COVID-19 and the use of digital technology in mathematics education

Mansour Saleh Alabdulaziz¹

Received: 2 December 2020 / Accepted: 24 May 2021 / Published online: 28 June 2021

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract

Once the COVID-19 crisis is over, will everything” return to normal” or will we instead witness an ongoing boom in online learning? A time of crisis is an opportunity for all education systems to look to the future; there is enormous potential for digital technology in mathematics education, regardless of the impact of COVID-19. In this paper, the researcher focuses on answering two research questions: (1) Is COVID-19 the gateway for digital learning in mathematics education? (2) What type of digital technology is being used in mathematics education during the COVID-19 pandemic? The study also provided a discussion on the implications that such digital technologies could have on research into the field of mathematics education and practice in addition to suggestions for future research directions on this topic. Interviews were chosen as techniques for the purpose of this research, which were undertaken with hundred and twenty mathematics teachers from different secondary schools in the Kingdom of Saudi Arabia. The researcher found that 98% of participants believed that COVID-19 is the gateway for digital learning in mathematics education. In addition, 97% claimed that the use of online education by schools had expanded greatly following the coronavirus outbreak. This has resulted in various forms of software being used to facilitate communicate between teachers and students included mobile technologies, touchscreens and pen tablets, digital library and designing learning objects in mathematics education, Massive Open Online Courses (MOOCs) in mathematics, and computer algebra systems (CAS) such as Mathematical, Maple, MuPAD, MathCAD, Derive and Maxima.

Keywords COVID-19 · The use of digital technology · Mathematics education

---

✉ Mansour Saleh Alabdulaziz
malabdulaziz@iau.edu.sa

¹ Department of Curriculum and Instruction, College of Education, Imam Abdulrahman Bin Faisal University, P.O. 1982, Dammam, Saudi Arabia

1 Introduction

The response of educational organisations across the globe to travel bans and quarantines has resulted in a shift towards learning online. This could lead to an upsurge in education – and better prepare us to deal with subsequent emergencies. The nature of global digital education is such that COVID-19 may fuel the development of strong capabilities in areas where there is sufficient connectivity, infrastructure, and resources.

In Saudi Arabia, for example the use of online education by universities and schools had expanded considerably as a result of the coronavirus outbreak. Currently, there is a dearth of research conducted on the use of digital platforms for learning mathematics (Mulenga & Marbán, 2020). However, one such a recent study indicates that students learn mathematics better with effective and appropriate technology (Perienen, 2020), while another previous study highlights that the adoption of technology in mathematics education improves learning (Niess, 2006). It is not yet known exactly “is COVID-19 the gateway for digital learning in mathematics education?” “What type of digital technology is being used in mathematics education during the COVID-19 closure period?” As they will be required to learn remotely in their respective homes. It is against this gap of knowledge that this study wishes to narrow.

The study also provides a discussion on the implications that such digital technologies could have on research into the field of mathematics education and practice in addition to suggestions for future research directions on this topic. This will help the reader to understand how recent developments in this area of research have evolved in the last few years.

1.1 Research importance

- 1- Providing useful insights regarding the positive side-effects of COVID-19.
- 2- The research keeps pace with global and local trends that advocate the need to benefit from the use of digital technology in mathematics education.
- 3- Enriching educational libraries with a modern topic on COVID-19 and the use of digital technology in mathematics education.
- 4- Instructing teachers to use of digital technology in mathematics education.
- 5- Providing useful insights regarding the use or application of digital technology in mathematics education to those developing curricula in the Ministry of Education in the world.
- 6- Contributing to opening up new prospects for further research in order to keep pace with technology and exploit its positive role in mathematics education.

1.2 Research questions

- (1) Is COVID-19 the gateway for digital learning in mathematics education?

- (2) What type of digital technology is being used in mathematics education during the COVID-19 pandemic?

2 Literature review

2.1 Theoretical framework

The theoretical framework adopted to undertake this research include Technology Acceptance Model (TAM) (Davis et al., 1989) is the lense used to guide the data analysis and data interpretation to investigate the components that influence secondary students' interests in online interactions through digital technology.

Davis' (1993) Technology Acceptance Model (TAM) underpins this study as a theoretical framework. The TAM represents a good fit within a constructivist meta-theoretical paradigm, as it presents individual attitudes and subjective choice for using (or not using) ICT for teaching and learning. Two distinct attitude constructs namely, 'perceived usefulness' (PU) and 'perceived ease of use' (PEU) are used to frame the attitude of the academic towards engagement or indifference to the use of technology. These two behavioural constructs namely PU and PEU also directly influence whether actual engagement with the technology will occur.

2.2 Deployment of ICT innovations in mathematics education

The integration of technology within education is a highly complex process involving multiple factors and similar to all other innovative concepts, it is essential that it is not incorporated prior to testing the various different elements (Haddad & Draxler, 2002). It is important to substantiate innovations in terms of the level to which they are appropriate and suitable, their applicability in classrooms, their impact on the learning process and cost-effectiveness. With regard to mathematics education, numerous innovative concepts have been proposed, developed, piloted and implemented for usage with various different consequences. Particular fields in which they have verified to be successful are educational approaches based on ICT, application of open and distance learning (ODL), virtual educational platforms, distribution of open educational resources (OERs) and the propagation of research conclusions (Iji & Abah, 2018).

Educational approaches based on ICT are teaching and learning methods in which ICT instruments are actively utilised to enhance the student learning (Agbo-Egwu et al., 2018). Schools around the world are already using a wide variety of extant digital technologies for mathematics teaching. According to Clark-Wilson et al. (2011), existing tools that are based on innovation include dynamic graphing tools, dynamic geometry tools, algorithmic programming languages, spreadsheets, data loggers (motion detectors and GPS), and computer algebra systems (CAS). Furthermore, CASs like Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima are capable of facilitating active learning approaches, which enable students to become active participants in the process of discovering and consolidating their personal

knowledge, thereby enhancing their theoretical and geometrical comprehension and providing a more on-depth learning strategy (Kumar & Kumaresan, 2008). Based on the observations of Abari (2014), student interest was maintained and their achievement levels increased subsequent to the enhancement of teaching in a higher level secondary school mathematics class through GeoGebra. The use of dynamic geometry systems (DGS) such as Cabri and Geometers Sketchpad (GSP), among others, appear to offer new perspectives on geometry in the school setting, in addition to more advanced levels by clearly facilitating the experimentation and exploration of geometrical formations and linkages (Iji et al., 2018). In addition to the ability to actively enhance teaching, new aspects of ICT innovations have emerged in mathematics education including the Class Learning Interactions – Observation (CLIO) tools, which allow all interactions that occur within the classroom to be systematically observed and monitored (Manny-Ikan et al., 2013).

