Generative AI in teaching mathematics: Implications, affordances and challenges

Greg Oates
greg.oates@utas.edu.au
School of Education
University of Tasmania
Australia

Abstract: *With the advent of OpenAI, Generative AI (GenAI) has certainly taken the world by storm. To date, much of the debate around its use is very reminiscent of the debates around calculators, in the arguments for and against, and how it might best be used. This paper serves as a provocation in posing questions we should be asking about the future impact of AI, with a principal focus on what mathematical content and skills we believe our students should be learning in a world where AI is going to continue to develop. Indeed, what might our role as teachers be in such a world? Given how rapidly GenAI is developing, it is impossible to draw a line in the sand; nevertheless, this argues we should be thinking about the future, and how agile we must be in our own professional learning and curriculum development, in meeting constantly changing imperatives for learning.*

1. Introduction

In his 2016 ATCM address, Oates [27] considered the history of the use of digital technologies in mathematics education, focusing primarily on the period of growth from the mid-1990's. He described the 'current state of play' at that time for the effective integration of technology into the teaching and learning of mathematics, and using this position and framework as a starting point, postulated some significant challenges ahead for teachers and institutions in the continuing search for effective meaning-making in mathematics with technology. The 1990's had heralded a rapid growth in the development and use of digital technologies in mathematics education, with more powerful desktop computers, more advanced graphics calculators, and computer algebra systems (CAS) capable of symbolic manipulation. However, at the time of these reflections, while social media (SM) were having a burgeoning impact on mathematics teaching and learning, research at that time with respect to SM was somewhat limited [14], and further, while AI was prevalent in many aspects of technology, especially social media and many online learning platforms, the full awareness of the momentous impact of Generative AI (GenAI) in the form of OpenAI was still to come [15].

In tracing the history of technology developments, Oates [27] observed that the response to technology from mathematics educators (teachers, curriculum developers, and researchers alike) has often been critical, and slow to adapt to change. Notwithstanding the growth of social media use, and the looming impact of GenAI, Oates concluded that the critical challenge today and for the future is "How do we most effectively exploit the pedagogical, mathematical and motivational potential of the technologies available to our students and ourselves as teachers?" [27, p. 12]. Much earlier in 1996, Penglase and Arnold had suggested that:

> Even today, there remain widespread reservations regarding not only the best ways to incorporate such tools into teaching and learning, but fundamental questions regarding their appropriateness…The questions which practitioners have been asking (*What will be left to teach if students have access to tools which factorise, solve, and do calculus? What about their manipulative skills? What will we ask them to do in examinations?*)…were precisely the same questions asked twenty years ago regarding student access to traditional calculators [32, p. 21].

In the same year, Koblitz [20] had argued that that "…computers should not be a major component in math education reform…the intrinsic value of a pedagogical idea is not considered as important as its [the technology's] saleability…" (p.10), and such opinions were still being voiced some twenty years later, when Kardaras [19], who while not writing specifically about mathematics, observed in TIME magazine that:

> From inner-city schools to those in rural and remote towns, we have accepted tech in the classroom as a necessary and beneficial evolution in education. This is a lie. Tech in the classroom not only leads to worse educational outcomes for kids…it can also clinically hurt them (with reference to ADHD)…

Early responses to OpenAI have echoed such sentiments, and Devlin's comments in 2013 [8] may in some ways be seen as foreshadowing the wider GenAI debate, when he observed that technology developments may completely change the direction of mathematics forever:

> There is no denying that advances in technology change the kind of mathematics that gets done. When calculating devices are available to everyone on the planet … the world is unlikely to ever again see the kinds of discoveries made in earlier eras by mathematical giants such as Fermat, Gauss, Riemann, or Ramanujan. The notebooks they left behind showed that they spent many, many hours carrying out long hand calculations…There are likely to be properties of numbers that will never be suspected (using) powerful computing technology. On the other hand, there is also a gain, since the computer has given rise to what is called Experimental Mathematics, where massive numerical simulations give rise to a different kind of conjecture—conjectures that likely would not have been discovered without powerful computers.

The use of artificial intelligence has been around for many years, and its use has become increasingly more publicly prevalent in social media, education, and commercial platforms (see e.g., Advances in Mathematics Education: Social Media in the Changing Mathematics Classroom [14]). However, when OpenAI[1] (founded in 2015) introduced ChatGPT in November of 2022, a new level of artificial intelligence was achieved. ChatGPT and its quickly expanding GenAI variations (e.g., CoPilot[2], Grok[3]0 combine generative AI with large language models, resulting in artificial intelligence with the ability to think and reason. Questions of how to most effectively leverage the available technologies become even more critical in an environment where GenAI (most especially OpenAI) will take on an ever increasing role. The potential for technology to perform all the mathematics we currently base our curricula on, and to mimic or even take over the role of the teacher, certainly raises significant questions; indeed, this capacity is already occurring in the multitude of available online mathematics tutors leveraging AI such as in the long-standing platform WolframAlpha[4], the Khan Academy's khanmigo[5], or Thetawise[6], the latter of which claims to be "the world's most accurate AI for math". As well as showing students the steps in solving problems, these tools can provide effective individual feedback, including being able to respond to handwritten mathematics assignments. There are also myriad sites for teachers, which provide a range of supports from lesson plans, reporting, assessment, and designing appropriate

[1] https://openai.com/
[2] https://copilot.microsoft.com/chats/GJNDA5ZVak5Ux2MGHBpcB
[3] https://grok.com
[4] https://www.wolframalpha.com/input/?i=artificial+intelligence
[5] https://www.khanmigo.ai/
[6] https://thetawise.ai/.

learning activities (see for example School Genius[7] or Kangaroos AI[8], which incorporates a range of aids for mathematics teachers).

