NCTM (2023) outlined recommendations for equitable integration of technology for mathematics learning. As a contributing author, Suh et al., (2024) described a framework called EqT-tech that identified dimensions that were drawn from within and across the areas of equity,

mathematics, and technology. These dimensions identified ways technology tapped into the transformational potential to move a mathematics lesson and practices to be more equity-centered. As we reviewed the articles for this special issue, we found how the work of the authors in this volume also highlighted these key dimensions.

The EqT-tech LAT framework (www.eqttech.org) encompasses six key dimensions that collectively enhance equitable mathematics education through technology. The first dimension emphasizes providing access to inquiry-based learning, allowing students to explore, inquire, and solve problems, thus fostering deep mathematical understanding. The second dimension focuses on developing students' mathematical identities through authorship and agency, promoting self-efficacy and a sense of ownership in their learning. The third dimension highlights the importance of formative assessment to differentiate instruction, using technology to gather and analyze student data for tailored educational experiences. The fourth dimension underscores the power of collaborative learning, where technology facilitates collective problem-solving and communication, enhancing student engagement and equity. The fifth dimension showcases how technology can amplify mathematical and cognitive processes, enabling students to delve deeply into mathematical concepts through interactive and dynamic tools. Finally, the sixth dimension integrates these aspects, demonstrating how technology-supported tasks can provide insight into issues of social justice and inequity that can transform learning by providing equity-oriented exploration in mathematics learning.

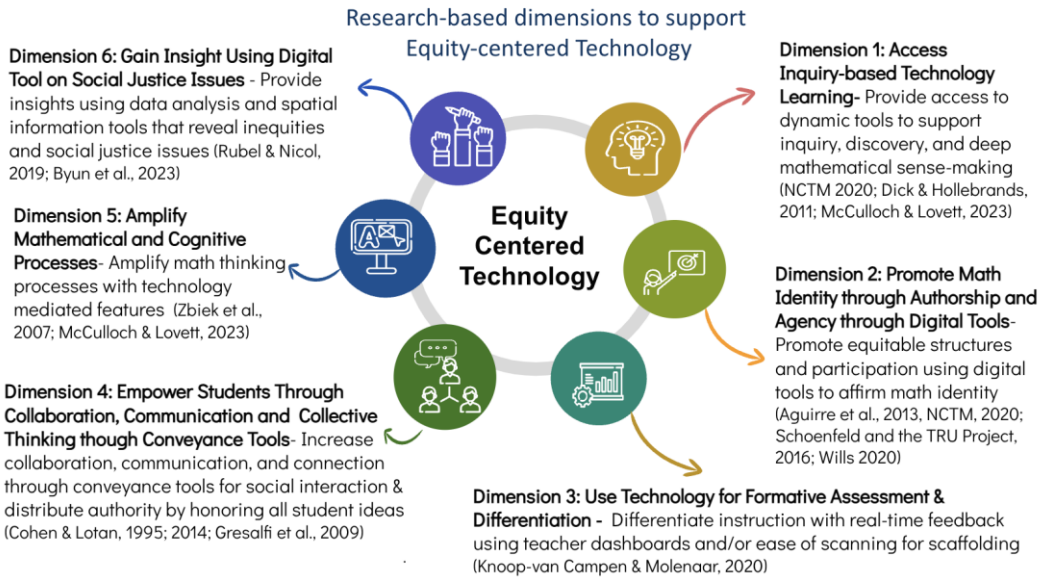

Figure 1. EqT-tech framework (eqttech.org)

As we reviewed the seven manuscripts with the lens of the EqT-tech framework, three recurring themes emerged across the studies. First, we noticed that several of the studies focused on highlighting specific technology that were used with explicit equitable

teaching strategies attending to the development of students' mathematics identity and agency. Second, another set of studies focused on the emergent features of technology that offer collaborative platforms and dashboards that can enhance collective learning. Finally, the third theme focused on the expanding nature of the integration of technology in the mathematics classroom that promotes the use of emergent technology to increase mathematical rigor as well as awareness for teaching mathematics for social justice exploring inequities within our communities.