An area of particular significance in terms of the implementation of ICT innovations within the field of mathematics teaching is Open and Distance Learning (ODL). The first usage of the name Massive Open Online Course was in relation to the 2008 version of the Connectivism and Connective Knowledge' Course (Kady & Vadeboncoeur, 2013). Massive Open Online Courses (MOOCs) are considered to be the leading type of such courses. The design of MOOCs courses allows multiple learners to participate simultaneously, they provide students the ability to access courses at any time and from any location provided they are connected to the Internet, are publicly accessible with no entry criteria, and offer comprehensive course experiences via the Internet at no charge (Azevedo & Marques, 2017). Additionally, Open University frameworks offered in numerous countries are powered by a robust collection of technologies, providing high-quality competencies necessary for those who wish to be employed in long-tenured careers in the field of mathematics. ODL schemes are frequently developed for the purpose of establishing a social, cognitive and teaching presence through the Internet (Hanover Research Council, 2009). In this respect, synchronous online classrooms can even be more effective for educating younger children compared to conventional types of teaching as they allow visual, auditory and kinaesthetic processes to be integrated at the same time (Hastie et al., 2007). Likewise, crowd-based design approaches have been developed as a means of facilitating mathematical interactions between students and teachers in virtual environments (Hui et al., 2014).

Online teaching platforms are frequently used for augmenting discussion and cooperation among mathematicians. As suggested by Holzl (1999), the different tools utilised within virtual learning environments can include electronic mail, online forums, computer conferencing and chat groups. The development of different innovative technologies has enabled the replication of mathematical experiences based on technology both within and external to the classroom (Hofmann, 2014). [Elluminate.com](https://www.illuminate.com) represents an effective example of an online classroom as it offers a basic user interface as well as a powerful participant window that displays the names of all session participants, along with a collection of interactivity tools including the ability to raise a hand when requesting to contribute to the debate. Messaging between users and the mathematics teacher is facilitated by the instant messaging functionality, while the whiteboard can be used by the teacher for projecting slides

or by the students for writing or drawing with the text and drawing applications. Different examples of frequently utilised online learning platforms include Blackboard and Moodle (Iji et al., 2018).

A different field in which ICT innovations have been deployed in mathematics teaching is mobile technologies. After the emergence of mobile technologies, one of the areas in which the fastest growth has been observed is educational applications, and it is anticipated that the expansion of these apps along with mobile technologies will continue going forward (Cherner et al., 2016). Hence, the following section will explain to readers how mobile technologies are used for mathematics teaching.

2.3 Use of Mobile Technologies in Mathematics Teaching and Learning

There has been increased focus among educational scholars and practitioners on the utilisation of mobile technologies (e.g., tablets and tablets) by teachers and learners in the field of mathematics. The particular attributes of mobile devices including the fact that they are portable, available, allow users to access the Internet, and are widely embraced by members of the younger generation and others mean that they are considered an emerging medium with the capability to expand the boundaries of mathematics teaching and learning outside the traditional classroom environment. White and Martin (2014, p. 64) contended that the specific features of mobile devices (like the ability to capture and collect data, communicate and collaborate with different users, consume and critique media, build and generate individual forms of expression and representation) can be easily translated into the scientific, mathematical and engineering practices emphasised within the Common Core Math and Next Generation Standards (NGSS Lead States, 2013).

Researchers are increasingly focussing on the potential areas of application and possibilities of mobile technologies; however, this remains an under-researched subject with regard to mathematics education. Nonetheless, some studies have been conducted (e.g. Crompton & Traxler, 2015; Larkin & Calder, 2015) that have addressed the manner in which this type of technology could be utilised for mathematics teaching and learning.

The first studies into the application of mobile learning in mathematics can be traced back to the end of the 2000s (e.g. Franklin & Peng, 2008), and since that time, there has been considerable expansion in this kind of research in terms of both international conferences and sector-specific journals. The majority of studies analysed within this research can be categorised into three main groups: (a) research into the possible areas of application of mobile devices for mathematics teaching and learning; (b) affective studies on the utilisation of mobile devices; and (c) the utilisation of mobile devices for educating mathematics teachers.

Various researchers have concentrated on taking advantage of the features of mobile devices, including the benefits of being portable, mobile, and the ability to photograph and video actual phenomena that can subsequently be examined and discussed from a mathematical perspective. One such study was conducted by Wijers et al. (2010), who employed a game based on location named *MobileMath* for mobile devices with GPS technology that facilitated the creation and exploration

of quadrilateral equations along with their properties in a real environment in an external location.

Other studies have concentrated on investigating the opinions and feelings experienced by mathematics teachers and students when teaching or studying mathematics via mobile devices. For instance, Holubz (2015) gathered feedback from teachers and students regarding a programme titled “Bring Your Own Device” (BYOD), which encouraged the utilisation of the Internet and mobile equipment when studying mathematics.

Lastly, it can be observed the design of inquiry tasks in mobile environments for preservice and inservice that several studies have analysed the usage of mobile devices for educating mathematics teachers. For example, Yerushalmy and Botzer (2011) presented a discussion on the theoretical aspects in addition to the problems and potential benefits underpinning teachers.

The study conducted by Crompton (2015) particular exemplifies the manner in which mobile devices can be utilised for promoting mathematical concept learning. As part of her work, Crompton proposed a research study based on design whereby iPads were utilised as a medium for supporting the learning of the notion of angles in primary school children.

Within this learning environment, mobile devices were employed by the children for the purpose of identifying and photographing forms that resembled angles that existed naturally in their environment (e.g., tree stumps, shoe patterns, or table corners). Subsequently, the photographed shapes were analysed by the students through dynamic geometry apps installed on their mobile devices. Consequently, this enabled the students to examine whether the naturally formed angles they observed in their physical surroundings in fact corresponded to the mathematic characteristics of an angle.

The usage of mobile technologies in the context of mathematics learning and teaching is a developing field of research that continues to enlarge at an exponential rate. Hence, the following part of this paper will provide an explanation on how touchscreens and pen tablets are used for Mathematics Teaching and Learning.

2.4 Use of touchscreens and pen tablets in mathematics teaching and learning

Researchers have contended that the attention spans of individuals could be impacted by the input devices utilised when performing activities or tasks supported by computers (Chen et al., 2017; Evans et al., 2011; Mangen, 2008; McLaughlin et al., 2009). For example, Chen et al. (2017) conducted a study in which they attempted to investigate and make a comparison between student’s attention span with regard to the time spent on a task and the amount of distractions when utilising touchscreens and pen tablets for problem solving tasks in the field of mathematics with virtual manipulatives. The findings revealed that those students who used touchscreens when performing the task had an increased attention span, meaning that the time spent on the task increased and they had less distractions compared to those who used pen tablets. Mangen (2008) argued that the action of clicking a mouse could distract the user from the information they are reading on the computer

screen. Technologies that have emerged recently such as touchscreens, which offer intuitive and shared interfaces, introduce new methods of incorporating technology into educational practice, including the use of virtual manipulatives on touchscreen gadgets for supporting the learning of mathematics (e.g., Moyer-Packenham et al., 2016; Watts et al., 2016). Studies have indicated that when using touchscreens, there is a stronger association between the hand gestures of the user and the on-screen results compared with use of a mouse or physical keyboard (Romeo et al., 2003). Additionally, recent studies have shown that various teachers have tried to utilise pen-based technologies to promote student learning, specifically in the context of mathematics teaching (e.g., Cantu et al., 2008; Huang et al., 2017; Koile & Rubin, 2015), due to the fact that such technologies enable students to learn how to write equations or draw mathematical representations.

