European EdTech Network

Making school math concepts more accessible with EdTech

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This paper reviews key ideas from over fifty years of research that have focused on how existing and new technologies can transform approaches to learning school and university mathematics by making challenging concepts more accessible for learners - and more teachable for educators.

INRTODUCTION

In this piece I provide a review of some of the key ideas from research literature that underpin a more transformative approach to mathematics education that might be incorporated in the design of EdTech products. Such an approach ensures that learners have opportunities to explore mathematical concepts in greater depth prior to, or alongside opportunities for drill and practice. The purpose of this paper is to support EdTech designers in making well-founded decisions about the mathematical learning components of their products.

THE NATURE OF MATHEMATICS

Mathematics is a vital and essential subject that is within every country's school curriculum around the world as it is seen to be an essential and vital part of human knowledge that enables us to make sense of and solve big and small problems in the real world. It is inherently a human activity through which we have created techniques, representations, language and tangible tools to help to work on and communicate our mathematical thinking and work. At its most creative end, mathematicians continue to devise, model and apply theories, algorithms and mathematical models that push the boundaries of knowledge and its applications. Of course, mathematics is also at the heart of many other careers - data analysts, computer scientists, operational research analysts, actuaries etc. are all working as mathematicians and the intersection between mathematical and computational work has also become increasingly apparent. Mathematical knowledge is highly prized, with the top 50 jobs that involve mathematics amongst the highest paid in the world (University of California, Davis, n.d.). By contrast, school maths curricula around the world have become a mainly human-free zone and in most countries, it is being taught as a dry set of facts, vocabulary, 'standard' procedures and algorithms that have to be mastered before students are asked (or required) to work more creatively (Leikin, 2008). In this context, students' work is assessed and valued using high stakes examinations that test small bites of mathematical knowledge using paper and pencil and, increasingly technology based, timed assessments.

Therefore, it is not a surprise that over the last 50 years, technology has such had a huge impact on school mathematics and millions of EdTech resources have been created in this period by teachers, researchers, governments and industry to assess individual students' responses to predominantly 'closed' maths questions, i.e. questions with a single correct answer. One of the very first mechanical "teaching machine" was designed by the American behavioral psychologist B.F Skinner, who believed that rewarding students correct answers with immediate feedback was fundamental to the process of effective students' learning (Skinner, 1960).

However, the advent of technology opened the opportunities to offer students digital tools so they could work more creatively, collaboratively and productively on mathematical tasks. At Massachusetts Institute of Technology in the US, Seyour Papert led a team that designed one of the earliest computer languages for education, LOGO, defining a different educational philosophy, which he named constructionism (Papert, 1983).

Since this time, the huge proliferation of free and paid-for EdTechs that address mathematics have mainly followed Skinner's philosophy – that students *learn* by being offered sequential closed questions that require a simple numeric (or other) response that is automatically marked to provide immediate "reward". This can then be followed by subsequent questions as student progress through the curriculum content. Of course, the quality of the feedback, the suggestion of remediation activities and the involvement of the teacher, lecturer, parent(s) and peers can all supplement such technologies, but at their heart, the goal for the learner is to attain correct answers and be rewarded for doing so.

However, the 4th Industrial revolution is creating sophisticated digital tools that will lessen the need for humans to know and use some basic mathematical methods, such as those for carrying out particular multiplication and division calculations. Hence, educationalists such as Ken Robinson and Rose Luckin are calling for a rapid rethink of both the role of schooling and the nature of human intelligence (Luckin, 2018; Robinson, 2006). Alongside this, the teaching of collaboration, problem solving, inter-disciplinary thinking and creative skills that will underpin future workplace roles is being considered as countries review and revise their school curricular. For school mathematics, this has major implications as so much of what is currently assessed in high-stakes tests is likely to become redundant knowledge over the next 30 years.

MAKING SENSE OF EDTECHS FOR MATHEMATICS

A useful categorisation of technologies that support the teaching and learning of school and university mathematics is offered by Drijvers in Figure 1.

