Online learning in adults learning mathematics: Literature review

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Abstract

This systematic literature review provides an overview of research and practices that have occurred over the last five years in the realm of adults learning mathematics through online learning. It includes research in the tertiary space, much of which has focused on university education. Systematic literature reviews are a method of making sense of large bodies of information and are a method for 'taking stock' and understanding of the evolution of a field of inquiry. The review found that there have been three main streams of research in the literature on adults learning mathematics online. The research in these three streams is summarised and discussed. From the review it is apparent that in the context of adults learning mathematics, there is a dearth of research on online learning in general; while there are studies that have examined the use of certain technologies, there is less of a focus on the online learning context for adults learning mathematics. Recommendations for areas of research are provided.

Key words: online learning; online technologies; adult learning, mathematics

Introduction

E-learning or online learning first emerged in the late 1980s and early 1990s when computers were increasingly being used in the home (Li, 2018). Among the first tertiary institutions to begin online learning during this time were the Open University in Britain, the University of Phoenix in the USA (Kentor, 2015) and the University of Southern Queensland in Australia as a mixed mode university (Postle et al., 2003). Since its emergence, online learning has been made increasingly possible and accessible not only by the advent of the Internet and World Wide Web but also by the high-speed internet connections that have typified internet usage in the last decade.

Since the emergence of online learning, its adoption has been rapid and transformational, leading to a paradigm shift in learning and teaching practice in higher education and vocational training institutions. For many educators, online learning is seen as a way to enhance and improve the student learning outcomes while battling shortages in resources, facilities and equipment (Castro & Tumibay, 2021). Resources that are freely available and accessed online, called open access resources or open educational resources, have been found to be useful in providing content, practice problems, grading, and feedback to students. Khan Academy, for example, has been a leading educational resources repository, with mathematics its most popular subject. Other open access resources in mathematics include *Matific* and *Geogebra*, both of which use interactive technologies and resources that support the learning of mathematics.

From a student perspective, online learning has led to a democratizing of educational delivery. At the same time, however, it has also led to a digital divide. On one hand, due to its potential for providing more flexible access to content and instruction at any time and from any place, online learning has become synonymous with accessibility, affordability, flexibility, and life-long learning. For many learners, online learning makes the ability to engage in education possible as it enables them to integrate

education into their lives rather than interrupting their lives for an immersive experience. One group of learners for which this is particularly the case is adult learners.: For this group of learners, who are more likely to have work and family obligations to balance alongside attaining a degree, online learning provides the flexibility they require to engage in more advanced levels of study (Francis, Wormington, & Hulleman, 2019; Meisami, 2020). However, research has also recognised that online learning may be more beneficial for some types of students compared to others (Francis et al., 2019). This means that as well as democratizing of educational delivery, online learning has also led to a digital divide. Inequalities in the ways different students access and engage with online learning occurs due to such factors as network coverage, device type, time of day, socio-economic status, age, educational background, and digital competence and experience (Azıonya & Nhedzı, 2021; Dhawan, 2020; Eynon, 2009; Hillier, 2018). Thus, as recognised by Dhawan (2020), while online learning can help in providing inclusive education, online learning systems, pedagogies and practices need to be developed in such a way that ensures no student is disadvantaged by the use of online learning as a result of, for example, their location, social class, and ethnicity. The need to continually consider this digital divide also means there remains the need to be highly cognizant of the impacts on students of the technologies, systems, pedagogies, and practices used on online learning and teaching.

Although online learning was already experiencing a rapid uptake by educators and students before the Covid-19 pandemic, for many universities and vocational education providers, the pandemic accelerated the move to online learning. Large numbers of lectures were quickly moved online as online learning became a panacea in the time of crisis. This quick transition meant that educators who may have had little or no experience of teaching online were suddenly tasked with adapting their classroom-based teaching approaches and materials to the online space, and they had to quickly learn how to teach and engage students in an online environment (Albano, Antonini, Coppola, Dello Iacono, & Pierri, 2021; Livy, Muir, Murphy, & Trimble, 2021).

For many educators, this rapid move online proved challenging, and while in some cases the impact was ‘bad online teaching’, it also challenged educators and researchers to engage with learners using Information and Communications Technology (ICT) tools and methodologies and it stimulated new ideas and new ways of approaching teaching and learning. It also prompted educators to re-examine their teaching (e.g. Albano et al., 2021; Brunetto, Bernardi, Andrà, & Liljedahl, 2021; Maciejewski, 2021) and has opened up a whole new vista of education possibilities (Trenholm & Peschke, 2020). Furthermore, while concerns for student equity was one of the reasons some educators resisted the move to fully online learning formats prior to the Covid-19 pandemic, during the emergency transition to online learning, strategies related to an ethos of care were adopted by educators to mitigate and address equity issues, including those of flexibility, reducing coursework to essential content, and personalization (Goin Kono & Taylor, 2021).

As the adoption of online learning has been rapid and transformational, and is constantly leading to evolutions and innovations in learning and teaching practice, it is useful to regularly stop to ‘take stock’ of the innovation and research that has occurred to identify trends and innovation in practice, impacts on and changes in student experiences, and potential areas where learning and teaching practice needs be improved. It is also cognizant to pause to reflect regularly. First, the sector needs to ensure learning and teaching practices address contemporary students’ learning needs and lead to deep learning rather than an ‘illusion of understanding’ (Schwartz, 2013, p. 1). Second, the sector should explore and articulate how learning methods in a discipline have evolved with changes and developments in online learning technologies and online learning trends. To contribute to our understanding of how online learning has impacted on how adults learn mathematics, this paper provides a systematic literature review of the research from the last five years on online learning in mathematics, with a focus on adult learners and adult learning contexts.