2.5 Digital library and designing learning objects in mathematics education

According to the definition provided by the Digital Library Manifesto (Candela et al., 2007), a digital library is a virtual entity that engages in a process of collecting, managing and preserving rich digital content of all types for the benefit of users. Clearly, such libraries require some form of digital storage. In the field of education, digital repositories utilise learning objects for the purpose of organising their content, which differentiates their organisational approach from those used for printed documents.

Learning objects (LO) suggested by IEEE Learning Technology Standards Committee (2002) are components of a novel kind of e-learning based on an object-focused approach in computer science. According to the definition, an LO is a digital object that one can use, reuse, and tag with metadata targeted at promoting learning.

The primary characteristics of learning objects are that they are accessible, interoperable and reusable (Polsani, 2003). Accessibility denotes the ability to tag learning objects with metadata, while interoperability is the technique via which learning objects are shared with other technology systems without the requirement to modify the objects, and reusability denotes the utilisation of learning objects in various different learning settings.

Widely used learning resources in virtual repositories include MERLOT (Multimedia Educational Resources for Learning and Online Teaching), Wisc-Online, DRI, Khan Academy, and EBA (Digital Repository of Turkey) (Borba et al., 2017).

In 1997, the Multimedia Educational Resource for Learning and Online Teaching (MERLOT) (<https://www.merlot.org/>) was established. A resource developed by California State University, it has wide usage around the world. Users are not charged to use MERLOT and it is largely financed by higher education establishments in different countries.

The Khan Academy (<https://www.khanacademy.org>) is an individualised learning resource that caters to learners from different age groups; it provides practice tasks, educational videos and a tailored learning dashboard that allows learners to work at their own speed both within and out of the classroom environment. The mathematics missions provide guidance for early learners through to those studying calculus

by using the latest adaptive technology, which is capable of identifying the learners' strengths and learning deficiencies (Borba et al., 2017). Murphy et al. (2014) found also a connection between Khan Academy exercises and improved scores on basic mathematics.

What Will You Do In Math Today? (<http://researchideas.ca>) is an open repository of resources accessible on the Internet for teaching mathematics that was developed by George Gadanidis at Western University, Canada. This platform receives support from different organisations and incorporates a research-based mathematics text in which learning objects are categorised as numbers, patterns and algebra, measurements, geometry, data and probabilities (Borba et al., 2017).

Existing research into learning objects has largely focused on measures of quality, individualisation and mobile learning. Gadanidis et al. (2004) examined the pedagogy and the design of interfaces used in interactively visualising mathematical investigations. They reached the conclusion that a large proportion of interactive visualisations have poor designs in terms of both pedagogy and interface design. Research has demonstrated that an important aspect of the ability to predict the effectiveness of repositories is quality assurance of the LORs (Clements et al., 2015).

2.6 Similarities between the literature and this research

- 1- This research is consistent with (White & Martin, 2014; NGSS Lead States, 2013) who explored the effect of mobile technologies in mathematics teaching and learning. It is also consistent with (Chen et al., 2017; Evans et al., 2011; Mangen, 2008; McLaughlin et al., 2009), who found the positive effect in touchscreens and pen tablets in mathematics teaching and learning. It is also consistent with (Pol-sani, 2003; Borba et al., 2017), who determine the effectiveness of using digital library and designing learning objects in mathematics education. This research is consistent with (Kumar & Kumaresan, 2008), who believe that emergence of such mathematical tools and its ability to deal with most of the secondary school cannot be ignored by mathematics educators. It is also consistent with (Azevedo & Marques, 2017), who found the advantage of using Massive Open Online Courses (MOOCs) in mathematics education. However, this research differs from all literature reviews in terms of handling the COVID-19 variable.
- 2- The previous studies were implemented in non-Arab countries. This also represents the first study on this subject within Saudi Arabia.
- 3- The researcher used semi-structured interviews to collect his data, but the tools used in previous studies varied due to differences in their objectives.
- 4- The current study extended the recommendations of previous studies, such as that of Mulenga and Marbán (2020), the findings of his study motivate new areas of research. Other researchers could carry out studies on the effects of COVID-19 on Education. Others could investigate on some useful digital resources for students during the COVID-19 crisis and lockdown. It may also interest other researchers to examine if digital learning will eventually replace physical classroom in future. While digital learning is a life-long process for many students caught in the

consequences of the spread of the deadly virus but may also be a way of coping with home confinement for all.

- 5- At the time of data collection for this current study, schools were closed and there were confirmed cases of COVID-19 in Saudi. Health intervention measures had been put in place to restrict movements. The researcher interviewed the participants via Microsoft Teams or Zoom. Thus, this was very helpful to answer my research questions. In contrast to other studies, who during the time of data collection, schools were not yet closed and there were no confirmed cases of COVID-19. Health intervention measures had not yet been put in place to restrict movements. Thus, delivery mode was face-to-face in classroom settings and in the presence of the researcher.

What distinguishes this research from the existing literature The researcher contend that this research is distinct because it is the only study to have explored COVID-19 and the use of digital technology in mathematics education in Saudi Arabia.

Aspects drawn from the literature reviews:

- Drawing on the pedagogical literature, literature reviews, and adopted scientific methodology to form the theoretical framework used in this research.
- Identification of the research methodology and tools appropriate for this research.
- Reviewing the statistical methods employed and adopting them as appropriate for this research.

3 Methodology

In this study, the researcher used a semi-structured interview, and the questions included in the interviews were discussed with ten academic faculty members of mathematics in universities in Saudi Arabia to determine the face validity and appropriateness of the content. The interview questions (please see Appendix 1) were written in Arabic and later translated into English, a process that was followed by asking a different person, to produce a translation to compare and ensure accuracy.

Pilot interviews were then conducted to determine the relevance of the interview questions, as well as to assess the duration of the interview and to evaluate the ability to perform the task. The interview rehearsal was administered to two mathematics teachers.

The sample was selected randomly and consisted of 120 mathematics teachers whose teach third stage of secondary education, in the second semester, 2019-2020. These 120 teachers have various academic backgrounds. Some have between 3 to 10 years' teaching experience and others between 11 and 25 years.

3.1 Sampling procedures

Emails and WhatsApp inviting teachers who were specializing in mathematics and other related areas to participate in the study. A reminder email was sent two weeks after the initial invitation to encourage participation. The message included an introductory letter and consent form that was requested be sent back to the researcher to indicate willingness to participate (the research's principal topic, invitation paragraph, purpose of the study, why have I been chosen? Do I have to take part? Who will have the access to the research information (data)? Who do I speak to if problems arise? What will happen to the results of the research project? Ethical review of the study and contact for further information). Finally, the participants were thanked in advance for their participation. The researcher chose the first 120 participants that returned the letter to him to be part of his research since he was subject to time restrictions. The researcher interviewed the participants via Microsoft Teams or Zoom. Before the interview, in order to ensure a smooth interview process, the researcher copied the invitation and send it out to the participant. A 25 min interview was planned for each interviewee.