II. THEME 1: EQUITABLE TEACHING STRATEGIES WITH TECHNOLOGY TO DEVELOP IDENTITY & AGENCY

Role of Mathematical Action Technology in Positioning Students as Mathematical Explorers

Many of these EQTtech dimensions work in tandem to elevate equitable teaching and learning practices. For example, we highlight the article "It's easy. We got Desmos right here: The role of mathematical action technology in positioning students as mathematical explorers" by Kristen Fye and Samantha Fletcher that emphasize the potential of technology to provide access to discovery and exploration and impacting students' agency (Dimensions 1 and 2). The researchers examine how Mathematical Action Technologies (MATs), such as Desmos, can position students as mathematical explorers and sustain their mathematical authority. The study focuses on a case involving two ninth-grade students using Desmos to explore the sine function. In terms of Dimension 1, the task designed for exploring the sine function encourages students to manipulate sliders and observe changes in the graph, fostering an inquiry-based approach to learning. This hands-on experience promotes exploration, inquiry, and problem-solving, enabling students to craft their understanding of mathematical concepts. In terms of Dimension 2, teachers' positioning moves, such as asking students to justify their thinking and create their own examples, empower students to see themselves as capable mathematicians. The article also discusses the importance of task design in positioning students as mathematical explorers, ensuring that students can independently navigate and understand the tasks. Through task-based interviews and analysis of the students' interactions with the technology, the authors identify key teacher moves and task designs that facilitate meaningful mathematical activity. The findings highlight the importance of teacher actions, task design, and students' ability to troubleshoot technology in fostering an environment where students can explore and understand mathematical concepts deeply. The study emphasizes the role of teachers in integrating technology into the learning environment to support students' mathematical identity development. By leveraging the affordances of MATs, teachers can create an equitable learning environment that promotes students' agency and authorship in mathematics.

Developing Agency and Authority through the use of both Math Action and Conveyance Technology

The study "Using transformative technology to teach central tendency and promote equity" by Asli Özgün-Koca, Jennifer Lewis, Christopher Nazelli, and Lenuel Hernandez explores how technology, combined with carefully designed tasks, can advance equity in mathematics education. The study examines the use of GeoGebra and Padlet technologies in teaching measures of central tendency in two 9th grade classrooms. The focus is on how these technologies support the development of student authority, identity, and agency. The lesson involved creating data sets with specific means and medians, using GeoGebra to visualize and manipulate data, and sharing results on Padlet for collective discussion. The major theme in their study was how technology-enhanced tasks promoted agency and authority. Highlighting dimension 2, students develop their mathematical identities by authoring their own data sets and sharing them on Padlet. This process promotes a sense of ownership and confidence in their mathematical abilities. The authors state, "By posting anonymously, students could choose to make ideas public without the risk of losing face. Some students went back to the Padlet canvas to update their posts with their names, associating their mathematical work with themselves." The study also emphasizes inquiry-based learning by allowing students to explore and manipulate data sets using GeoGebra. This hands-on approach helps students understand the concepts of mean and median deeply. The use of GeoGebra and Padlet allows teachers to collect formative assessment data, highlighting dimension 3, providing immediate feedback and enabling differentiated instruction based on student needs. The authors noted that the teachers recognized the efficiency of the digital platform that enabled them to be more responsive to their students' mathematical thinking than in non-digital environments. The study highlights how Padlet facilitates collaborative learning by allowing students to view and build on each other's work, enhancing collective problem-solving and communication, highlighting dimension 4. The author describes how a math action technology like GeoGebra can be used in tandem with a conveyance tool, "where student responses could be gathered, examined, and appraised publicly to provide opportunities for students to revisit, reflect, and revise initial thoughts." GeoGebra amplifies mathematical processes by providing dynamic and interactive ways for students to engage with mathematical concepts, such as visualizing the effects of changing data points on the mean and median. The dynamic nature of the application displayed changes in the data sets instantaneously, allowing students to test their own conjectures about the effects of shifting data points.