Methodology

Systematic literature reviews are a method of making sense of large bodies of information and involve an interpretation of a selection of documents on a specific topic that optimally involves summarization, analysis, evaluation, and synthesis of the documents (Petticrew & Roberts, 2016). Singh and Thurman (2019) suggest systematic literature reviews are a useful method for understanding of the evolution of a field of inquiry, while Tondeur, van Braak, Ertmer, and Ottenbreit-Leftwich (2017) propose the advantage of such a review is that is can produce a map of the 'bigger picture' of a specific topic or area of research. The purpose of this systematic literature review is to explore and highlight the innovations that have occurred in online mathematics education, as well as changes in both practice and the contemporary learning needs of adult learners.

The researchers collected papers relating to adults learning mathematics using online learning or online learning technologies. Journals that focus on mathematics learning (in higher education) and adults learners were of particular interest, including Educational Studies in Mathematics, Mathematics Education Research Journal, International Journal of Mathematical Education in Science and Technology, and Adults Learning Mathematics; however the search terms 'adults' and 'online learning'; and 'mathematics' were also used to find related papers published in other journals, such as those in with a focus on teaching and learning or technology use in higher education.

In determining what constituted 'online learning', it was important to define our understanding of online learning. This is because, despite the central role online learning now plays in the higher and vocational education space, authors and scholars often use the term 'online learning' to mean very distinct, and sometimes contradictory concepts, and the term has a range of meanings attached to it (Singh & Thurman, 2019). For example, it may be defined as learning taught live via technology, or hybrid learning with online content and practice problems, or fully online [perhaps even self-paced] with teachers available to help, or asynchronous learning with recorded teaching lectures.

In this paper we understand online in terms of a definition proposed by Singh and Thurman (2019). From their systematic literature review of definitions of online learning (1988-2018), Singh and Thurman (2019) suggested that online education may be defined as "education being delivered in an online environment through the use of the internet for teaching and learning. This includes online learning on the part of the students that is not dependent on their physical or virtual co-location. The teaching content is delivered online, and the instructors develop teaching modules that enhance learning and interactivity in the synchronous or asynchronous environment" (p. 306). We also acknowledge there may be two streams to online learning: one in which learning is undertaken fully online; and a second in which online learning technologies are used as a tool for learning and teaching.

Based on the results obtained from the literature search, the researchers found 31 articles that met the criteria; that is, they were about adults learning mathematics though online learning. While the literature search was limited to the last five years (since 2016), most of the articles (20) were published in the last two years (2020, 2021). Of these, half (10) were written in response to the Covid-19 and the rapid move to online education as this move led to much innovation and practice change in online mathematics instruction and learning. Thus, in undertaking a systematics review of the literature, we identified three main streams of research and the papers are reviewed within these three streams:

- Adults learning mathematics online;
- Teaching mathematics online; and
- The impact of the Covid-19 pandemic on online mathematics education

Systematic Literature Review (2016-2021) about online learning and adults learning mathematics

Adults learning mathematics online

One of the consequences of the increased accessibility of online education and the resultant democratization of higher education has been an increase in the number of adults undertaking tertiary study (Barr, 2016; Talmage, Mark, Slowey, & Knopf, 2016). As mathematics-based courses are part of the curriculum for many programs and disciplines (e.g. in nursing, paramedicine, business, psychology, engineering, computing), many adult learners undertaking tertiary study will be required to study a mathematics-based course as part of their program. The increased prevalence of online learning in mathematics education, as well as the increasing number of adults studying mathematics online has led to concerns about how the delivery of content through online methods has affected these learners' engagement and outcomes in mathematics courses and subjects.

Attitudes towards technology, online learning, and mathematics

Mature students are often anecdotally thought to be more anxious about technology than younger students, to the extent that they avoid using technology; however, research has shown this is not generally the case. In their research exploring age differences in use and attitudes towards online learning and the use of digital technologies, Staddon (2020) found no difference between mature and non-mature students' attitudes overall, nor for the dimensions related to confidence and utility (students in this research came from a range of disciplines, including mathematics). While this research did find that mature students used fewer technologies than younger students and used them less frequently, the mature students had used those technologies for a longer period over their lives.

Research by Heretick and Tanguma (2021) into attitudes towards statistics among adult learners discovered older adult students found their online learning experiences in statistics to be more rewarding than younger adult learners. In addition, when their possible deficits in online technology were addressed, these older students performed as well, or better than, their younger colleagues.

For adults learning mathematics, including in the online learning mode, research has shown that challenges are often more related to the mature-aged status of the learners rather than the mode of study, especially in relation to mathematics competence and attitudes. For many mature-aged students, there can be a considerable gap in time between finishing compulsory education and beginning more advanced study, such as at university (Galligan, Frederiks, et al., 2017; Robinson et al., 2019). Engagement with mathematics may also be accompanied by apprehension and fear, particularly if previous experiences of mathematics have been negative, or if learners lack mathematics experience or are underprepared, lack confidence, feel anxious about mathematics, or have protected themselves by avoiding the subject (Cousins, Brindley, Baker, & Johnston-Wilder, 2019; Ryan & Fitzmaurice, 2017). Many mature students may also feel at a disadvantage compared with their younger counterparts who have entered higher levels of education straight from high school where they have had recent mathematics educational experience (Ryan, 2019). Some research has also found that mathematics prerequisites for entry into undergraduate programs are not enforced at many universities (Robinson et al., 2019). When students are only advised of the level of senior mathematics that is 'assumed' or given the 'recommended knowledge' for their degree, they can feel uncertain whether their current mathematical skills are enough for the tertiary study they are about to undertake.