The sheer scope of what AI can currently perform and the realisation that every few months, the landscape will have changed significantly, poses many more questions than may have been suggested with previous technology innovations such as the graphics calculator, CAS, and more recently social media. Engelbrecht, Oates, and Borba [15] nevertheless argue that mathematics education is well-poised to consider the affordances and challenges of GenAI, with experience built on the use of calculators, and more recently computer algebra systems (CAS). In their discussion of the use of GenAI in social media, they conclude that "…teachers must be agile and open to adapting to the changing dynamics of AI … ensuring we remain at the forefront of digital engagement" and further emphasise that "…as AI continues to develop, there is a pressing need for further research to identify the true extent of AI obstacles and affordances" [15, p. 43].

How the impact of GenAI compares to, and differs from, previous technological developments is considered next.

2. How does OpenAI compare to previous technology developments?

OpenAI has exploded onto the educational stage, with exponentially increasing uses being proposed, and a dramatic growth in research, with many special issues focusing on its uses and effects. There will doubtless be several papers at this year's ATCM conference that will consider aspects of GenAI in mathematics learning and teaching, and the systematic reviews of artificial intelligence in mathematics education in [24; 30], and the Springer Special Issue (SI) due to be released in 2026, *Reimagining Mathematics Teacher Education and Research Through Artificial Intelligence*[9] both evidence the significant attention being paid to GenAI. The 2025 call for papers in the Springer SI noted:

> The use of artificial intelligence (AI), particularly generative AI, has garnered significant attention from educators and researchers. While much of the current conversation emphasizes AI's potential to transform education, it is equally important to focus on how AI can be responsibly and ethically integrated into educational practice and research. Specifically, we must consider how to ensure that AI does not amplify existing challenges and inequities. As AI rapidly evolves and shapes educational tools and systems, there is a growing need for critical, research-informed perspectives on their use in mathematics education. Ideally, AI should serve as a tool to create new opportunities for teachers, teacher educators, and researchers to address the complex problems within mathematics education.

In a similar vein, the Special Issue of the *Computers and Education: Artificial Intelligence* journal, entitled *Empowering learners for the age of AI* [17] showcases papers within which they identify seven main themes: the intersection between AI and humans [see also 5; 14; 43]; challenges and opportunities afforded by the use of AI in educational assessment; the critical need for humans in education to understand and trust AI; assessment design for learning that offers principles for designing AI-driven systems and educational opportunities; the need to explore the conceptual underpinnings of AI and to develop new theories of learning connected with existing theoretical foundations in education; accurate predictions and their role in future education; and finally applications of AI in classrooms and educational systems. In their editorial, the editors conclude that "…the findings of these studies highlight pressing research and policies challenges

[7] https://aischoolgenius.com/
[8] https://www.kangaroos.ai/about/
[9] https://link.springer.com/collections/efjicdgeej

and opportunities that arise with the broad penetration of AI in education [17, p. 1]. These challenges and opportunities lie at the heart of the provocations raised in this current discussion.

From its launch, OpenAI has generated widespread educational excitement about its potential for knowledge development, and the very performance of work [15]. Educationally, as well as its potential learning benefits, GenAI developments have raised many concerns, including, significant ethical concerns about academic integrity and the impact on assessment, and 'cheating' in higher education [7]. As in the response to calculators in the preceding decades, many early responses looked at ways of blocking or limiting the use of GenAI, to minimise negative impacts. Other responses included the use of AI-detection tools, but these quickly grew out of favour as while they do provide some indication of AI-use, it was difficult to use these as a definitive basis for penalising students' work. Some higher education institutions have seen an increasing demand for 'AI-proof' assessment which for many has seen a return to 'safe' invigilated examinations that had previously lessened considerably post-COVID in higher education settings. There has been the emergence of ever-more sophisticated tools for preventing unwanted use of AI in summative assessment, for example the *Proctortrack*[10], which offers to secure your exams from ChatGPT & other AI Cheatbots. Unlike ordinary proctoring solutions, which operate on conventional browsers and are vulnerable to ChatGPT, chatbots, AI Cheatbots, and AI extensions, this system uses PEBble, a standalone browser that blocks all unauthorized applications, along with other advantages such as dual cameras, student data privacy and provision for access to their personal data.