Learning Technologies to Support Learners' Access, Power, and Achievement

The article "Examining the enactment of learning technologies to support learners' access, power, and achievement in elementary school mathematics" by Drew Polly and Christie Martin investigates how mathematics learning technologies (MLTs) can promote equity in mathematics education. The study focuses on two cases involving the use of MLTs in elementary school classrooms. The first case examines the use of the NCTM Fraction Game with sixth graders, while the second case explores the use of Thinking Blocks Addition and Subtraction with second graders. The authors analyze how these

technologies support students' access to high-quality mathematics instruction, empower students by giving them control over their learning, and enhance their achievement in mathematics. The use of MLTs in the study supports Dimension 1 by allowing students to explore mathematical concepts through interactive and engaging activities. For example, the Fraction Game encourages students to experiment with different strategies for moving game pieces on a number line, fostering an inquiry-based approach to learning fractions. Similarly, the Thinking Blocks activity enables students to construct bar models and solve word problems, promoting exploration and problem-solving. In terms of Dimension 2, by positioning students as mathematical explorers, the technology allows them to take ownership of their learning. The teachers' moves, such as asking students to justify their thinking and create their own examples, empower students to see themselves as capable mathematicians. Authors shared that "The teachers' enactment of the Fraction Game MLT allowed for students to use their own words to vocalize their strategies and the connection they are making when deciding how a card should be used." In terms of Dimension 3, the study shows how technology can provide real-time formative assessment data. Teachers used students' interactions with the MLTs to assess their understanding and provide immediate feedback. The authors state, "While the teacher observed and asked questions, the MLT provided students with feedback on the placement of the labels and rectangles before allowing them to move the numbers into the workspace." The findings indicate that the design and enactment of MLTs can significantly impact students' learning experiences. In the Fraction Game case, students had access to visual number lines and engaged in discussions about strategies, promoting both access and power. In the Thinking Blocks case, students used bar models to solve word problems, receiving immediate feedback from the technology. Both cases demonstrated that MLTs could support students' engagement and understanding of mathematical concepts while providing access and empowerment and ownership of their thinking.

III. THEME 2: COLLABORATIVE PLATFORMS TO ENHANCE COLLECTIVE LEARNING

Using Evidence of Student Thinking as Resources in a Digital Collaborative Platform

The study by Park, Going and Edson, "Using evidence of student thinking as resources in a digital collaborative platform" investigates the use of a digital collaborative platform embedded with *Connected Mathematics Project 4* (CMP: The Connected Mathematics Project, 2023; Phillips et al., in press), a problem-based middle school mathematics curriculum. It examines how students generate mathematical inscriptions during small group work and how teachers use this evidence of student thinking to facilitate whole-class discussions and plan future lessons. This study highlighted many of the dimensions for equitable teaching using technology and is centrally based on dimension 4, highlighting how the digital platform facilitates collaborative learning by allowing students to view and build on each other's work. The features like the "four-up" view enable

students to share their strategies and learn from their peers, enhancing collective problem-solving and communication. The CMP digital collaborative platform and investigative nature of the tasks echoes the importance of dimension 1, inquiry-based learning by showing how students engage in problem-solving and exploration using digital tools. The digital platform allows students to experiment with different strategies and representations, fostering a deep understanding of mathematical concepts. The authors state that "Digital flexibility and mobility allowed students to easily explore different strategies and focus on developing mathematical big ideas." This workspace available for students aligns with dimension 2, where students develop their mathematical identities by authoring their own work and sharing it with peers. "Each student has ownership of their own workspace but can also use digital tools to get 'inspiration' from others' different approaches and build up their ideas." The significant aspect of this study is the dashboard that allows teachers to attend to dimension 3, where the teachers use the digital platform to collect formative assessment data, which helps them understand student thinking and provide immediate feedback. The platform's features, such as real-time monitoring and the ability to view and copy student work, enable teachers to tailor instruction to meet individual student needs. The authors noted that teachers recognized the efficiency of the digital platform that enabled them to be more responsive to their students' mathematical thinking than in non-digital environments. In terms of dimension 5, the digital tools on the platform amplify mathematical processes by providing dynamic and interactive ways for students to engage with mathematical concepts. For example, students can easily create and manipulate graphs and tables, which helps them focus on understanding relationships and patterns rather than getting bogged down in manual calculations. The findings highlight the benefits of digital flexibility and mobility, allowing students to explore different strategies and focus on developing mathematical big ideas. Teachers can foreground student thinking, making it a central resource for planning and teaching.