Heretick and Tanguma (2021) suggested that for adults learning mathematics, online learning provides opportunities for the application of heutagogical principles, also known as self-directed learning. Methods based on heutagogy expand learners' control and choices over their own learning experiences. Such methods are particularly relevant in online education as it is a learning context that often requires students to guide their own learning and be self-motivated in that learning (Yen & Liu, 2009). When applying heutagogy to the online education of adults learning quantitative-based content

(such as in statistics and mathematics), Heretick and Tanguma (2021) argued that it is a method that is most appropriate for adult learners who come to online study with competence but also with positive attitudes, expectations, and adaptability.

Impact of online learning on student success and engagement

Researchers have been interested in comparing the learning outcomes for students undertaking online learning with those students undertaking traditional face-to-face learning. Findings from these comparisons have delivered mixed results. For example, in a study of 1,411 learners (of various ages) undertaking mathematics courses, Francis et al. (2019) found that students enrolled in online courses received lower course grades and lower pass rates compared to students enrolled in face-to-face courses. The authors noted, however, that the students enrolled in online courses were more likely to be women, identify as an underrepresented ethnic/racial minority group, adult learners (i.e., 25 or older), and enrolled part time, all of which are considered factors that impact student success (i.e. gender, race/ethnicity, age and type of attendance; see Alyahyan & Düştegör, 2020, for a review of the literature on the factors that impact and predict student success). The authors acknowledged, however, that in interpreting their research it was important to note that the size of effects were small (Cohen's ds = 0.17–0.28).

In a study of 132 adult learners learning mathematics, Moreno-Guerrero, Aznar-Díaz, Cáceres-Reche, and Alonso-García (2020) reported finding that students studying through the e-learning method (online) were more likely to do better than their counterparts studying through the traditional expository method (direct instruction by the educator). The authors found that the use of online learning had a positive influence on the motivation, autonomy, participation, understanding of mathematical concepts, and grades of learners (compared to traditional teaching methods). The authors did note, however, that while the teaching to the e-learning cohort occurred through online methods, students had the option of attending a face-to-face teaching session if they felt they needed it; although, "hardly any [e-learning] students attended the face-to-face option" (p. 6).

Meisami (2020) examined the impact of online learning on the success of undergraduate students enrolled in a low-level mathematics course. As well as comparing differences between modes of delivery (online versus face-to-face), the author also compared whether characteristics such as age (adult students versus school leaver) had an impact on success in the course. The authors found that adult students studying in low-level mathematics courses that were fully online performed just as well as their adult learner counterparts who were studying face-to-face. They also found no correlation between age and success in the course.

In a review of the literature on fully online undergraduate mathematics instruction, Trenholm, Peschke, and Chinnappan (2019) found that while some studies reported lower student achievement in fully online mathematics courses, other studies reported finding no differences in student outcomes in fully online instruction compared to face-to-face instruction. In their review, the authors also found that students in fully online mathematics courses tended to be more dissatisfied compared to students in face-to-face instruction, and retention rates were lower. They therefore argued that compared to face-to-face instruction and fully online instruction occurring in other disciplines, the fully online modality has not worked well in tertiary mathematics instruction and suggested that more pedagogical – rather than just technological – innovations were needed.

The mixed findings emerging from research exploring how online learning has affected student engagement and outcomes (compared to face-to-face instruction) could be a result of different ways that researchers define and interpret online learning (for example, is it learning that is undertaken fully online or is it learning in which online learning technologies are used as one tool in the instruction). In addition, in many studies the definition of online learning informing the research is not well articulated, thus making comparisons across studies difficult. Research by Johnson and Mejia (2014) has also

shown that success in online learning (in general, not specific to mathematics) has a relational link to time; the authors found that while online students displayed negative short-term effects for course-level performance and persistence, in the long-term there were positive long-term outcomes from ongoing engagement in online learning (including degree completion).

Teaching mathematics online

As mathematics teaching and learning has increasingly moved into the online realm, researchers have been interested in exploring how to best teach mathematics online and the impacts of this online learning on student understanding and student success in mathematics. Indeed, an ongoing issue in mathematics learning and teaching is the visual nature of mathematics, which can become problematic when instruction and learning is moved online. In a review on the use of digital technologies in tertiary mathematics, Attard, Calder, Holmes, Larkin, and Trenholm (2020) noted that concerns related to how to communicate mathematically in digital technology-enabled mediums, continue to be a recurring research theme. Such research has raised concerns about the constraints these technologies place on effective communication of mathematical language, syntax, and symbolism, critical to interactions and, ultimately, successful task completion in mathematics. The authors suggested such constraints may increase cognitive load, thus making an already challenging subject even more difficult to learn.

Since the early 1990s, when technological tools of video conferencing and audio graphics first started to emerge, they have been trialled to make mathematics 'e-learning' more visual (Galligan, McDonald, Hobohm, Loch, & Taylor, 2015), with varying success. Today, the use of video as an online learning tool still continues to challenge current boundaries of educational practice in mathematics education (Attard et al., 2020). Screencasts (Dunn, Loch, & Scott, 2018), recorded lecture videos (Tisdell & Loch, 2017; Trenholm, Hajek, et al., 2019), and student-created videos (Galligan, Hobohm, & Peake, 2017) are some of the ways educators deliver and discuss mathematics online.