3.2 Data analysis

Thematic analysis, which is one of the tools of grounded theory was utilized in order to analyze the interview data. Initially, every interview was recorded and subsequently transcribed and the data were then read and re-read. The next stage involved the application of thematic coding (underlining the text in various colors) and then the data were matched to separate categories, thereby enabling reduction and synthesis of the large amount of data. Subsequent to this, every recognized commonality was divided into topics. It was necessary to supply the following three categories of the most significant with ethical issues. In the first category, all participants were informed that they were volunteers in this study and had the right to ask for any of the that responses they had given previously to be removed. In the second category, the confidentiality of participants' identities and personal details was guaranteed, meaning that their names would not be included in the course of the translation procedure. The third category involved providing the participants comprehensive details regarding the purposes of the research.

4 Results

Interviews were chosen as techniques for the purpose of this research, therefore, the researcher will discuss the findings concluded from answers to the interview questions and the literature review according to the research questions see Table 1 and Fig. 1.

The above table shows that 98% of participants believed that COVID-19 is the gateway for digital learning in mathematics education. 97% claimed that the use

Table 1 Summary of the answers to the research questions

The research question	The answers	Number of participants	Percentage
(1) Is COVID-19 the gateway for digital learning in mathematics education?	COVID-19 is the gateway for digital Learning in mathematics education.	118	98%
	The use of online education by schools had expanded greatly following the coronavirus outbreak. In line with extreme changes worldwide, schools and universities have closed and thus interactions with colleagues and teaching through traditional lectures have transformed into an online, virtual experience. This has resulted in various forms of software being used to facilitate communicate between teachers and students.	116	97%
(2) What type of digital technology is being used in mathematics education during the COVID-19 pandemic?	Mobile technologies	48	40%
	Touchscreens and pen tablets.	36	30%
	Massive Open Online Courses (MOOCs) in mathematics	17	14%
	Computer algebra systems (CAS) such as Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima.	12	10%
	Digital library and designing learning objects in mathematics education	4	3%

Fig. 1 The type of digital technology is being used in mathematics education during the COVID-19 pandemic?

of online education by schools had expanded greatly following the coronavirus outbreak. In line with extreme changes worldwide, schools and universities have closed and thus interactions with colleagues and teaching through traditional lectures have transformed into an online, virtual experience. This has resulted in various forms of software being used to facilitate communication between teachers and students. In the teaching and learning of mathematics, 40% of these used mobile technologies, whereas 30% used touchscreens and pen tablets please see Fig. 1. Furthermore, 3% concentrated on using digital library and designing learning objects in mathematics education, while 10% used computer algebra systems (CAS) such as Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima. Additionally, 14% used Massive Open Online Courses (MOOCs) in mathematics education as follows:

One participant stated that:

“Umm...Yes, particularly the use of mobile technologies, touchscreens and pen tablets, and digital libraries in mathematical education.”

He added:

“Following the coronavirus outbreak, the nature of education may, in some ways, have fundamentally changed, potentially for the better.”

He provided the following example to illustrate this:

“Once the coronavirus outbreak has passed, the adoption of online education by schools will have expanded substantially. This is because the crisis will have provided a larger number of opportunities to develop online delivery. What remains uncertain is the extent to which the use of online

teaching will remain, although it is often the case that once people become accustomed to a specific modality, they will be far more likely to use it.”

He also said:

“My students found many advantages when using mobile devices such as: cooperation and communication with various users, the capability of capturing and gathering data, constructing and generating individual types of representation and expression, and consuming and evaluating media. This can be easily translated into the scientific and mathematical.”

Another participant also contended that:

“Yes, COVID-19 is the gateway to digital learning in mathematical education. Students’ opinions of online learning may have become more positive as a result of the outbreak. Having previously viewed distance education as “very second rate”, some schools and students may now come to appreciate its potential.”

He added:

“I noticed that students’ attention spans were positively affected when touchscreens and pen tablets were used for problem-solving tasks in the field of mathematics. Therefore, as I have already mentioned, the opinions and attitudes of students towards online learning may have become more positive as a result of the outbreak.”

Another participant noted that:

“I think that COVID-19 is the gateway to digital learning in mathematical education. I did not use digital learning previously, but when COVID-19 arrived, I did use it, because these tools has become mandatory for all educational institutions, and I will continue to do so even after this pandemic is over.”

He added:

“I tried to use pen-based technologies to promote and support student learning of mathematics, such as using virtual manipulatives on touchscreen gadgets. However, I can say that such technologies enable students to learn how to draw mathematical representations easily.”

Similarly, another participant stated:

“I tried to use the devices with a touchscreen with my students. Consequently, I found that touchscreen gadgets involve virtual manipulatives that students can control in order to support the visualisation of mathematical concepts. Therefore, I can say that technology provides additional opportunities for learners to see and interact with mathematical concepts. Students can explore and make discoveries with digital tools.”

Another participant stated:

“I think that COVID-19 is the gateway to digital learning in mathematics education, as it solved the many problems that students face in the classroom. For example, several students who were previously reluctant to participate are now putting themselves forward. This is because quieter, more introverted students feel able to participate as they are not on display in front of their peers.”

Another participant also noted that:

“Teachers can see what every single student is doing, which is not how things usually work in the standard classroom.”

However, another contended that:

“Working online, it is difficult to establish whether a student is fully engaged and has sufficient understanding, a basic issue that has yet to be solved by technology.”

Another participant stated:

“Yes, prior to COVID-19, I did not encourage my students to use digital library in mathematics education, because I thought that digital technology is not easy to use. However, I do try to use it now, and have found it to be an individualised learning resource which is accessible, interoperable and reusable.”

Furthermore, another participant noted that:

“Yes, I think that the positive side effects of COVID-19 enable me and my students to see the advantage of using digital library in mathematics education, such as MERLOT (Multimedia Educational Resources for Learning and Online Teaching), Wisc-Online, DRI, Khan Academy, and EBA (Digital Repository of Turkey).”

One participant wanted to talk about the positive side-effects of COVID-19:

“As expected in a period of crisis, every day we are inundated with negative information about COVID-19. However, although its negative effects are widely known, the outbreak of COVID-19 has also had a somewhat unexpected positive outcome.”

He went on to explain “the importance of using mathematics and understanding numeracy, which refers to the ability to use mathematics and numbers in everyday life. An individual’s level of numeracy in both their personal and work lives is extremely important. It also provides a tool to enhance critical thinking and the use of logic. These can facilitate decision making and the completion of both minor and major tasks. The greater a person’s ability to use numbers, the easier everyday chores will become. Indeed, it would not be inaccurate to state that a person’s aptitude with numbers will substantially determine their level success. Referring back to the previous question you asked me, I will now explain what I mean by the positive side-effect of COVID-19, and the use of digital technology in mathematics education.”

He added:

“All students are now studying from home, which means they have (an immense amount of) time in which to think and have to countenance the fact that everybody is buying far more than they need! I therefore asked the students to think about what they really need and what they really value. They should not buy products they will not use. Students thus have to budget on a monthly basis to avoid spending too much.”

He added:

“It is worthy of mention that I noticed that those students who used touchscreens when thinking about their real needs and values developed an increased attention span, compared with those who did not use them. In fact, before COVID-19 arrived in this country, I did not try to use touchscreens and pen tablets for problem-solving tasks in the field of mathematics, because I thought that digital technology is complicated and difficult to operate and use. However, I will now use them to support my students in mathematics.”