Most educational institutions have rapidly developed, and are continually reviewing, policies around AI use, for example the guidelines released by TEQSA (Tertiary Education Quality and Standards Agency) in Australia, *Gen AI strategies for Australian higher education: Emerging practice*, which asks for "a credible institutional action plan addressing the risk generative artificial intelligence (Gen AI) poses to award [degree] integrity"[37]. The Organisation for Economic Co-operation and Development (OECD) has released the document *Empowering Learners for the Age of AI: An AI Literacy Framework for Primary and Secondary Education* [29], and aligned with this, in 2029, the Programme for International Student Assessment (PISA) will conduct the *Media & Artificial Intelligence Literacy (MAIL) assessment*[11], to shed light on whether young students have had opportunities to learn and to engage proactively and critically in a world where production, participation, and social networking are increasingly mediated by digital and AI tools. The results of this assessment are expected to be available in December 2031.

Engelbrecht, Oates and Borba [15] note that most educational professionals are now shifting from a focus on preventing and/or mitigating AI-use, advocating instead for a more balanced approach, which seeks to exploit the affordances of AI, while minimising harmful effects. They describe the considerable debate that focuses on the relationship between artificial intelligence and human learning, and suggest we need to rethink the capabilities our learners need for a world with AI? [4; 15]. Markauskaite et al. [22] suggest we need to rethink the entwinement between artificial intelligence and human learning, asking what capabilities do learners need for a world with AI? They identify three areas in which these capabilities might fall, which collectively can be seen to encompass much of the research cited to date (see Figure 1). The machine-human interface (humanistic perspectives in Figure 1) is a common research focus in mathematics education, for example the humans-with-media concept developed by Borba and colleagues. (e.g., 5; 43], and from a neuroscience perspective, for example Zotos [44], who explored how concepts and methods from numerous mathematical fields can be used to prepare and optimise AI models that are understandable to humans. One Australian university, while simultaneously adopting careful

[10] https://proctortrack.com/
[11] https://www.oecd.org/en/about/projects/pisa-2029-media-and-artificial-intelligence-literacy.html

policies for safe and effective AI-use, has adopted an approach that recognises the knowledge dimension of AI, observing that the biggest transformation that AI makes may be what we teach - knowledge that will enhance human agency in the AI age, and nurture what is distinctly human. Some mathematics educators nevertheless raise concerns about the impact of AI on students' reasoning abilities, and question the future of the teaching profession, when *ChatGPT* and the development of Chatbots can impersonate teachers and tutor, possibly threatening the end of mathematics teachers, and potentially the beginning of the end of all human educators [4]. Aligned with the social and cognitive dimensions of Figure 1, Borba et al. [3] highlight the urgent need for criteria to assess the mathematical and educational quality of technologies and resources available to teachers, given these are largely the very same resources GenAI will draw from in its search and generation of solutions. Borba et al. suggest that "student access to [new] technologies creates a student-mathematics relationship that disrupts the traditional flow of mathematics knowledge from teacher to student, and they ask how can we offer guidance and influence the quality of these interactions? [3, p. 27].]

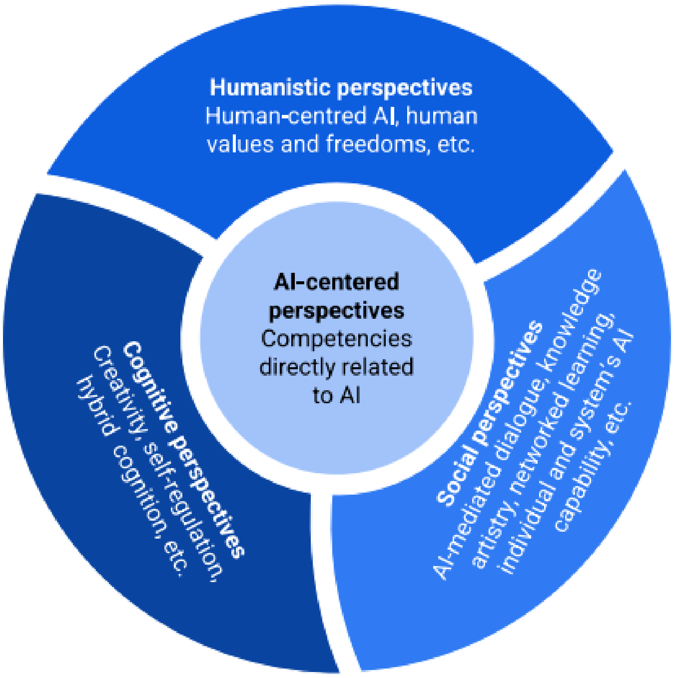

Figure 1 Synthesis of different perspectives towards the capabilities for a world with AI [22, p. 12]

In many ways, the capabilities of AI, and its affordances and obstacles mirror those of previous technologies; for example, like CAS systems (many of which now incorporate AI components), in its ability to take care of the procedural skills and algorithms that have long been key components of our curricula [15, 44]. With respect to assessment integrity, many educational institutions have adopted similar approaches to those adopted for calculator use in the past, opting for a 'two-lane' or 'traffic light' approach which sees some assessment as AI-free, similar to calculator use, where some examinations allow open use of CAS, while others are limited to scientific calculators only, and in some cases, calculator-free components. For example, in the Victorian Curriculum and Assessment Authority (VCAA) Year 12 'Mathematical Methods' course in Australia, where students are expected to apply techniques, routines and processes with and without technology:

> They [students] should have facility with relevant mental and by-hand approaches to estimation and computation.
>
> The use of numerical, graphical, geometric, symbolic and statistical functionality of technology for teaching and learning mathematics, for working mathematically, and in related assessment, is to be incorporated throughout each unit as applicable [42].