The growth of open access instructional video repositories and their widespread use as a tool to support mathematics education has also raised a need to assess how those educational resources impact on learning. For example, although Kahn Academy has been an educational resource since 2008, and it is regularly updated and improved, studies of its impact on teaching and learning, particularly since the employment of the flipped classroom model, are still emerging. A recent investigation of the effectiveness of Kahn Academy, including for mathematics teaching and learning, has highlighted the need for more robust research into these types of resources (Yassine, Kadry, & Siciilia, 2020). While there is little research exploring adults' use of open access resources to support their learning in mathematics, a study by Attard (2016) evaluating *Matific* as a learning resource, found that *Matific* enabled teachers to individualise learning, and that when learning is differentiated this way, students appeared to be more engaged as the content with which they were interacting contained an appropriate level of challenge. While the research examined the attitudes of primary school teachers, arguably the same principles of individualisation and differentiation could be applied in an adult learning context – this would, however, be an interesting question for researchers exploring adults learning mathematics.

While much research suggests that students are generally satisfied with such 'online' forms of instruction (either as a supplemental resource or a replacement for live lectures; Attard et al., 2020), Trenholm, Hajek, et al. (2019) found that a reduction in live lecture attendance coupled with a dependence on recorded video lectures has been associated with an increase in surface approaches to student learning. Surface approaches to learning are based on extrinsic motivations where the goal is to avoid failure with minimum time and effort, leading to 'surface' type learning actions such as rote learning and memorizing concepts. Alternatively, deep approaches to learning are based on intrinsic motivation, where the goal is to maximize understanding (Le, Joordens, Chrysostomou, & Grinnell, 2010). A student who takes a surface approach focuses on the concrete aspects of tasks, while a student who adopts a deep approach focuses on the meaning of the task (Trenholm, Hajek, et al., 2019). The

authors concluded that regular use of recorded video lectures as the main tool for instruction may therefore reduce the quality of student learning.

The impact of the Covid-19 pandemic on online mathematics education

Since the pandemic, a volume of research has emerged examining how the pandemic and the rapid move to online education has impacted mathematics learning and teaching. This research has focused on a range of impacts and can be broadly categorised into three main streams: impacts of the pandemic and the rapid move online on student learning, impacts on educators, and pedagogical innovation in mathematics that resulted from the rapid transition online.

Research exploring the impacts on students learning in mathematics

A small number of studies have investigated the impact of the pandemic and the rapid move online on student learning. For example, Bringula, Reguyal, Tan, and Ulfa (2021) examined the challenges for 69 online college learners studying 'numerical analysis' in Manila, the Philippines during the pandemic. The authors found that the shift to online learning had a negative impact on the mathematics self-concept of learners (i.e. students confidence in their skills and abilities to accomplish certain tasks). Tyaningsih, Arjudin, Prayitno, Jatmiko, and Handayani (2021) similarly explored the impacts of the pandemic and the move to 'learning from home' on students in Indonesia. The study was undertaken with 169 higher education students studying mathematics. Using qualitative surveys to explore students experience of online learning from home, the authors reported that students experienced several constraints and difficulties that impacted on their ability to learn and participate in their learning. These included internet network constraints, costs related to increase internet use (and not having the resources for those costs), and environmental restraints (such as no room in the house to adequately be able to learn online).

Matthews, Jessup, and Sears (2021) highlighted how students of colour, who have traditionally been marginalised, continued to experience inequalities during the pandemic and this was exacerbated by the historical positioning of Black parents as obstacles to learning. The authors thus argued for the expansion of direct networks for Black parents to share, communicate, and advocate for their own needs and spaces around mathematics as a way to support the online mathematical learning of their children.

Darragh and Franke (2021) explored parent perspectives on home-learning mathematics during the lockdown in New Zealand. One hundred and sixty-four parents participated in the study, and their children (n =1 260) were from all levels of school (primary, intermediate and secondary). The authors reported that parents were generally very engaged in the home learning of mathematics. They also found that to support their child's mathematics learning, many parents turned to online mathematics programs (open access education resources), about which they were very positive.

Research exploring the impacts on educators of mathematics

A larger number of studies focused on the impacts of the pandemic and the rapid transition to online education on educators at all levels of education (primary, secondary, tertiary). This body of research examined issues that include how educators responded to the sudden move to online learning, how they managed their teaching activities, what distance/online practices in mathematics education emerged in response to the pandemic and the push to move online and how educators experienced these practices. A common thread through many of these studies was the process of discovery – discovering new ways to teach, new ways to teach online, new ways to use technology, and importantly, new ways to teach mathematics.

For example, Albano et al. (2021) used essays composed by 44 Italian mathematics teachers from primary school to undergraduate level to explore how these teachers perceived the unexpected transition from a face-to-face setting to distance education. The authors found that the disruption of the educational setting led to teachers' discovering key aspects of the didactic system including the

teacher's roles, their reflection on mathematics and its teaching, and attempts to reconstruct the didactic system in a new way.

Cassibba, Ferrarello, Musso, Pennisi, and Taranto (2021) explored how 27 Sicilian State University mathematics professors taught mathematics at distance, something many had never experienced before. The authors found that the educators started to appropriate new artifacts (pen tablets, mathematical software, e-learning platforms) to replicate their face-to-face teaching modality, with the majority (59%) finding the move online beneficial in terms of better teaching or learning.