Another participant noted:

“Many students readily confess to a dislike of some basic mathematical concepts, and have misapprehensions about mathematics. These have a strong impact on their capacity to learn and understand mathematics and often cause a considerable amount of confusion. The most frequent misconceptions relate to the use of fractions. For instance, students may erroneously believe that $1/12$ is smaller than $1/13$ because 12 is less than 13.”

He then went on to add:

“For instance, when students were asked to multiply fractions by a whole number, some multiplied the numerator and denominator. This is a misconception as it shows students do not understand why you only multiply the numerator by a whole number. We should work to eradicate such misunderstandings as it is vital to apply knowledge about fractions to the real-world problems students encounter and must try and understand. Regarding health statistics, misunderstanding the size of numbers can have negative outcomes such as underestimating the risks of COVID-19.”

He added:

“Returning to your question, I can say that COVID-19 is the gateway to digital learning in mathematics education. As coronavirus grips the nation, digital technologies are increasingly being used to deliver lessons to students at home. In order to help my students with their misconceptions in mathematics, I tried to use Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima, and noticed that they provide a more in-depth learning strategy.”

He also said:

“Actually, I used these types of software because of the COVID-19 outbreak, but I do not think that I will use them if no COVID-19 is present. I think that

this pandemic has given me an opportunity to start looking at the use of digital technology in mathematical education.”

Other participants sent a message to teachers who specialize in mathematics and other related areas across the world:

“All teachers are being provided with a unique opportunity to exploit students’ natural curiosity about the virus, the science underlying the mechanism of viral infections, and the mathematics elucidating pandemics.”

He continued:

“I do not think that we would have done this as teachers in the traditional classroom setting, but COVID-19 gave us an opportunity to use Massive Open Online Courses (MOOCs). This gave the students the ability to access courses at any time, and enabled multiple students to participate simultaneously. Increased access to digital technology for mathematics allows for a more customised learning experience. Because no two learners are exactly alike, technology can provide individual students with content and supports that are particularly helpful to their individual needs.”

Another participant noted:

“Students worldwide are coming to terms with the realities of life during a pandemic; this provided mathematics teachers with an abundance of opportunities to integrate current events into lessons in a way that helps students develop empathy, self-reflection, and personal growth.”

He added:

“During the pandemic, I used computer algebra systems (CAS) such as Mathematica, Maple, MuPAD, MathCAD, and I think that this digital technology facilitated active learning methods. It also gave the students an opportunity of becoming active participants in the process of discovering and consolidating their personal knowledge.”

He also stated:

“Unfortunately, before the coronavirus, I did not try to use any of this digital technology in mathematical education. However, the sudden and unprecedented closure of our nation’s school buildings, due to the COVID-19 pandemic, forced educators to face the most jarring and rapid change of perhaps any profession in history. Therefore, I can say that COVID-19 is the gateway to digital learning in mathematical education; therefore, I will never stop using digital technology in mathematical education, because digital technology brings mathematics education to life! We can bring videos, animations, and other into the learning process to help our students develop skills and understandings. And it can help to motivate and excite our students about their learning.”

He added:

“I think that when teachers’ anticipations towards the digital technology in mathematics education benefits are confirmed, these tools will enhance their satisfaction which ultimately achieves the perceived objectives.”

5 Discussion of results

The responses of the participants varied on the research questions. 98% contended that the use of digital technology in mathematics by schools had expanded considerably as a result of the coronavirus outbreak, and this was a positive aspect of the pandemic. The researcher think that due to Corona Virus Disease 2019 (COVID-19) crisis, e-learning has become a very urgent need and an imperative of education necessities in most countries all over the world. Its great importance manifested in solving the problem of quarantined students, reduce the effects of the corona-virus epidemics. According to the interviewees, teachers will perceive the digital technology as easy to use because these tools has become mandatory for all educational institutions all over the world. Another possible explanation for these findings is the fact that when teachers’ anticipations towards the digital technology in mathematics education benefits are confirmed, these tools will enhance their satisfaction and acceptance which ultimately achieves the perceived objectives. These findings could be explained by the reason that if teachers think or perceive that it is uncomplicated and simple to use the digital technology, then they are willing and intent to spend more effort and time to learn how to do so, which would undoubtedly improve their performance. In contrast, if the digital technology is complicated and difficult to operate and use, then teachers would be unwilling to try to use it.

Teachers are becoming familiar with its ‘ease of use’, and then found pedagogical purpose or ‘perceived usefulness’ (Davis, 1993). In this study, teachers’ ‘turn’ towards digital technology seemed to satisfy both TAM constructs of ‘ease of use’ and ‘perceived usefulness’ (Davis, 1993). Teachers’ beliefs and attitudes also changed with their practice as they experienced ‘ease of use’ and appreciated the ‘perceived usefulness’ of digital technology in mathematics education (Davis, 1993).

However, the question that arises is whether such a boom in online learning represents an enduring solution or a tool with which to respond to a crisis. The teachers’ responses indicated to the researcher that they will continue to use digital technology in mathematical education, because they have learned that technology can make mathematics easy. They provided the type of digital technology used in mathematics education during the COVID-19 pandemic? In addition, they gave us examples to show that digital technology in mathematics education encourages students to learn more than in a traditional classroom environment.

40% of them used mobile technologies in mathematics teaching and learning, one of them mentioned that “my students found many advantages when using mobile devices such as the ability to capture and collect data, communicate and collaborate with different users, consume and critique media, build and generate individual forms of expression and representation, and this is can be easily translated into the scientific and mathematical”. This is consistent with other researcher’ findings, such

as (White & Martin, 2014; NGSS Lead States, 2013), who showed that the specific features of mobile devices (like the ability to capture and collect data, communicate and collaborate with different users, consume and critique media, build and generate individual forms of expression and representation) can be easily translated into the scientific, mathematical and engineering practices emphasised within the Common Core Math and Next Generation Standards. The participants mentioned that when the student finds it difficult to solve the task in mathematics, he can access to the mobile technologies and open the videos see the solutions, which allows students to learn at their own pace and in their own learning style. The researcher thinks that students and teachers are given new experiences through the application of mobile devices as instruments in mathematical education. Since the way in which we teach and learn is being quickly transformed by technology, it is important for teachers to be aware of conventional techniques of teaching mathematics and to be willing to support them. However, these methods need to be coordinated with efficient and relevant utilisation of technology, possibly involving applications and mobile devices.

With respect to the utilisation of mobile technologies for teaching and learning mathematics, the majority of learners have already determined that mobile phones constitute large parts of their lives both within and out of the classroom. While different technologies, such as pencils and paper in addition to computer software were also recognised as being part of this group, those currently studying in schools cannot perceive a world without mobile devices. Nonetheless, the availability of mobile technologies for students forms a relation between students and mathematics that is not broadly embraced by mathematics teachers, which interrupts the conventional transferal of mathematics knowledge between teachers and students, and has received minimal attention in the literature.