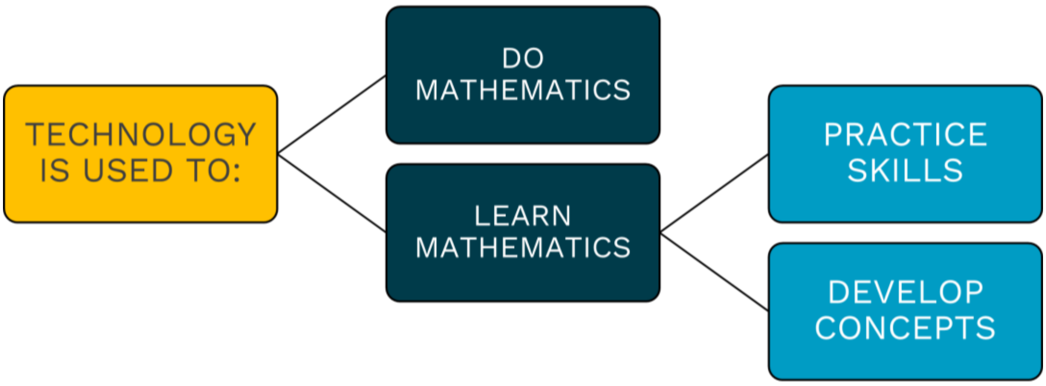

Figure 1 Didactical functions of technology in mathematics education (Drijvers, 2015)

So, at the simplest level one of the earliest EdTechs - the electronic calculator - could be used both to “do mathematics”, by performing a calculation or to “learn mathematics” if it is used as a checking device (when practising skills) or exploring iteration (when developing concepts).

To date, many EdTechs have provided extrinsic motivational devices (badges, points, leader boards) in an attempt to maintain students’ engagement to practice previously taught skills and techniques. For example, if the educational goal is for younger learners to retain multiplication facts in the “times tables” up to 10 X 10 (or 12 X 12 in England), then such tools offer a support. However, despite a number of studies that have been designed to evaluate the impact of such technologies on students' cognitive outcomes, there is limited evidence of positive effects, although the positive effects on students' motivation and engagement are more evidenced (Higgins, Huscroft-D'Angelo, & Crawford, 2019; Outhwaite, Faulder, Gulliford, & Pitchford, 2019).

Alternatively, research-based EdTech apps such as *TouchTimes* (Chorney, Gunes and Sinclair, 2018), offer an environment for younger learners to develop mathematical concepts by exploiting the touch sensitive screens of Tablet devices to enable a more exploratory learning environment (Chorney, Gunes and Sinclair, 2018). Through its design, *TouchTimes* and its related app *TouchCounts* aim to transform the way that number concepts are introduced to younger learners by exploiting the important gestural movements of fingers (See Figure 2) - crucial tools for early counting.

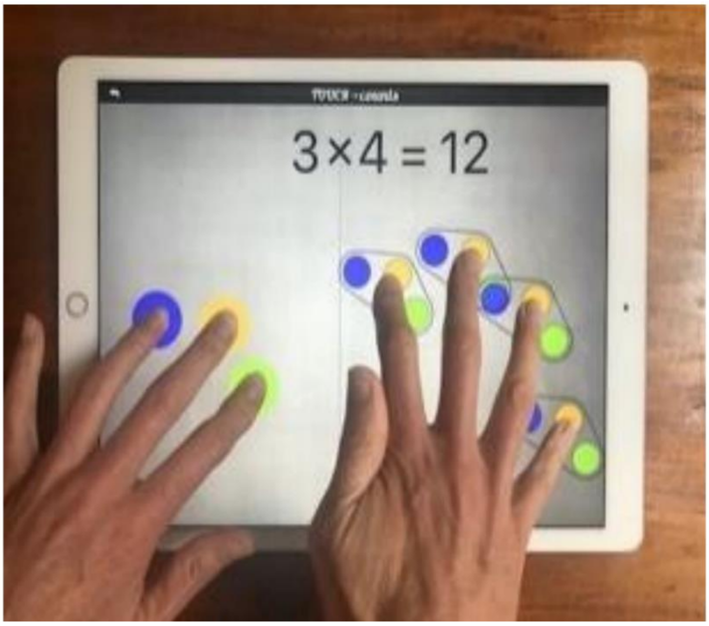

Figure 2 TouchTimes application (Chorney, Bakos and Sinclair, 2018, p. 2)