In a study of 1719 secondary mathematics teachers, Drijvers et al. (2021) explored the distance practices that emerged during the pandemic and how teachers reacted to the experience. Results from the research showed that the use of video conferencing tools increased substantially, while the use of mathematics-specific tools that were used before the lockdown reduced. Unsurprisingly, teachers' confidence in using digital technologies was found to increase considerably during the lockdown.

Krause, Di Martino, and Moschkovich (2021) used personal narratives to show the impact of the pandemic on their goals related to teaching mathematics, as well as to examine aspects of the standards for mathematics education. Three common themes emerging from the three narratives were: developing a positive mindset toward mathematics; improving interdisciplinary connections; and considering interpersonal and collective matters beyond the individual.

Lopez, Bruun, Mader, and Reardon (2021) explored the experiences of 51 mathematics and statistics instructors before and after the rapid pivot to online teaching and found that while most educators did not change their preference for face-to-face teaching, many were amenable to using more online tools and were slowly accepting additional technological formats.

Fakhrunisa and Prabawanto (2020) explored the perceptions of 48 teachers on online mathematics learning challenges and possibilities during the pandemic. The teachers came from various educational backgrounds, including holding a bachelor's degree, master's degree, or graduating from a professional teacher education program. The authors found that educational experience was one of the factors that impacted teachers' ability to pivot to, and teach online. While the mathematics teachers generally held positive perceptions of online learning and felt it encouraged students to learn more independently, challenges they faced included their readiness and confidence in using the technologies and programs required to undertake online learning, limitations in achieving learning that demands mathematical thinking (online), and constraints in giving feedback to students.

Research exploring pedagogical innovation in mathematics

In exploring the impacts of the pandemic and the resultant rapid move online, a number of researchers recognised the opportunities the pandemic offered to usher in major pedagogical innovation in mathematics. For example, Livy et al. (2021) discussed how the Substitution, Augmentation, Modification and Redefinition (SAMR) Model can be used to adapt mathematics courses to be taught fully online. The model, developed by Puentedura (2015), was designed to classify types of tasks teachers can use to integrate technology into their classroom. In the model, Substitution refers to the use of technology to replace a task with little or no change, such as narrating a PowerPoint presentation. Augmentation occurs when the technology provides additional functions for the task, such as using an interactive quiz application. Modification occurs when significant changes are made to the learning experience via technology, such as using Google Classrooms or Zoom, and Redefinition occurs when the task is adapted and is unimaginable without the use of technology and cannot be completed without the technology.

From interviews with 120 secondary school mathematics teachers in the Saudi Arabia, Alabdulaziz (2021) explored the types of digital technology that were (and are still being) used in mathematics education during the pandemic. These 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 Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima. Alabdulaziz (2021) reported a positive attitude towards the required use of such technologies, as well as a positive view towards the increased adoption of digital learning in mathematics education in the future.

Future research

As the pandemic has become recognised as a 'gateway for digital learning in mathematics' (Alabdulaziz, 2021, p. 7609), and mathematical learning and teaching will, as a consequence, be increasingly fully online, we argue that more than ever it is important that researchers and practitioners consider how to best design online learning environments to ensure optimal engagement for learning. Indeed, teaching mathematics online requires more than simply transferring learning materials designed for the traditional classroom-based learning environment to an online learning platform. It also requires careful consideration of the design and functionality of online content, including how it is sequenced, its delivery, and its ease of use – these factors have been identified as among the most influential factors determining student satisfaction, engagement, and their perceived learning in online learning (Jordan & Duckett, 2018; Kite et al., 2020; Xu & Mahenthiran, 2016).

It would be interesting to see research that explores and discusses how online learning design and content can be tailored to meet the learning needs of adults learning mathematics – and it would be prudent for such designs (and the associated research) to consider the research findings presented in this systematic literature review about adults learning mathematics online. For example, it would be interesting for research to explore and provide examples of how heutagogical principles (as suggested by Heretick & Tanguma, 2021) can be applied to online learning design in mathematics to cater to adults' learning needs, and the impact of this design on those learners.

It is also essential that future research considers how to bridge the digital divide to ensure no students are disadvantaged by online learning (particularly where it is the only study option). Such research needs to also consider the technologies, systems, pedagogies and practices used in online learning and teaching and how these may be developed to ensure equitable access for all students.

With the increasing number of adult learners entering more advanced levels of study, such as higher education and vocational education, it is important that research considers how to best meet the needs of these learners. While adult learners (or mature-aged students) no longer show any differences in attitude towards the use of educational technologies compared to their younger counterparts (Heretick & Tanguma, 2021; Staddon, 2020), challenges more related to the mature-aged status of the learners rather than the mode of study remain an issue for these learners (e.g. Cousins et al., 2019; Galligan, Frederiks, et al., 2017; Ryan & Fitzmaurice, 2017). Here, researchers and practitioners have the opportunity to explore how online learning can be used to bridge any educational gaps the learner is experiencing. Indeed, exploring how online learning and online learning design and content can be used to improve mathematics anxiety or a lack of mathematics confidence for adult learners is another relevant issue that should be explored.

Another issue of ongoing importance in research exploring adults learning mathematics online is student outcomes in online learning contexts. Findings from research comparing the learning outcomes for students undertaking online learning with students undertaking traditional face-to-face learning have been mixed. While some research has shown no difference in student learning outcomes between the modes of learning (online versus face-to-face), other research has found that students are less likely to be successful when studying online – and this is a concern. Thus, as well as continuing to evaluate student outcomes (success and engagement) when they are undertaking online learning, it is important to also explore how students best learn mathematics through the different modes (online,

face-to-face) and, if there are differences in learning outcomes, how these can be addressed when that learning is moved online.