30% of participants used touchscreens and pen tablets in mathematics teaching and learning, one of them stated that “it is worth to mention that I noticed that those students who used touchscreens when thinking about what they really need and what they really value had an increased attention span, compared to those who did not use touchscreens. Actually before COVID-19 come to this country I did not try to use touchscreens and pen tablets for problem solving tasks in the field of mathematics, but now I will use them to support my students in mathematics”. This is consistent with (Chen et al., 2017; Evans et al., 2011; Mangen, 2008; McLaughlin et al., 2009), who indicated that the attention spans of individuals could be impacted by the input devices utilised when performing activities or tasks supported by computers. The participants analysed students’ attention when using touchscreens and pen tablets to solve equations problems with virtual manipulatives. They found that the students could maintain more attention, in terms of greater time-on-task and fewer distractors. This is consistent with recent studies have who shown that various teachers have tried to utilise pen-based technologies to promote student learning, specifically in the context of mathematics teaching (e.g., Cantu et al., 2008; Huang et al., 2017; Koile & Rubin, 2015), due to the fact that such technologies enable students to learn how to write equations or draw mathematical representations. Therefore, students have to pay attention to the learning process if effective learning is to occur, and this very important because if they do not do that the information they receive will quickly fade and

rarely have a lasting impact. The researcher is of the opinion that teachers could utilise touchscreen in the mathematics classroom in order to support the activities which concentrate on student manipulations associated with the attention given to learning content.

3% of them concentrated on using digital library and designing learning objects in mathematics education, one of them mentioned that “yes, because before the COVID-19 I did not encourage my students to use Digital library in mathematics education, and now I tried to use it and I found that an individualised learning resource that they are accessible, interoperable and reusable.” This is consistent with (Polsani, 2003). Another participant also noted that: “yes, I think that the positive side-effects of COVID-19 that make me and my students to see the advantage of using Digital library in mathematics education such as MERLOT (Multimedia Educational Resources for Learning and Online Teaching), Wisc-Online, DRI, Khan Academy, and EBA (Digital Repository of Turkey)”. This is consistent with (Borba et al., 2017). For example, Khan Academy enabled students to move at a pace that is more appropriate to their learning needs. He reported that students are doing more mathematics problems than they would in a standard classroom. Therefore, we can say that it is not surprising that their skill level would also increase. One of the participants reported that many more of his students were getting 100% on their homework. This is consistent with Murphy et al., 2014 who found a connection between Khan Academy exercises and improved scores on basic mathematics. Khan Academy also gives teachers and students access to graphics and illustrations that are hard to replicate at the blackboard. At least two teachers in the study talked about the value of Khan Academy to teach students skills such as responsibility and self-discipline. The researcher think that the accessibility of mathematics education resources via the Internet (e.g., digital libraries and learning objects) has led numerous students to consult such resources prior to seeking assistance from teachers or textbooks, which leads one to question how such resources are structured to provide this type of access and the manner in which they are designed pedagogically to promote conceptual understanding.

A point worth mentioning is that there are useful insights regarding the positive side-effects of COVID-19. According to the participants, their opinion of digital technology in mathematics education has grown more positive as a result of the increased usage of it during the coronavirus school building closures. In addition, they plan to continue using those newfound skills even when school buildings reopen. We can see that this shift in practice has provided an opportunity to reconsider how technology use in mathematics can be utilised to improve student learning. On the other hand, one of participants mentioned that “In fact, before COVID-19 arrived in this country, I did not try to use touchscreens and pen tablets for problem-solving tasks in the field of mathematics, because I thought that digital technology is complicated and difficult to operate and use. However, I will now use them to support my students in mathematics.” Therefore, the researcher do not want to forget the IT help desks who also played a significant role in helping prevent those negative feelings from being much higher, actually the calls and emails were flooding in around the clock.

10% of the participants used computer algebra systems (CAS) such as Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima, one of them stated that “to help my students with their misconceptions in mathematics, I tried to use Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima, and I noticed that they provided a more on depth learning strategy.” This is consistent with (Kumar & Kumaresan, 2008), who mentioned that these softwares can providing a more on-depth learning strategy. Another participant noted “I used during the epidemic, computer algebra systems (CAS) such as Mathematica, Maple, MuPAD, MathCAD, and I think these digital technology facilitated active learning methods, which gave the students the chance to become active participants in the process of discovering and consolidating their personal knowledge”. This is consistent with also (Kumar & Kumaresan, 2008). The researcher believe that emergence of such mathematical tools and its ability to deal with most of the secondary school cannot be ignored by mathematics educators. Because what the researcher understanding from the participants that using a computer algebra system (CAS) during the pandemic crisis provided many opportunities for improving student learning. The students who were taught with CAS were more successful than students without CAS at three levels: basic computation, more advanced computation and complex symbolic problems. This is not surprising because eight of the participants reported for their students who were taught the concept of derivative with and without CAS. Four of the participants has also examined student motivation when used effectively during the pandemic crisis, they found that CAS can make mathematics more interesting and meaningful to students.

14% of them used Massive Open Online Courses (MOOCs) in mathematics education, one of the participants noted that “I do not think we can done this as teachers in traditional classroom, but COVID-19 gave us the oppotinty to use Massive Open Online Courses (MOOCs), which gave the students the ability to access courses at any time, and allows multiple students to participate simultaneously”. This is consistent with (Azevedo & Marques, 2017). Further research is needed into the nature of the learning that participants engage in when participating in MOOCs and in what conditions before it will be possible to make definite conclusions. However, students are enabled, by digital learning, to study in the comfort of their own homes. If they have the required digital devices, they are able to occupy the front seats in the virtual mathematics classroom. It is implied by results that teachers hold the opinion that they will be enabled by digital learning to have a pedagogical mathematical move towards a less formalised teaching technique, such a method would be interesting and entertaining, instead of being traditional and rigorous.

To sum up, as we see from above that 40% of participants used mobile technologies in mathematics teaching and learning, and this is considered as high percentage compared with other digital technologies used. The main feature of mobile technologies that distinguishes it from other learning technologies is its mobility. The researcher think that mobile technologies are highly popular amongst secondary students due to their being easily carried, wireless, containing many apps making it easy for the student to do multiple tasks at one stand. As a result, commercial competitive industry has compelled manufacturers to present new creative features of competitive traits. In addition, it is only understandable why mobile

phone companies have worked hard to develop the 5th generation mobile phones that enabled users not only to talk but actually do almost everything they now do with their PC. This mean that all other application or digital technologies ran in mobile technology at any environment, regardless of the OS, the Net or the type of cellular. Users can download any applications from many websites, whenever they want. They can run the application without being connected to the net. In addition, the mobile technologies is also Mobile phones are available and are part of the daily culture of almost every student. The researcher do not want to forget that coronavirus pandemic is a chance to see all these types and benefits of digital technologies in mathematics education, because 98% of participants above believed that COVID-19 is the gateway for digital learning in mathematics education. In addition, 97% claimed that the use of online education by schools, teachers and students had expanded greatly following the coronavirus outbreak.

6 Summary

Results show different types of digital technology used in mathematics education included (mobile technologies, touchscreens and pen tablets, digital library and designing learning objects in mathematics education, Massive Open Online Courses (MOOCs) in mathematics, and computer algebra systems (CAS) such as Mathematical, Maple, MuPAD, MathCAD, Derive and Maxima.), and the effects varied by the type of educational technology used. However, in view of the COVID-19 school closure period, it is apparent that digital learning in mathematics education is the instant positive response.