Collaborative Practices in Virtual Group Work on Dynamic Geometry Tasks

The study "Collaborative practices in virtual group work on dynamic geometry tasks" by Younggon Bae, Rani Satyam, and Zareen Aga explores how students engage in group work using dynamic geometry tasks in online synchronous classroom environments. The study investigates how three online groups of students collaboratively worked on dynamic geometry tasks using Desmos applets to explore geometric transformations. The study highlights dimension 4, how Desmos and Zoom facilitate collaborative learning by allowing students to view and build on each other's work, enhancing collective problem-solving and communication. The students shared their screens in Zoom, discussed their findings, and produced visual representations and written descriptions of the transformations. The study identified three emerging practices: drawing in response, co-construction, and writing in real time. These practices highlight the social, mathematical, and technological aspects of student collaboration in virtual spaces. The study emphasizes dimension 1 and 5 through inquiry-based learning by allowing students to explore and manipulate geometric transformations using Desmos. This hands-on approach helps students understand geometric concepts deeply. As authors state, "The guiding principles

of the task design include providing explorative and open-ended problems at a high cognitive demand." Students develop their mathematical identities by authoring their own visual representations and written descriptions, promoting a sense of ownership and confidence in their mathematical abilities, highlighting dimension 2. The authors also point out the usefulness of Desmos and Zoom which allowed teachers to collect formative assessment data, highlighting dimension 3, providing immediate feedback and enabling differentiated instruction based on student needs as they note, "Students' written descriptions were intended to be precursors to formally defining each transformation after the Desmos activity." The authors highlighted the screen sharer drawing of one student's contributions eliciting mathematical and social aspects of virtual collaboration. The study showed how the digital platform can enhance teachers' capacity to quickly monitor different strategies and prepare for summary discussions, making student thinking a central resource for collective mathematics learning. Desmos amplifies mathematical processes, dimension 5, by providing dynamic and interactive ways for students to engage with geometric concepts, such as visualizing the effects of transformations.

IV. THEME 3. NATURE OF EMERGENT TECHNOLOGY TO INCREASE MATHEMATICAL RIGOR AND AWARENESS OF INEQUITIES IN OUR COMMUNITIES

Increasing Mathematical Rigor with Emergent Technology-3D Printing

The article "Purposeful integration of 3D modeling and printing" by Anna Wan and Jessica Ivy which explores how advancements in 3D modeling and printing technology can enhance mathematics education providing access to inquiry-based learning and amplifying the math and cognitive processes (Dimension 1 & 5). The authors argue that these technologies can address challenges in visualizing three-dimensional (3D) figures from two-dimensional (2D) representations, which is a common struggle in both mathematics and everyday tasks. They build on Ball and Stacey's (2005) framework for the judicious use of technology in education, proposing strategies for integrating 3D modeling and printing into the mathematics curriculum. These strategies include promoting careful decision-making about technology use, integrating 3D modeling and printing into the curriculum, tactically restricting the use of these technologies, and promoting habits of spatial visualization. The article provides examples of activities that can be used in the classroom, such as machine function activities, teacher-created models, and student-created models. These activities are designed to enhance students' understanding of geometric concepts through hands-on experiences and real-world applications. The use of 3D modeling and printing supports Dimension 1 by allowing students to explore mathematical concepts through interactive and engaging activities. For example, students can use 3D modeling software to create and manipulate models of geometric figures, fostering an inquiry-based approach to learning. This hands-on experience encourages students to experiment with different strategies and solutions, promoting exploration, inquiry, and problem-solving. In terms of Dimension 5, 3D modeling and printing amplify students'