While research has considered how certain technologies may be used to enhance learning in mathematics, such as the use of screencasts and pen technologies, a wider consideration of adults learning mathematics in fully online learning contexts remains under-researched in relation to this issue and therefore a less understood area of adult learning. Thus, when exploring the use of online learning technologies, there is the opportunity to engage in research that explores how adult learners use and engage with the innovations, as well as how such technologies may be used to support the needs of adult learners.

Further understanding how adults use open access educational resources is a related stream of research. As identified by Yassine et al. (2020) from their investigation into the effectiveness of Kahn Academy, there is a the need for more robust research into these types of resources. From an adult learning mathematics perspective, as adult learners often engage in help-seeking behaviours (Richardson, 2018), it would also be interesting for research to explore how adults learning mathematics use open access education resources to support their learning and how they go about seeking help from these resources in a individually motivated way. Exploring how open access resources that offer interactive learning technologies and resources can be used to individualise learning for adults is another area for research. As has been found for younger students (Attard, 2016), when learning and content is differentiated and individualised to the adult learner's required level of challenge, do adult learners become more engaged? This is indeed an important question in higher education where online engagement remains a contemporary challenge and issue.

Finally, while much innovation and change in practice emerged as a consequence of the pandemic, it is important that we do not lose this momentum in innovation and practice change. Researchers need to continue to engage with the innovation that occurred to explore long term changes in practice, ongoing impacts on adult learners, and how those innovations may be further developed and evolved.

References

Alabdulaziz, M. S. (2021). COVID-19 and the use of digital technology in mathematics education. *Education and Information Technologies, 26*(6), 7609-7633. doi:10.1007/s10639-021-10602-3

Albano, G., Antonini, S., Coppola, C., Dello Iacono, U., & Pierri, A. (2021). "Tell me about": a logbook of teachers' changes from face-to-face to distance mathematics education. *Educational Studies in Mathematics*. doi:10.1007/s10649-021-10108-2

Alyahyan, E., & Düştegör, D. (2020). Predicting academic success in higher education: literature review and best practices. *International Journal of Educational Technology in Higher Education, 17*(1), 3. doi:10.1186/s41239-020-0177-7

Attard, C. (2016). *Research Evaluation of Matific Mathematics Learning Resources: Project Report*. Penrith, NSW: Western Sydney University.

Attard, C., Calder, N., Holmes, K., Larkin, K., & Trenholm, S. (2020). Teaching and Learning Mathematics with Digital Technologies. In J. Way, C. Attard, J. Anderson, J. Bobis, H. McMaster, & K. Cartwright (Eds.), *Research in Mathematics Education in Australasia 2016–2019* (pp. 319-347). Singapore: Springer Singapore.

Azıonya, C. M., & Nhedzı, A. (2021). The digital divide and higher education challenge with emergency online learning: Analysis of tweets in the wake of the COVID-19 lockdown. *Turkish Online Journal of Distance Education, 22*(4), 164-192. doi:10.17718/tojde.1002822

Barr, J. (2016). The Plus 50 Population in Higher Education: Challenges and Triumphs. *The Journal of Continuing Higher Education, 64*(1), 51-55. doi:10.1080/07377363.2016.1130570

Bringula, R., Reguyal, J. J., Tan, D. D., & Ulfa, S. (2021). Mathematics self-concept and challenges of learners in an online learning environment during COVID-19 pandemic. *Smart Learning Environments, 8*(1), 22. doi:10.1186/s40561-021-00168-5

Brunetto, D., Bernardi, G., Andrà, C., & Liljedahl, P. (2021). Teaching as a system: COVID-19 as a lens into teacher change. *Educational Studies in Mathematics*. doi:10.1007/s10649-021-10107-3

Cassibba, R., Ferrarello, M., M.F., Musso, P., Pennisi, M., & Taranto, E. (2021). Teaching Mathematics at Distance: A Challenge for Universities. *Education Sciences, 11*(1). doi:10.3390/educsci11010001

Castro, M. D. B., & Tumibay, G. M. (2021). A literature review: efficacy of online learning courses for higher education institution using meta-analysis. *Education and Information Technologies, 26*(2), 1367-1385. doi:10.1007/s10639-019-10027-z

Cousins, S., Brindley, J., Baker, J., & Johnston-Wilder, S. (2019). Stories of mathematical resilience: How some adult learners overcame affective barriers. *Widening Participation and Lifelong Learning, 21*(1), 46-70. doi:10.5456/WPLL.21.1.46

Darragh, L., & Franke, N. (2021). Lessons from Lockdown: Parent Perspectives on Home-learning Mathematics During COVID-19 Lockdown. *International Journal of Science and Mathematics Education*. doi:10.1007/s10763-021-10222-w

Dhawan, S. (2020). Online Learning: A Panacea in the Time of COVID-19 Crisis. *Journal of Educational Technology Systems, 49*(1), 5-22. doi:10.1177/0047239520934018

Drijvers, P., Thurm, D., Vandervieren, E., Klinger, M., Moons, F., van der Ree, H., . . . Doorman, M. (2021). Distance mathematics teaching in Flanders, Germany, and the Netherlands during COVID-19 lockdown. *Educational Studies in Mathematics, 108*(1), 35-64. doi:10.1007/s10649-021-10094-5

Dunn, M., Loch, B., & Scott, W. (2018). The effectiveness of resources created by students as partners in explaining the relevance of mathematics in engineering education. *International Journal of Mathematical Education in Science and Technology, 49*(1), 31-45. doi:10.1080/0020739X.2017.1338771

Eynon, R. (2009). Mapping the digital divide in Britain: implications for learning and education. *Learning, Media and Technology, 34*(4), 277-290. doi:10.1080/17439880903345874

Fakhrunisa, F., & Prabawanto, S. (2020). Online Learning in COVID-19 Pandemic: An Investigation of Mathematics Teachers' Perception. In *ICEEL 2020: 2020 The 4th International Conference on Education and E-Learning* (pp. 207-213). New York: Association for Computing Machinery.