7 Implications for further studies

This study has showed that the adoption of digital learning as a response to COVID-19 stimulates the growth of digital learning in mathematics education in Saudi Arabia. The privilege of the current situation for students engaged in digital learning is to position this transformation not just as a quick response but as a way of combating the spread of COVID-19 and the next transferable disease. The findings of this study motivate new areas of research. Other researchers could carry out studies on the effects of COVID-19 on other areas of the education field. Others could investigate on other useful digital resources for mathematics students during the COVID-19 crisis. It may also interest other researchers to answer the following questions: Will digital learning replace classroom education anytime soon? What the future holds for digitised education post-Covid-19. How will Covid-19 affect the future of igital mathematics education? While some believe that the unplanned and rapid move to digital technology – with no training, insufficient bandwidth, and little preparation will result in a poor user experience that is uncondusive to sustained growth, others believe that a new hybrid model of education will emerge, with significant benefits. The researcher believed that a time of crisis is also an opportunity for all education systems to look into the future, adjust to possible threats, and build their capacity.

Major world events are often an inflection point for rapid innovation – while we have yet to see whether this will apply to digital technology post-COVID-19. Finally, the researcher think that digital learning system designers and developers should pay further attention to these two essential factors (perceived usefulness and perceived ease of use).

8 Limitations of the study

Although this study was carefully prepared, it still faced a number of limitations:

- 1- This study focused only on government secondary schools in the east of Saudi Arabia. However, the researcher believes that this city was a good place to conduct this study, because it has a big population which is drawn from different parts of the Kingdom of Saudi Arabia.
- 2- The study sample focused on teachers only, because they are the first people who play a key role in educating students in the classroom. However, the study could have included students if there were no restrictions of time.

9 Recommendations

In view of the findings, the researchers recommend the following:

- 1- These digital technologies must be included in mathematics curricula at various stages of education.
- 2- The stakeholders should take advantage of the findings of this study to encourage teachers to continue using these technologies in mathematics education.
- 3- Further research is needed to answer the questions that arose in the discussion section.

Appendix 1

- 1- Did you use of digital technology in mathematics education before COVID-19 outbreak?
- 2- Are you going to continue to use the digital technology in mathematics education after corona the COVID-19? Why? Do you think this is an enduring solution or a tool with which to respond to a crisis?
- 3- Is COVID-19 the gateway for digital learning in mathematics education?
- 4- How could digital technologies help during the pandemic?
- 5- What type of digital technology is being used in mathematics education during the COVID-19 pandemic?

- 6- Regarding the use of technology in mathematics education, are there any particular technologies you feel excited about?
- 7- How COVID-19 is changing mathematics teacher's perception of using digital technology?
- 8- Does "perceived usefulness" influence mathematics teachers' acceptance of digital technology? How?
- 9- Does personal experience influence mathematics teachers acceptance of digital technology? How?
- 10- Does "perceived ease of use" influence mathematics teachers' acceptance of digital technology? How?
- 11- Is there anything else you would like to add?

Acknowledgements I would like to thank our almighty God who gave me the power and the will to finish this research. My heartfelt appreciation and gratitude go to my family, particularly my parents and my wife for their encouragement and cooperation.

References

- Abari, M.T. (2014). *Effect of Geogebra on senior secondary school students' interest and achievement in statistics in Makurdi Local Government Area of Benue State*. An unpublished M.Ed Thesis submitted to the Department of Science Education, University of Agriculture, Makurdi, Nigeria. pp. 1-170.
- Agbo-Egwu, A. O., Abah, J. A. & Abakpa, B. O. (2018). Perceptions of tech-augmented learning in basic mathematics among university students: A case of matrix algebra tools. *International Refereed Journal of Arts, Science & Commerce*, 6(1), 121-131. <https://hal.archives-ouvertes.fr/hal-01758515>. Accessed 9 Mar 2020.
- Azevedo, J., & Marques, M. M. (2017). MOOC success factors: Proposal of an analysis framework. *Journal of Information Technology Education: Innovations in Practice*, 16, 233–251. <https://doi.org/10.28945/3861>.
- Borba, M. C., Askar, P., Engelbrecht, J., Gadanidis, G., Llinares, S., & Aguilar, M. S. (2017). Digital Technology in Mathematics Education: Research over the Last Decade. In *Proceedings of the 13th International Congress on Mathematical Education*, (pp. 221-233). Springer.
- Candela, L., Castelli, D., Ferro, N., & Koutrika, G. (2007). *The DELOS digital library reference model: foundation for digital libraries, version 0.96*. Resource document. European Commission within the Sixth Framework Programme. http://delosw.isti.cnr.it/files/pdf/ReferenceModel/DELOS_DLReferenceModel_096.pdf. Accessed 20 May 2020.
- Cantu, P., Phillips, J., & Tholfsen, M. (2008). Three is not a crowd: The pedagogical power of tablet laptops, digital organizers, and digital textbooks in middle school mathematics. In R. H. Reed & D. A. Berque (Eds.), *The impact of tablet PCs and pen-based technology on education: Evidence and outcomes*, 2008 (pp. 21–29). Purdue University Press.
- Chen, C-H., Chiu, C-H., Lin, C-P., & Chou, Y-C. (2017). Students' Attention When Using Touchscreens and Pen Tablets in a Mathematics Classroom. *Journal of Information Technology Education: Innovations in Practice*, 16, 91-106. <https://doi.org/10.28945/3691>
- Cherner, T., Lee, C-Y., Fegely, A., & Santaniello, L. (2016). A Detailed Rubric for Assessing the Quality of Teacher Resource Apps. *Journal of Information Technology Education: Innovations in Practice*, 15, 117-143. <https://doi.org/10.28945/3527>
- Clark-Wilson, A., Oldknow, A., & Sutherland, R. (2011). *Digital technologies and mathematics education*. A report from the working group of the Joint Mathematical Council of the United Kingdom, pp 1-32.