The two-lane approach for AI demands a certain proportion of assessment should demonstrate no use of AI (lane 1), while the remainder can allow for and encourage appropriate use of AI (lane 2). The traffic light approach extends this to red, amber and green, for none, limited, and open use respectively. It is worth noting that at the time of writing this paper, no examples were found where the use of AI in mathematics assessment was explicitly included in examination statements in Australia, or in a general international search, although in Finland, where their matriculation mathematics exam is delivered digitally online (no external calculators allowed) with access to a range of digital tools (e.g., GeoGebra, Logger Pro, Texas Instruments TI-Nspire CAS, Casio ClassPad Manager), it seems the platform for considering AI inclusion may feasibly be not too distant?

One key area worth exploring with respect to GenAI capabilities lies in the theoretical conceptualisation of pedagogical technology knowledge (PTK, [38]), also characterised as technological pedagogical content knowledge (TPACK, [23]), and the intersection of this with instrumentation [2; 9; 39]. Oates [27] describes how the ability of students to interact effectively with the increasing complexity of available digital technologies (instrumentation) raises important issues with respect to the time needed to learn the technology and interact effectively with the mathematics [36]. With GenAI, while on the face of it a much simpler interface, may in some ways extend the notion of instrumentation, with respect to how to generate appropriately effective prompts to direct accurate and targeted searches and outputs by the AI? PTK on the other hand describes the ability of a teacher to realise the full potential of technology to effectively support learning. It requires the teacher for example to be sufficiently familiar with the technology to recognise its affordances and constraints [6] and to be aware of potential obstacles [9; 11]. In the rapidly and ever changing GenAI environment, it remains highly problematic how teachers may maintain possess sufficient levels of PTK to appropriately integrate the task into their teaching and suitably orchestrate student learning [11].

Further, like all technological innovations, GenAI introduces its own concerns, constraints and obstacles. Hallucinations and bias have been identified as significant challenges in the field of artificial intelligence, often stemming from flaws in training data or the inherent limitations of AI models. AI hallucinations are incorrect or misleading outputs generated by AI models, which may appear as factual inaccuracies, nonsensical text, or unrealistic visual content. AI bias refers to the unfair or discriminatory outcomes generated by AI systems, often reflecting biases present in the training data. Mathematically for example, AI models, especially those trained on numerical data, may learn to approximate relationships rather than grasp the underlying mathematical rules. This can result in close, but not exact, solutions. AI can make errors when solving quadratic equations due to limitations in its training data, reliance on approximations, and occasional misinterpretations of mathematical rules. Specifically, AI might struggle with incorrect expansions or subtractions, especially when dealing with signs or distributing terms in factored and standard forms, executing the same error we have commonly seen students make, to expand $5(x\text{-}2)$ as $5x\text{-}2$. It can also treat expressions such as $(x^2 \text{ -}1)/(x+1)$ and $(x\ 1)$ as the same, while neglecting to notice that the first expression is not necessarily defined at $x = -1$, or fail to consider both positive and negative solutions when using the quadratic formula. AI can also provide factually correct solutions that might be elegant and correct, but might often be at an advanced mathematical level, that might not be accessible to a student at their stage of learning. While is it of course might be an effective way of extending a student's thinking, it can also confuse a student and lead to anxiety? Consider the example in Figure 2, where the AI was asked "Can you explain to me how to solve the equation $\cos x = 0.6$?". This solution might be very unhelpful for a student meeting the solving of trigonometric equations for the first time, as they are unlikely to have met trigonometric identities at that point.

1. Start by recognizing that

$$\cos^2(x) + \sin^2(x) = 1$$

(the Pythagorean identity).

2. Since we know that

$$\sin(x) = \sqrt{1 - \cos^2(x)}$$

, we can find the value of

$$\sin(x)$$

:

$$\sin(x) = \sqrt{1 - 0.6^2} = 0.8$$

3. Now, we have

$$\sin(x) = 0.8$$

Figure 2 An elegant, but potentially unhelpful solution to solving $\cos x = 0.6$

A further concerning aspect of AI is currently its inability to discern the accuracy/correctness/reasonableness of outputs, and its tendency to provide answers with unwavering confidence, even when they are wrong, or to change its answer in the face of concerted, but incorrect evidence? This can be misleading, as humans tend to be more hesitant when unsure, and we encourage our students to check their answers to avoid such mistakes. These examples have significant implications for how we approach the ongoing use of AI, considered in the next section.