Francis, M. K., Wormington, S. V., & Hulleman, C. (2019). The Costs of Online Learning: Examining Differences in Motivation and Academic Outcomes in Online and Face-to-Face Community College Developmental Mathematics Courses. *Frontiers in Psychology, 10*(2054). doi:10.3389/fpsyg.2019.02054

Galligan, L., Frederiks, A., Wandel, A. P., Robinson, C., Abdulla, S., & Hussain, Z. (2017). Nursing students' readiness for the numeracy needs of their program: Students' perspective. *Adults Learning Mathematics: An International Journal, 12*(1), 27-38.

Galligan, L., Hobohm, C., & Peake, K. (2017). Using an evaluative tool to develop effective mathscasts. *Mathematics Education Research Journal, 29*(3), 329-348. doi:10.1007/s13394-017-0204-8

Galligan, L., McDonald, C., Hobohm, C., Loch, B., & Taylor, J. (2015). Conceptualising, Implementing and Evaluating the Use of Digital Technologies to Enhance Mathematical Understanding: Reflections on an Innovation-Development Cycle. In J. Lock, P. Redmond, & P. A. Danaher (Eds.), *Educational Developments, Practices and Effectiveness: Global Perspectives and Contexts* (pp. 137-160). London: Palgrave Macmillan UK.

Goin Kono, K., & Taylor, S. (2021). Using an ethos of care to bridge the digital divide: Exploring faculty narratives during a global pandemic. *Online Learning, 25*(1), 151-165. doi:10.24059/olj.v25i1.2484

Heretick, D. M. L., & Tanguma, J. (2021). Anxiety and Attitudes Toward Statistics and Research Among Younger and Older Nontraditional Adult Learners. *The Journal of Continuing Higher Education, 69*(2), 87-99. doi:10.1080/07377363.2020.1784690

Hillier, M. (2018). Bridging the digital divide with off-line e-learning. *Distance Education, 39*(1), 110-121. doi:10.1080/01587919.2017.1418627

Johnson, H. P., & Mejia, M. C. (2014). *Online learning and student outcomes in California's community colleges*. Washington, D.C: Public Policy Institute Retrieved from https://luminafoundation.org/wp-content/uploads/2017/08/r-514hjr.pdf

Jordan, M. M., & Duckett, N. D. (2018). Universities confront 'tech disruption': Perceptions of student engagement online using two Learning Management Systems. *The Journal of Public and Professional Sociology:, 10*(1), Article 4. Retrieved from https://digitalcommons.kennesaw.edu/jpps/vol10/iss1/4

Kentor, H. (2015). Distance Education and the Evolution of Online Learning in the United States. *Curriculum and Teaching Dialogue, 17*(1-2), 21-34.

Kite, J., Schlub, T. E., Zhang, Y., Choi, S., Craske, S., & Dickson, M. (2020). Exploring lecturer and student perceptions and use of a learning management system in a postgraduate public health environment. *E-Learning and Digital Media*, *17*(3), 183-198. doi:10.1177/2042753020909217

Krause, C. M., Di Martino, P., & Moschkovich, J. N. (2021). Tales from three countries: reflections during COVID-19 for mathematical education in the future. *Educational Studies in Mathematics*. doi:10.1007/s10649-021-10066-9

Le, A., Joordens, S., Chrysostomou, S., & Grinnell, R. (2010). Online lecture accessibility and its influence on performance in skills-based courses. *Computers & Education, 55*(1), 313-319. doi:https://doi.org/10.1016/j.compedu.2010.01.017

Li, K. C. (2018). The evolution of open learning: A review of the transition from pre-e-learning to the era of e-learning. *Knowledge Management & E-Learning, 10*(4), 408-205. doi:10.34105/j.kmel.2018.10.025

Livy, S., Muir, T., Murphy, C., & Trimble, A. (2021). Creative approaches to teaching mathematics education with online tools during COVID-19. *International Journal of Mathematical Education in Science and Technology*, 1-9. doi:10.1080/0020739X.2021.1988742

Lopez, S. R., Bruun, G. R., Mader, M. J., & Reardon, R. F. (2021). The Pandemic Pivot: The Impact of COVID-19 on Mathematics and Statistics Post-Secondary Educators. *International Journal for Cross-Disciplinary Subjects in Education, 12*(1), 4369-4378. doi:10.20533/ijcdse.2042.6364.2021.0535

Maciejewski, W. (2021). Teaching math in real time. *Educational Studies in Mathematics*. doi:10.1007/s10649-021-10090-9

Matthews, L. E., Jessup, N. A., & Sears, R. (2021). Looking for "us": power reimagined in mathematics learning for Black communities in the pandemic. *Educational Studies in Mathematics*. doi:10.1007/s10649-021-10106-4

Meisami, P. (2020). *The impact of online learning on the success of nontraditional undergraduate students in low-level mathematics courses.* (Dcoctor of Education). Northeastern University, Boston, Massachusetts.