cognitive processes by providing dynamic visualizations and interactive features. The technology allows students to experiment with different parameters and see the immediate impact on the model, enhancing their conceptual understanding and cognitive engagement with the material. The authors noted the ease of assessing student 3D mental models with quick screenshots to capture a specific perspective of the model, or as a link for interactive feedback. They noted the advantage of using 3D modeling and printing for mental visualization and communication. The authors also discuss the importance of aligning these activities with the Substitution Augmentation Modification and Redefinition (SAMR) model for technology integration. By incorporating 3D modeling and printing into the curriculum, teachers can create an engaging and interactive learning environment that promotes deeper understanding and retention of mathematical concepts.

Gaining Insight using Technology on Social Justice Issues in Our Community

The study "Technology as an equity lever: Applying the EqT-tech framework to center equitable integration of technology in the math classroom" by Jennifer Suh, Kate Roscioli and Gretchen Maxwell describes a framework called the Equity-centered Transformative Technology Lesson Analysis Tool (EqT-tech LAT), which integrates research across mathematics, equity, and technology to support equitable teaching practices. The case study documents a 6th-grade mathematics class that used the EqT-tech LAT framework to plan and implement a lesson focused on social justice. The lesson involved students using Google Maps to analyze access to sports facilities in different communities and creating a survey using Google Forms to gather data on barriers to sports participation and Google Sheets that generated graphical representations of barriers to accessing youth sports. The authors highlighted all 6 dimensions. Students used Google Maps to explore and formulate questions about access to sports facilities. Students created and analyzed their own graphs using Google Sheets, giving them ownership of their learning. The teacher used Google Classroom to monitor student progress and provide real-time feedback. Students worked together in Google Slides to plan and present their findings. Technology allowed students to manipulate and visualize large datasets, enhancing their understanding. In addition, this lesson incorporates dimension 6, gaining insight using technology tools on social justice issues which is one of the dimensions that is not often highlighted in technology- enhanced lessons. The lesson focused on addressing inequities in access to sports facilities, empowering students to take action. "The comparison of maps was eye-opening for students to understand the issue at hand. With the Google Maps and their understanding of scale and distance allowed for them to compare their community with another and quantify the disparity in the number of fields and green space that would not be possible without the Google Map." This framework and case study illustrate how technology can be leveraged to promote equity in mathematics education by addressing each of the six dimensions.

V. CONCLUSION

An important implication from the collection of the articles in our special issue is the importance of task development and teacher knowledge in implementing equitable teaching practices. It is important to underscore that in all the studies, technology pedagogical content knowledge played a role. TPACK identifies the knowledge teachers need to teach effectively with technology, integrating three primary forms of knowledge: Content (CK), Pedagogy (PK), and Technology (TK). In these studies, TPACK added another layer in how teachers used technology to enhance mathematics instruction while addressing equity. For example, in the study by Suh et al. (this issue) the teacher in the case study needed to be able to have deep content knowledge on data analysis skills and how students could use data to interpret their findings. It required Ms. M to know how to use various technology tools such as Google Suite (Forms, Sheets, Slides, Maps) to collect, organize, and analyze data. These tools were chosen for their ability to support inquiry-based learning, provide real-time feedback, and facilitate collaboration among students. In addition, she needed to employ various pedagogical strategies to support equitable learning. This included using formative assessments, promoting student agency and authorship, and facilitating collaborative learning. The pedagogical approaches were designed to ensure all students could engage deeply with the mathematics content.