3. Implications and questions for our future use: Where to from here?

Previous studies with technology and mathematics have considered the potential for technology to reshape and remould mathematical activity. Noss and Hoyles for example, in their seminal 1996 book *Windows on mathematical meanings: Learning cultures and computers* [25], took pains to point out the significance of keeping mathematics as our principal focus, with technology viewed as a background tool, when they emphasise that their "focus of interest is not on the computer, it is on what the computer makes possible for mathematical meaning-making [25, p. 5]. However, it is probable that OpenAI blurs the lines of the human-machine interface, and changes the bounds of mathematics itself from the time when Noss and Hoyles were writing.

There are many questions we might ask of ourselves as educators, for example “to what extent do we limit/ allow/ encourage the use of AI?” As teachers, we should ask questions about what content should we teach, what competencies/capabilities do our students need to be mathematically literate in our future world, and how might our role increasingly become as a facilitator, where AI has taken over as the ‘sage on the stage’ role? Students might question what AI they are allowed to use, how they are allowed to use it, and how to know which one they should select for the best learning outcome? They also need to judge how accurate and effective their solutions are, not just seeking and accepting an answer gained solely at the input of an appropriate prompt.

A key implication that follows from this lies with respect to research, for example in revisiting our theoretical underpinnings for mathematical learning and the use of technology itself, and how we might develop a roadmap for AI use that keeps the human role central to the mathematics, with technology as an aid to teaching and learning, not a replacement for it [40]. We should consider how *instrumental genesis* might be reframed in an AI environment [2], and question how the *orchestrations* framework might be extended to describe and inform teachers’ facilitation of student learning with AI [11; 39]. With graphing calculators for example, students need to know how to input examples, and interpret output (e.g., with respect to appropriate scales on axes, or identifying the undefined value at x = -1 in the earlier example). With AI, students need to know how to generate and progressively develop appropriate prompts, as well as critically analyse the outputs for accuracy and completeness.

We should also consider how social constructivist perspectives might be consistent with, and useful in examining, the use of AI in mathematics teaching and learning [e.g., APOS theory, 12; zone theory,16], and the opportunities AI offers for personalised, or hyperpersonalised learning, consistent with self-determined learning, theorised as heutagogy [13]. AI extends the opportunities available to support student learning outside the classroom beyond the multitude of commercial and freely available online sites (such as WolframAlpha and the Khan Academy described earlier). Students can explore readily in their own time, which has implications for example with respect to homework beyond the common rote practice of immediate lessons and content, and the potential for students to prepare in advance for upcoming lessons.

The TPACK model [23] highlights Technological Pedagogical Content Knowledge (TPACK) as lying at the intersection of three components:

- Technological Knowledge (TK): Knowledge about the use of technology, including how it works and how to operate it.
- Pedagogical Knowledge (PK): Knowledge about teaching and learning, including instructional strategies, assessment techniques, and classroom management.
- Content Knowledge (CK): Knowledge about the subject matter being taught, including concepts, theories, and methods specific to a particular discipline.

Oates [27] highlighted TPACK as an important area for exploration, asking the question “how can we develop suitable PTK for our teachers in an ever-burgeoning technology environment, so they can best realise the potential of the tools at their disposal, or the ones students’ are using or bring to the classroom?” This becomes even more critical with OpenAI, with the potential to impact all components of the TPACK model, suggesting a need to reexamine, and potentially extend the TPACK model in this respect.

Sadiku et al. [33] distinguish between seven different components of AI, several of which resonate closely with mathematical thinking and reasoning, for example:

- *Neural networks* consist of artificial synapses designed to imitate the structure and function of brains.
- *Machine learning* includes a range of algorithms and statistical models that make it possible for systems to find patterns, draw inferences, and learn to perform tasks without specific instructions.
- *Deep learning* is a form of machine learning based on artificial neural networks that can deal with complex non-linear problems.

Van Vaerenbergh and Pérez-Suay [41] expand on this, proposing a taxonomy for AI systems explicit to mathematics education:

- ***Information extractors*** are AI technologies that take observations from the real world and translate them into a mathematical representation, such as modelling word problems into mathematical equations or applying AI algorithms to extracted digitised data from a camera or a microphone, to get computer-interpretable mathematical information
- ***Reasoning engines*** are software systems that are capable of automatically solving a mathematically formulated problem. Reasoning engines also include the more sophisticated automated theorem provers, whose aim is to verify and generate proofs of mathematical theorems. Proof generation is much deeper than mere proof verification as it requires searching through huge numbers of possible steps in the proof sequence.
- ***Explainers*** in the field of mathematics education, have been built mainly for solving mathematical equations step by step. Reasoning engines can solve mathematical problems and generate correct proofs, but they do not necessarily produce results that can be understood by humans. In learning mathematics, it becomes important to have solutions and proofs that are understandable.
- ***Data-driven modelling*** allows building models that can be used to improve specific aspects in the learning process of individual students. It facilitates personalised learning, identifying individual problems and preferences of students. In a big-data fashion it also provides a way of building a database of common errors by analysing student tasks.