Moreno-Guerrero, A.-J., Aznar-Díaz, I., Cáceres-Reche, P., & Alonso-García, S. (2020). E-Learning in the Teaching of Mathematics: An Educational Experience in Adult High School. *Mathematics, 8*(5), 840. Retrieved from https://www.mdpi.com/2227-7390/8/5/840

Petticrew, M., & Roberts, H. (2016). *Systematic Reviews in the Social Sciences: A practical guide*. Malden, MA, USA; Oxford, UK; Carlton, Victoria, Australia: Blackwell Publishing.

Postle, G., Sturman, A., Mangubhai, F., Cronk, P., Carmichael, A., McDonald, J., . . . Vickery, B. (2003). *Online teaching and learning in higher education: a case study*. Canberra, Australia: Commonwealth of Australia

Puentedura, R. R. (2015, 14 October). SAMR: A Brief Introduction. Retrieved from http://hippasus.com/blog/archives/227

Richardson, A. P. (2018). *Studying and help-seeking behaviors: Preparation for calculus students.* (Master of Science). University of Oklahoma, Norman, Oklahoma.

Robinson, C., Galligan, L., Hussain, Z., Abdullah, S., Frederiks, A., & Wandel, A. (2019). Student Perceptions of Mathematics Readiness from a University Preparation Program to Undergraduate Studies. *Adults Learning Mathematics: An International Journal, 14*(2), 6-22.

Ryan, M. D. (2019). *An investigation into the extent and derivation of mathematics anxiety among mature students in Ireland.* (PhD). Retrieved from http://hdl.handle.net/10344/8146

Ryan, M. D., & Fitzmaurice, O. (2017). Behind the Numbers The Preliminary Findings of a Mixed Methods Study Investigating the Existence of Mathematics Anxiety Among Mature Students *Adults Learning Mathematics: An International Journal, 12*(1), 49-58.

Schwartz, M. (2013). Khan Academy: The Illusion of Understanding. *Online Learning Journal, 17*(4).

Singh, V., & Thurman, A. (2019). How many ways can we define online learning? A systematic literature review of definitions of online learning (1988-2018). *American Journal of Distance Education, 33*(4), 289-306. doi:10.1080/08923647.2019.1663082

Staddon, R. V. (2020). Bringing technology to the mature classroom: age differences in use and attitudes. *International Journal of Educational Technology in Higher Education, 17*(1), 11. doi:10.1186/s41239-020-00184-4

Talmage, C. A., Mark, R., Slowey, M., & Knopf, R. C. (2016). Age Friendly Universities and engagement with older adults: moving from principles to practice. *International Journal of Lifelong Education, 35*(5), 537-554. doi:10.1080/02601370.2016.1224040

Tisdell, C., & Loch, B. (2017). How useful are closed captions for learning mathematics via online video? *International Journal of Mathematical Education in Science and Technology*, *48*(2), 229-243. doi:10.1080/0020739X.2016.1238518

Tondeur, J., van Braak, J., Ertmer, P. A., & Ottenbreit-Leftwich, A. (2017). Understanding the relationship between teachers' pedagogical beliefs and technology use in education: a systematic review of qualitative evidence. *Educational Technology Research and Development, 65*(3), 555-575. doi:10.1007/s11423-016-9481-2

Trenholm, S., Hajek, B., Robinson, C. L., Chinnappan, M., Albrecht, A., & Ashman, H. (2019). Investigating undergraduate mathematics learners' cognitive engagement with recorded lecture videos. *International Journal of Mathematical Education in Science and Technology*, *50*(1), 3-24. doi:10.1080/0020739X.2018.1458339

Trenholm, S., & Peschke, J. (2020). Teaching undergraduate mathematics fully online: a review from the perspective of communities of practice. *International Journal of Educational Technology in Higher Education, 17*(1), 37. doi:10.1186/s41239-020-00215-0

Trenholm, S., Peschke, J., & Chinnappan, M. (2019). A Review of Fully Online Undergraduate Mathematics Instruction through the Lens of Large-Scale Research (2000-2015). *PRIMUS, 29*(10), 1080-1100. doi:10.1080/10511970.2018.1472685

Tyaningsih, R. Y., Arjudin, Prayitno, S., Jatmiko, & Handayani, A. D. (2021). The impact of the COVID-19 pandemic on mathematics learning in higher education during learning from home (LFH): students' views for the new normal. *Journal of Physics: Conference Series, 1806*, 1806 012119. doi:10.1088/1742-6596/1806/1/012119

Xu, H., & Mahenthiran, S. (2016). Factors that Influence Online Learning Assessment and Satisfaction: Using Moodle as a Learning Management System. *International Business Research, 9*(2), 1-18. doi:10.5539/ ibr.v 9 n 2 p 1

Yassine, S., Kadry, S., & Siciilia, M. A. (2020). Statistical profiles of users' interactions with videos in large repositories: Mining of Khan Academy rpository. *Korea Science, 14*(5), 2101-2121. doi:10.3837/tiis.2020.05.013

Yen, C.-J., & Liu, S. (2009). Learner Autonomy as a Predictor of Course Success and Final Grades in Community College Online Courses. *Journal of Educational Computing Research, 41*(3), 347-367. doi:10.2190/EC.41.3.e