In the study by Bae, Satyam & Aga (this issue), the authors focused on three main pedagogical aspects: social, mathematical, and technological interactions and demonstrated that as instructors of the method course, they used their knowledge and skills to create equitable learning opportunities while using the Desmos applet and google slides. The description of their study shows evidence of TPACK-which included designing tasks that leverage technology to support diverse learning styles; establishing norms and roles that promote inclusive participation.; using collaborative tools to ensure all students can contribute meaningfully; and addressing social dynamics to balance power and ensure all voices are heard. Their findings led them to recommending several TPACK skills such as assigning roles within groups to ensure all students have the opportunity to contribute, as well as ensuring that tasks are designed to be challenging enough to require collaboration but not so difficult that they hinder participation. By thoughtfully integrating technology and pedagogical strategies, educators can create a more equitable and effective learning environment for all students.

Attending to technology pedagogical content knowledge needed to transform learning experiences to equitable teaching and learning has important implications for mathematics educators and professional developers. Technology tools in mathematics education will continue to expand the possibilities and opportunities for mathematics learning and teaching. Many of these possibilities will have transformative potential to promote equitable teaching for each and every learner. However, the advancement in technology will not ensure that the affordances will be optimally used unless teachers can design and implement lessons with equity at the forefront with a deep knowledge of TPACK. In creating the EqT-tech lesson analysis tool, we encountered this dilemma and supplemented each dimension with question prompts to center equity and accounted for

TPACK to support equitable integration (see Table 1).

Table 1. Question prompts and TPACK teacher moves to enhance the equity dimensions

Equity-centered Transformative Technology	Question Prompts to Center Equity	TPACK to Support Equitable Integration
Dimension 1: Access to Inquiry -based Learning- Provide access to dynamic tools to support inquiry, discovery, and deep mathematical sense-making.	In what ways does the choice of technology give students equitable access to mathematical inquiry, discovery, conjectures, and foster sense -making?	The teacher supports inquiry by posing purposeful questions that support inquiry, discovery, and deep mathematical sense-making.
Dimension 2: Math Identity through Authorship and Agency- Promote equitable str - uctures and participation to affirm math identity.	In what ways does the technology allow student ownership and authorship to create, represent and share their mathematical thinking to build positive mathematical identities?	The teacher provides opportunities to highlight diverse ideas, take ownership and authorship in student learning as they create, represent and share their mathematical thinking.
Dimension 3: Formative Assessment & Differentiation- Differentiate instruction with real-time feedback using teacher dashboards and/or ease of scanning student work to provide scaffolding.	In what ways does the technology used in the lesson allow for formative assessment and differentiation to meet learners' needs?	The teacher skillfully monitors students' digital work to provide appropriate levels of challenge and feedback to advance student learning.
Dimension 4: Empowerment Through Collective Thinking- Collaboration, communication, and connection for social interaction and distributes authority by honoring all student ideas.	In what ways does the use of the technology allow for students to collaborate, communicate and build collective knowledge among their peers and provide opportunities to affirm multiple ideas and empower students' ideas?	The teacher provides class time and norms for small group interactions using the digital tool, as well as whole class discussions to collaborate, communicate, and build collective knowledge among their peers. This approach affirms multiple ideas and empowers students' contributions.
Dimension 5: Amplification of Mathematical and Cognitive Processes- Technology mediated features that amplify the mathematics process with fidelity.	In what ways do the features of the technology make mathematics concepts visible and amplify cognitive processes?	The teacher focuses on the affordances and the constraints within the digital tool to highlight the important mathematical thinking made visible through the learning activity.
Dimension 6: Gain Insight Using Technology Tool on Social Justice Issues-Technology tools can provide insights into inequities and social justice issues.	In what ways does the technology provide insight into issues of social justice?	The teacher focuses on how technology tools might provide information from data, geospatial information and other technological ways that can be mathematized.

We hope that the international mathematics education research community finds our special issue to be a robust contribution to the important dialogue of centering equity

considerations as we continue to implement emerging technology in our mathematics classroom. We invite all to continue to reflect on the many important implications our collective work has for teachers and designers of learning activities, emphasizing the need for professional development to help teachers effectively integrate technology to advance equity into their mathematics instruction.

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