[from 15, p. 48]

The ability of AI to mimic the cognitive function of humans and perform activities that would typically be performed by humans [24] further suggests we should consider cognitive and mathematical knowledge perspectives with respect to AI-use. While the scope of this paper does not extend to a detailed examination of the purpose and objectives of our mathematics curricula, the capabilities of AI make it clear that the focus will increasingly be on a higher cognitive functions, reasoning, interpretive skills, and critical thinking, rather than mere technical skills, algorithms, and processes. "If a given question or issue is raised and it is solved by a quick look at Google, at ChatGPT, or other tool impregnated with AI, then it is no longer a problem—it is just a question" [14, p. 60]. There is thus a pressing need to reevaluate our curricula, and Stacey, in her 2003 ATCM paper [35], provides a potentially effective means of conducting such an evaluation, from a perspective of the *pragmatic, epistemological* and *pedagogical (heuristic)* value of topics. She suggests for example that the *Product Rule* for differentiation may have lost its pragmatic value given we can now differentiate complex functions without it using CAS (and now AI), however it retains its epistemic value because of connections to other concepts and should thus be retained. Other areas and topics may have lost their value now AI can reproduce them directly [35].

This revaluation should extend to assessment, highlighted as a critical issue in the technology framework by Oates [26] and Stacey [35]. Prior to the release of OpenAI, Drijvers posed a central question of "how to design digital tests that assess mathematical knowledge in a valid way" and suggested we need to develop "assessment environments which offer rich opportunities for students to do mathematics and for test designers to design rich items [10, p. 41]. Oates [27] raised the issue of curriculum misalignment if students use technology in all aspects of their learning, only to have technology not permitted in assessment. Given the increasing frequency of students accessing activities and resources outside the classroom that OpenAi (and social media) provides, how might we better integrate the use of AI in our still-predominant summative assessment systems, or more importantly develop better ways of using the power of technology in formative assessment [21]? There is also a potential for assessment concerns where we require AI to be used, but students (or teachers and schools) remain sceptical, or hold beliefs opposed to its use. A recent case of this has occurred in one Australian university post-graduate teacher education course, where a group of students refused to engage in an assessment task that actively involved AI in designing constructively aligned lesson sequences, based on their own beliefs opposing AI-use. The activity was closely aligned to the Australian curriculum and had been designed around a well thought out strategy to challenge assumptions about AI and assessment [28]. The problem confronted in this example yet again mirrors some of the challenges faced in previous years with opposition to using calculators.

A final implication considered here concerns the exponentially increasing proliferation of options available to students and teachers, both in the forms of technology, and the platforms available to use. There are many exciting new tools which extend our teaching and learning options with the potential to make mathematics more fun and engaging. For students, in addition to the feedback provision discussed earlier, Patel [31] notes that AI can generate project ideas on a topic that are related to students' interest, and GenAI chatbots can generate worked examples related to a specific topic – a good tool to improve understanding of concepts. Abstract mathematics problems can also be converted into word problems and vice versa – giving students the opportunity to move between abstract and real-life representations. For teachers, there are many new opportunities; the example cited earlier with respect to the creation of lesson plans; the ability to examine student performance and make predictions and informed decisions in developing future teaching strategies [1]; and precision targeting to identify groups of students with specific needs, using data sourced for example from students' SM activities [34]. There is the potential for OpenAI to be used to create, and/or rewrite innovative word problems, and even pose new problems, although concerns have been identified with respect to such aspects as appropriateness, solvability and cognitive load, and there is variability in the quality between different platforms, both of which are the focus of current studies. Such issues are consistent with the final conclusion by Oates [27, p. 12], that "teachers and students need easily used and accessible tools to assess the mathematical and educational value of the exponentially increasing selection of technological tools, apps, software, and digital resources available to them".

4. Summary

As Engelbrecht, Oates and Borba conclude [15, p. 59], "There is little doubt that integration of AI in mathematics education [is, and] will transform the way we learn and teach mathematics." The discussion here has highlighted some of the similarities with past technology developments, and how mathematics education is well-poised, using this past experience to adapt to the GenAI environment. However, it has also offered some provocations in highlighting several challenges and directions for pressing attention, in respect of research, theoretical perspectives, the purpose and objectives of mathematics curricula, content, and assessment. A key conclusion we can draw from these considerations is that we must be considerably more agile to adapt to rapid change than we have shown in the more than 30 years it has taken for us to effectively integrate the increasing sophistication of calculators (from numeric, graphing and symbolic manipulation capabilities) into our curricula, and teaching and learning practice. We must urgently evaluate what we believe our students need to learn in this new GenAI mediated world; how might the curricula change to reflect new competencies and skills, with less emphasis on procedural skills and routines, and more on critical thinking and evaluation of AI-generated solutions? How can we as teachers best leverage the power of GenAI in creating effective lessons, and better preparing our students for their future? How might our students use GenAI to explore and create new spheres of mathematical knowledge? How should our assessment change to incorporate GenAI abilities [21], and value the new competencies and skills that our students now need? As the former CEO of IBM Ginni Rometty is credited with saying, "AI will not replace humans, but those who use AI will replace those who don't"[18]. We need to ensure that we as teachers, and our students in their future lives, are not those replaced.