EDUCATIONAL TECHNOLOGIES THAT DEVELOP THE UNDERSTANDING OF KEY MATHEMATICAL CONCEPTS

The more transformative approaches to the use of technology in mathematics involve the use of multiple dynamic representations that provide exploratory spaces for students to explore mathematical concepts in ways that unlock ideas that are known to be hard to grasp. This includes key ideas such as the role of algebraic variables - that is, when we assign a value to a letter of the alphabet to describe a relationship of some form.

Whereas many EdTechs only consider algebra as the use of “letters as objects” (Küchemann, 1981) to be manipulated (rearranged, collected together or simplified), there are other EdTechs that offer realistic contexts, building on the seminal work of Jim Kaput in the US (Hegedus & Roschelle, 2013). Kaput sought to democratise learners’ access to algebra (a traditional gate-keeping topic in many global curricular) by offering context-based tasks that required 11-14 year old students to interact with simulations of motion. Kaput’s approach informed the design of one of the “Cornerstone Maths” curriculum units (figure 3) that was trialled between 2013-17 in hundreds of English schools and was shown to impact positively on both students’ learning outcomes and, critically teachers’ knowledge and practices to teach with such technologies (Hoyles, Noss, Vahey & Roschelle, 2013; Clark-Wilson, Hoyles, Noss, Vahey and Roschelle, 2015).

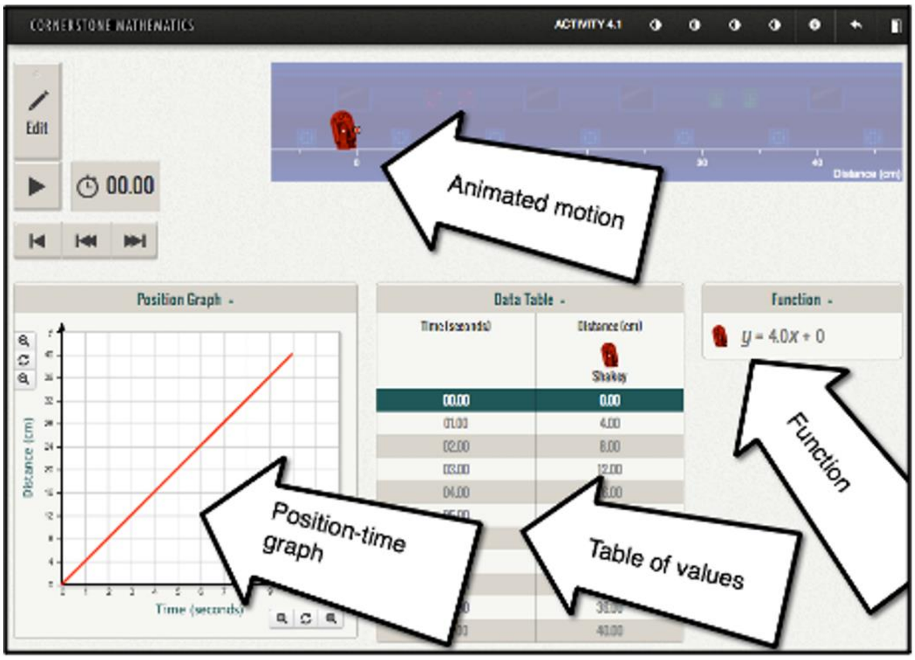

Figure 3 Cornerstone Maths Curriculum Unit on Linear functions (Clark-Wilson, Hoyles, Noss, Vahey and Roschelle 2015, p. 80)

Another key transformational technology in school mathematics, which has been shown to impact on students’ engagement with, and understanding of, geometry is “*dynamic geometry software* (DGS), which emerged in the late 1980s. DGS, such as Geogebra, are now embedded in several countries’ national curricular and integrated into e-textbooks and online examinations. DGS provide both creative spaces for students to produce their own mathematical models and solutions, alongside opportunities to interact with task that have been pre-designed by teachers or as part of published curriculum sequences (Sinclair et al 2016).