- Clements, K., Pawlowski, J., & Manouselis, N. (2015). Open educational resources repositories literature review—Towards a comprehensive quality approaches framework. *Computers in Human Behavior*, 51(Part B), 1098–1106. <https://doi.org/10.1016/j.chb.2015.03.026>
- Crompton, H. (2015). Understanding angle and angle measure: A design-based research study using context aware ubiquitous learning. *International Journal for Technology in Mathematics Education*, 22(1), 19–30. https://doi.org/10.1564/tme_v22.1.02.
- Crompton, H., & Traxler, J. (Eds.). (2015). *Mobile learning and mathematics. Foundations, design and case studies*. Routledge.
- Davis, F. D. (1993). User acceptance of information technology: System characteristics, user perceptions and behavioural impacts. *International Journal Man-Machine Studies*, 38, 475–487.
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, 35(8), 982–1003.
- Evans, M. A., Feenstra, E., Ryon, E., & McNeill, D. (2011). A multimodal approach to coding discourse: Col-laboration, distributed cognition, and geometric reasoning. *International Journal of Computer-Supported Collaborative Learning*, 6(2), 253–278. <https://doi.org/10.1007/s11412-011-9113-0>.
- Franklin, T., & Peng, L.-W. (2008). Mobile math: Math educators and students engage in mobile learning. *Journal of Computing in Higher Education*, 20(2), 69–80. <https://doi.org/10.1007/s12528-008-9005-0>.
- Gadanidis, G., Sedig, K., & Liang, H. N. (2004). Designing online mathematical investigation. *Journal of Computers in Mathematics and Science Teaching*, 23(3), 275–298.
- Haddad, W. D., & Draxler, A. (2002). *Technologies for education: Potentials, parameters, and prospects*. UNESCO.
- Hanover Research Council. (2009). *Best practices in online teaching strategies*. Hanover Research Council.
- Hastie, M., Chen, N.-S., & Kuo, Y.-H. (2007). Instructional design for best practice in the synchronous cyber classroom. *Education Technology & Society*, 10(4), 281–294.
- Hofmann, J. (2014). *Blended learning instructional design: A modern approach*. <http://insynctraining.com>. Accessed 12 July 2020.
- Holubz, B. J. (2015). Mobilizing mathematics. Participants' perspectives on bring your own device. In H. Crompton & J. Traxler (Eds.), *Mobile learning and mathematic. Foundations, design, and case studies* (pp. 213–222). Routledge.
- Holz, A. (1999). *Designing for diversity within online environments*. <http://ascilite.org.au/conferences/brisbane99/papers/holz.pdf>. Accessed 26 Apr 2020.
- Huang, C. S. J., Su, A. Y. S., Yang, S. J. H., & Liou, H.-H. (2017). A collaborative digital pen learning approach to improving students' learning achievement and motivation in mathematics courses. *Computers & Education*, 107, 31–44. <https://doi.org/10.1016/j.compedu.2016.12.014>.
- Hui, J.S., Gerber, E.M. & Dow, S.P. (2014). Crowd-based design activities: Helping student connect with users online. *Proceedings of the 2014 ACM Conference on Designing Interactive Systems (DIS)*, 875–884
- IEEE Learning Technology Standards Committee. (2002). Draft standard for learning object metadata. Resource document. IEEE. http://129.115.100.158/txtlor/docs/IEEE_LOM_1484_12_1_v1_Final_Draft.pdf. Accessed 22 Apr 2020.
- Iji, C. O., & Abah, J. (2018). Mathematics education for all through information technology innovations. *ABACUS (Mathematics Education Series)*, 43(1), 89–100.
- Iji, C. O., Abakpa, B. O., & Age, J. T. (2018). The effect of Geometer's sketch pad on senior secondary school students' interest and achievement in geometry in Gboko Metropolis. *International Journal of Research and Review*, 5(4), 33–39.
- Kady, H. R., & Vadeboncoeur, J. A. (2013). *Massive open online courses (MOOC)*. Salem Press Encyclopedia.
- Koile, K., & Rubin, A. (2015). Machine interpretation of students' hand-drawn mathematical representations. In T. Hammond, S. Valentine, A. Adler, & M. Payton (Eds.), *The impact of pen and touch technology on education* (pp. 49–56). Springer International Publishing. https://doi.org/10.1007/978-3-319-15594-4_5.
- Kumar, A. & Kumaresan, S. (2008). Use of mathematical software for teaching and learning mathematics. *ICME 11 Proceedings*, 373–388.
- Larkin, K., & Calder, N. (2015). Mathematics education and mobile technologies. *Mathematics Education Research Journal*. <https://doi.org/10.1007/s13394-015-0167-6>.

- Mangen, A. (2008). Hypertext fiction reading: Haptics and immersion. *Journal of Research in Reading*, 31(4), 404–419. <https://doi.org/10.1111/j.1467-9817.2008.00380.x>.
- Manny-Ikan, E., Tikochinski, T. B., & Bashan, Z. (2013). Does use of ICT-based teaching encourage innovative interactions in the classroom? Presentation of the CLI-O: Class learning interactions observation tool. *Interdisciplinary Journal of E-Learning and Learning Objects*, 9, 219–232.
- McLaughlin, A. C., Rogers, W. A., & Fisk, A. D. (2009). Using direct and indirect input devices: Attention de-mands and age-related differences. *ACM Transactions on Computer-Human Interaction*, 16(1), 1–15. <https://doi.org/10.1145/1502800.1502802>.
- Moyer-Packenham, P. S., Bullock, E. K., Shumway, J. F., Tucker, S. I., Watts, C. M., Westenskow, A., ..., Jordan, K. (2016). The role of affordances in children's learning performance and efficiency when using virtual manipulative mathematics touch-screen apps. *Mathematics Education Research Journal*, 28(1), 79–105. <https://doi.org/10.1007/s13394-015-0161-z>.
- Mulenga, E.M., & Marbán, J.M. (2020). Is COVID-19 the Gateway for Digital Learning in Mathematics Education?. *Contemporary Educational Technology*, 12 (2). <https://doi.org/10.30935/cedtech/7949>.
- Murphy, R., Gallagher, L., Krumm, A., Mislevy, J., & Hafter, A. (2014). *Research on the use of khan academy in schools: Research brief*. SRI International.
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. <http://www.nextgenscience.org>. Accessed 15 May 2020.
- Niess, M. L. (2006). Guest Editorial: Preparing teachers to teach Mathematics with technology. *Contemporary Issues in Technology and Teacher Education*, 6(2). Retrieved from <http://www.citejournal.org/vol6/iss2/mathematics/article1.cfm>. Accessed 16 Jan 2020.
- Perienen, A. (2020). Frameworks for ICT Integration in Mathematics Education - A Teacher's Perspective. *Eurasia Journal of Mathematics, Science and Technology Education*, 16(6). <https://doi.org/10.29333/ejmste/7803>.
- Polsani, P. R. (2003). Use and abuse of reusable learning objects. *Journal of Digital Information*, 3(4). <http://journals.tdl.org/jodi/article/viewArticle/89/88>. Accessed 5 Feb 2020.
- Romeo, G., Edwards, S., McNamara, S., Walker, I., & Ziguras, C. (2003). Touching the screen: Issues related to the use of touchscreen technology in early childhood education. *British Journal of Educational Technology*, 34(3), 329–339. <https://doi.org/10.1111/1467-8535.00330>.
- Watts, C. M., Moyer-Packenham, P. S., Tucker, S. I., Bullock, E. P., Shumway, J. F., Westenskow, A., ..., Jordan, K. (2016). An examination of children's learning progression shifts while using touch screen virtual ma-nipulative mathematics apps. *Computers in Human Behavior*, 64, 814–828. <https://doi.org/10.1016/j.chb.2016.07.029>.
- White, T., & Martin, L. (2014). Mathematics and mobile learning. *TechTrends*, 58(1), 64–70. <https://doi.org/10.1007/s11528-013-0722-5>.
- Wijers, M., Jonker, V., & Drijvers, P. (2010). MobileMath: Exploring mathematics outside the classroom. *ZDM—The International Journal on Mathematics Education*, 42(7), 789–799. <https://doi.org/10.1007/s11858-010-0276-3>.
- Yerushalmy, M., & Botzer, G. (2011). Guiding mathematical inquiry in mobile settings. In O. Zaslavsky & P. Sullivan (Eds.), *Constructing knowledge for teaching secondary mathematics* (pp. 191–207). Springer. https://doi.org/10.1007/978-0-387-09812-8_12.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.