References

[1] Ahmed, E. (2024). Student performance prediction using machine learning algorithms. Applied computational intelligence and soft computing, Volume 2024, Article ID 4067721. https://doi.org/10.1155/2024/4067721

[2] Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning, 7*, 245–274.

[3] Borba, M.C., Askar, P., Engelbrecht, J., Gadanidis, G., Llinares, S. & Aguilar, M. S. (2016). Blended learning, e-learning and mobile learning in mathematics education *ZDM Mathematics Education, 48*(5): pp 589-610. doi:10.1007/s11858-016-0798-4

[4] Borba, M. C., & Balbino, V. R., Jr. (2023). ChatGPT and mathematics education. *Educação Matemática Pesquisa, Sao Paulo, 25*(3), 142–156.

[5] Borba, M. C., Souto, D. L. P., Cunha, J. F. T., & Domingues, N. S. (2023). Humans-with-media: Twenty-five years of a theoretical construct in mathematics education. In B. Pepin, G. Gueudet, & J. Choppin (Eds.), *Handbook of digital resources in mathematics education*. Springer.

[6] Brown, J., Stillman, G. & Herbert, S. (2004). Can the notion of affordances be of use in the design of a technology enriched mathematics curriculum? In I. Putt, R. Faragher, & M. McLean (Eds.), *Proceedings of the 27th annual conference of the Mathematics Education Research Group of Australasia* (pp. 119-126). Melbourne: MERGA.

[7] Dawson, P. (2020). *Defending assessment security in a digital world: Preventing e-cheating and supporting academic integrity in higher education*. Routledge.

[8] Devlin, K. (2013). The death of mathematics. Accessed 15 June 2015 from *Edge: https://edge.org/annual-question/what-should-we-be-worried-about*

[9] Drijvers, P. (2012). Digital technology in mathematics education: Why it works (or doesn't). In *Pre-Proceedings of the 12th International Congress on Mathematical Education*, Seoul, Korea, *Regular Lectures 2-8*, 1-17.

[10] Drijvers, P. (2018). Digital assessment of mathematics: Opportunities, issues and criteria. *Mesure et Évaluation En Éducation, 41*(1), 41–66.

[11] Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, 75, 213–234. DOI 10.1007/s10649-010-9254-5

[12] Dubinsky, E., & McDonald, M. A. (2001). APOS: A constructivist theory of learning in undergraduate mathematics education research. In *The teaching and learning of mathematics at university level* (pp. 275-282). Springer Netherlands.

[13] Engelbrecht, J., & Oates, G. (2022). Collaboration in blending digital technology into the learning of mathematics. In M. Borba, J. Engelbrecht, & R. Scucuglia (Eds.), *Mathematics education and technologies, handbook of cognitive mathematics* (pp. 1–39). Springer Nature.

[14] Engelbrecht, J., Oates, G., & Borba, M. C. (2025). Social media in the changing mathematics classroom. In In J. Engelbrecht, G. Oates, & M. C. Borba (Eds.), *Advances in Mathematics Education*: *Social Media in the Changing Mathematics Classroom*, pp. 43-66. DOI: 10.1007/978-3-031-82837-9. Springer.

[15] Engelbrecht, J., Oates, G., & Borba, M. C. (2025). Artificial intelligence and social media in mathematics education. In J. Engelbrecht, G. Oates, & M. C. Borba (Eds.), *Advances in Mathematics Education*: *Social Media in the Changing Mathematics Classroom*, pp. 1-26. DOI: 10.1007/978-3-031-82837-9. Springer.

[16] Galbraith, P. & Goos, M. (2003). From description to analysis in technology aided teaching and learning: A contribution from zone theory. In L. Bragg, C. Campbell, G. Herbert, & J. Mousley (Eds.), *Proceedings of the 26th annual conference of the Mathematics Education Research Group of Australasia* (pp. 364-371). Geelong, Vic: MERGA.

[17] Gašević, D., Siemens, G., & Sadiq, S. (2022). Empowering learners for the age of artificial intelligence. *Computers and Education: Artificial Intelligence*, *4*, 100130. https://doi.org/10.1016/j.caeai.2023.100130

[18] Haroch, R., & Harroch, D. (2025). *15 Quotes on the Future of AI*. TIME, https://time.com/partner-article/7279245/15-quotes-on-the-future-of-ai/

[19] Kardaras, N. (2016). Screens in schools are a $60 billion hoax. *TIME Magazine*, 31 August 2016, http://time.com/4474496/screens-schools-hoax/?xid=fbshare.

[20] Koblitz, N. (1996). The case against computers in k-13 math education (kindergarten through calculus), *Mathematical Intelligencer, 18*(1), 9-1.