CONCEPTUALISING THE USE OF TECHNOLOGY IN SCHOOL MATHEMATICS – A STUDENT-CENTRED APPROACH

Many EdTech developers like to adopt a user-centred approach to the design of their products, which, for mathematical applications, requires them to think about the different experiences a learner might encounter when they are learning. An adaptation of Diana Laurillard's "conversational framework" for digitally mediated learning (Laurillard, 2012) when applied to mathematics might look like the image in Figure 4.

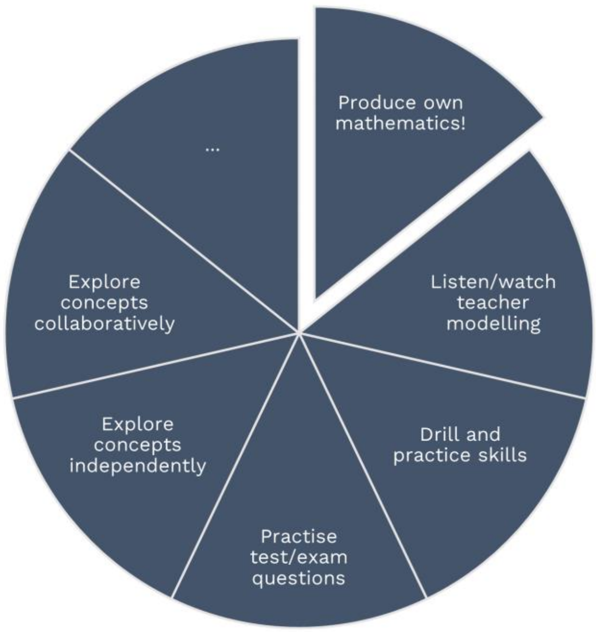

Figure 4 Healthy eating plate for learning mathematics with technology

This "healthy eating plate for learning mathematics" framework, which includes a diversity of learning activities that might be experienced over time, captures the essential components of a broad and balanced learning experience. Mathematics educational researchers would not contest that these sections are important at an individual level. However, no educational research has ever concluded what the right proportions on such a plate might be, nor how these proportions might change according to a learner's age or the mathematical concept being learned.

What is clear that, the learning experiences that underpin each activity would benefit from:

- **Offering a carefully chosen range of mathematical representations**, that is text, contextual images, audio, video, mathematical graphics (graphs, equations, tables, interactive sliders), which go far beyond what is possible in a printed text.

- **Providing scaffolding and feedback** to act as both motivational tools for learners to stay engaged, but also through the assessment of mathematical understandings and the careful diagnosis of errors. The seminal research of Kath Hart and her team in the UK in the 1980s provides a solid foundation for EdTech companies to know which mathematical concepts learners find difficult at the secondary level (Booth, 1984; Hart, 1981, 1984; Küchemann, 1981).
- **Rewarding students' collaborative work** in addition to their individual endeavours. In the classroom, when students are given opportunities to share problem-solving strategies and work of substantial tasks, they benefit from the peer-to-peer conversations and mathematical arguments.
- **Incentivising productive failure**. Very few learners find mathematical success at the first attempt. It is normal for learners to have to grapple with new ideas and concepts as they meet them.

CONCLUSION

This article has summarised some key ideas from over fifty years of research that have focused on how existing and new technologies can transform approaches to learning school mathematics by making challenging concepts more accessible to a wider group of learners - and more teachable for educators. Of course, no one EdTech product can (or should) include all of the ideas that have been presented. In addition, from a learner's perspective, they will encounter many EdTechs over their time in formal education. What matters is that EdTech companies are explicit about how their particular product contributes to a healthy mathematical learning experience for the particular learners it is designed to reach.