[21] Liu, D., & Bridgeman, A. (2023). *ChatGPT is old news: How do we assess in the age of AI writing co-pilots?* https://educational- innovation.sydney.edu.au/teaching@sydney/chatgpt-is- old- news- how- do- we- assess- in- the- age- of- ai- writing- co- pilots/

[22] Markauskaite, L., Marrone, R., Poquet, O., Knight, S., Martinez-Maldonado, R., Howard, S., Tondeur, J., De Laat, M., Buckingham Shum, S., Gašević, D., & Siemens, G. (2022). Rethinking the entwinement between artificial intelligence and human learning: What capabilities do learners need for a world with AI? *Computers and Education: Artificial Intelligence, 3*, 100056.

[23] Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054

[24] Mohamed, M. Z., Hidayat, R., Suhaizi, N. N., Sabri, N. M., Mahmud, M. K. H., & Baharuddin, S. N. (2022). AI in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education*, *17*(3), em0694.

[25] Noss, R., & Hoyles, C. (1996). *Windows on mathematical meanings: Learning cultures and computers* (Vol. 17). Springer Science & Business Media.

[26] Oates, G. (2010). Integrated Technology in Undergraduate Mathematics: Issues of Assessment. *Electronic Journal of Mathematics and Technology, 4*(2), pp. 162-174. Available at http://www.radford.edu/ejmt

[27] Oates, G. (2016). Technology in mathematics education: A stocktake & crystal-ball gazing. In W.-C. Yang, D. B. Meade, & K. Khairee (Eds.), *Proceedings of the 21st Asian technology*

conference in mathematics (pp. 103–119). Mathematics & Technology, LLC. http://mathandtech.org/

[28] Ollington, N. (2025). Challenging assumptions: AI and teacher assessment identity formation. *Australian Journal of Teacher Education*, *50*(2), 56-72.

[29] Organisation for Economic Co-operation and Development (OECD). (2025). *Empowering learners for the age of AI: An AI literacy framework for primary and secondary education* (Review draft). OECD. Paris. https://ailiteracyframework.org

[30] Opesemowo, O. A. G., & Adewuyi, H. O. (2024). A systematic review of artificial intelligence in mathematics education: The emergence of 4IR. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(7), em2478.

[31] Patel, N. (2023). *AI tools for math education: Use cases & tools to make math fun and engaging.* https://www.smartpaperapp.com/post/ai-tools-for-math-education

[32] Penglase, M., & Arnold, S. (1996). The graphics calculator in mathematics education: A critical review of recent research. *Mathematics education research journal*, *8*(1), 58-90.

[33] Sadiku, M. N. O., Ashaolu, T. J., Ajayi-Majebi, A., & Musa, S. M. (2021). AI in social media. *International Journal of Scientific Advances, 2*(1). https://www.ijscia.com/

[34] Schildge, G. (2023). *AI social media plan for college institutions.* https://matrixmarketinggroup.com/ai- social- media- plan- college- university- institutions/

[35] Stacey, K. (2003). Using computer algebra systems in secondary school mathematics: Issues of curriculum, assessment and teaching. In S-C. Chu, W-C. Yang, T. de Alwis, & M-G. Lee (Eds.), *Technology Connecting Mathematics, Proceedings of the 8th Asian Technology Conference in Mathematics*, Taiwan R.O.C: ATCM.

[36] Stewart, S., Thomas, M. O. J., & Hannah, J. (2005). Towards student instrumentation of computer-based algebra systems in university courses. *International Journal of Mathematical Education in Science and Technology*, *36*(7), 741-750.

[37] Tertiary Education Quality and Standards Agency (TEQSA). (2024). Gen AI strategies for Australian higher education: Emerging practice. Australian Government: https://www.teqsa.gov.au/guides-resources/resources/corporate-publications/gen-ai-strategies-australian-higher-education-emerging-practice

[38] Thomas, M. O. J., & Hong, Y. Y. (2013). Teacher integration of technology into mathematics learning. *International Journal of Technology in Mathematics Education, 20*(2), 69-84.

[39] Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: guiding students' command process through instrumental orchestrations. *Educational Studies in Mathematics, 9*, 281-307.

[40] Trouche, L., & Drijvers, P. (2010). Handheld technology for mathematics education: flashback into the future. ZDM, The International Journal on Mathematics Education, 42(7), 667–681. DOI 10.1007/s11858-010-0269-2

[41] Van Vaerenbergh, S., & Pérez-Suay, A. (2021). A classification of AI systems for mathematics education. In P. R. Richard, P. Vélez, & S. Van Vaerenbergh (Eds.), *Mathematics education in the age of AI.* Springer Nature.

[42] Victorian Curriculum and Assessment Authority (VCAA). (2023). *Victorian Certificate of Mathematics Study Design: Mathematical Methods.* https://www.vcaa.vic.edu.au/sites/default/files/2025-03/2023MathematicsSD.docx

[43] Villarreal, M., & Borba, M. C. (2010). Collectives of humans-with-media in mathematics education: Notebooks, blackboards, calculators, computers and… notebooks throughout 100 years of ICMI. ZDM, 42(1), 49–62.

[44] Zotos, K. (2024). Computer algebra systems & artificial intelligence. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience*, *15*(2), 427-436.