REFERENCES

Booth, L. (1984). *Algebra: Children's strategies and errors*. Berkshire: NFER-Nelson.

Chorney, S., Gunes, C., & Sinclair, N. (2019, 2019-02-06). Multiplicative reasoning through two-handed gestures. Paper presented at the Eleventh Congress of the European Society for Research in Mathematics Education, Utrecht, Netherlands. https://hal.archives-ouvertes.fr/hal-02422197

Clark-Wilson, A., Hoyles, C., Noss, R., Vahey, P., & Roschelle, J. (2015). Scaling a technology-based innovation: Windows on the evolution of mathematics teachers' practices. *ZDM Mathematics Education*, 47(1), 79-92. doi:10.1007/s11858-014-0635-6

Drijvers, P. (2015). Digital Technology in Mathematics Education: Why It Works (Or Doesn't). In S. J. Cho (Ed.), *Selected Regular Lectures from the 12th International Congress on Mathematical Education* (pp. 135-151). Cham: Springer International Publishing.

Hart, K. (1981). *Children's understanding of mathematics*. London: John Murray.

Hart, K. (1984). *Ratio: Children's strategies and errors*. Berkshire: NFER-Nelson.

Hegedus, S. & Roschelle, J. (2013). *The SimCalc vision and contributions*. Netherlands: Springer.

Higgins, K., Huscroft-D'Angelo, J., & Crawford, L. (2019). Effects of Technology in Mathematics on Achievement, Motivation, and Attitude: A Meta-Analysis. *Journal of Educational Computing Research, 57*(2), 283-319. doi:10.1177/0735633117748416

Hoyles, C., Noss, R., Vahey, P., & Roschelle, J. (2013). Cornerstone Mathematics: Designing digital technology for teacher adaptation and scaling. *ZDM Mathematics Education, 45*(7), 1057-1070. doi:10.1007/s11858-013-0540-4

Küchemann, D. (1981). Algebra. In K. Hart (Ed.), *Children's understanding of mathematics*. London: John Murray.

Laurillard, D. (2008). The teacher as action researcher: Using technology to capture pedagogic form. Studies in Higher Education, 33(2), pp. 139-154. https://doi.org/10.1080/03075070801915908

Laurillard, D. (2012). *Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology*. New York: Routledge.

Leikin R (2008) Teaching mathematics with and for creativity: an intercultural perspective. In: Ernest P, Greer B, Sriraman B (eds) *Critical issues in mathematics education*. Information Age Publishing Inc./The Montana Council of Teachers of Mathematics, USA, pp 39–43.

Luckin, R. (2018). Machine Learning and Human Intelligence: The future of education for the 21st century. In. London: IOE Press.

Outhwaite, L. A., Faulder, M., Gulliford, A., & Pitchford, N. J. (2019). Raising early achievement in math with interactive apps: A randomized control trial. *Journal of Educational Psychology, 111*(2), 284-298. doi:10.1037/edu0000286

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.

Robinson, K. (2006, February). Do schools kill creativity [Video]. TED Conferences. https://www.ted.com/talks/sir_ken_robinson_do_schools_kill_creativity

Sinclair, N., Bartolini Bussi, M. G., de Villiers, M., Jones, K., Kortenkamp, U., Leung, A., & Owens, K. (2016). Recent research on geometry education: an ICME-13 survey team report. ZDM, 48(5), 691-719. doi:10.1007/s11858-016-0796-6

Skinner, B. (1960). Teaching Machines. *The Review of Economics and Statistics*, 42(3), 189-191. doi:10.2307/1926170

University of California, Davis. (n.d.). *"Why Choose a Mathematics-Related Profession?".* UC, Davis. https://www.math.ucdavis.edu/~kouba/MathJobs.html