CROSSROAD BLUES

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In this paper I take up the questions posed by the conference organisers with respect to what we have learned and where we are going in technology-based research in mathematics education research. I begin by troubling the metaphors of crossroads and intersections and argue—through a wide range of considerations in relation to past research, to theory development, to teaching practices, to assessment and curriculum design and to concerns around access and equity—that there may be more fruitful metaphors for understanding our past and imagining our future.

Keywords: Technology, Learning Theory, Equity and Diversity

The metaphors of 'crossroads' and 'intersections' that were chosen for this conference are worth dwelling upon, in relation to research on the use of digital technologies. Crossroads are often used symbolically in literature, drawing on Sophocles' work *Oedipus*, to indicate a crucial moment of choice. In Oedipus there were three possible roads to follow, perhaps evoking past, present and future. But Sophocles' idea of choice may be less about making an independent decision, than about following the roads that have been carved by destiny: Oedipus was always going to end up killing his father. The invitation of the conference organisers to think in terms of crossroads provoked for me some questions about whether we really are at a decision point with numerous options available and whether one choice might be inevitable. The metaphor of intersections, which is similar in some ways, also has more mathematical connotations, ones that evoke significant ideas in geometry, especially around whether lines will intersect, how many times they will intersect and what it means to not intersect at all—all these questions being beautifully perturbed by moving to dimensions beyond the plane. But what could it be, in the context of research on technology in mathematics education, that could be seen as a crossroad or an intersection?

In considering this question, I was reminded of the work of the anthropologist Tim Ingold (2007), whose book *Lines: A brief history* traces the way in which the very idea of *line* functions metaphorically in Western society. He argues that it is so deep and entrenched that we can often find ourselves using it to describe a wide range of phenomena—often using words such as trajectories, paths, roads, trails, courses, routes—that might not actually be so linear or straight or one-dimensional. In his book, Ingold distinguishes two ways of thinking lines: as transporting and as wayfaring. In the former, we might think of getting from point A to point B and the line is the journey that gets us there. In the latter, the line is what one makes as one moves; there is no path independent of the travelling. Transposed to a theory of learning, the former would tend to conceive of learning as a sequence of journeys one might make from one concept to the next; the latter would focus on the act of tracing, on the direction that is taken and the new territory being explored. The former involves reaching successive destinations while the latter involves creating paths. Whereas crossroads and intersections, at least in my own imagery of them, have the past, the present and the future already laid out—you can go this way or that—I wonder whether it is possible to dwell in the present and so withhold the temptation to pre-determine a destination, let alone the journey that will take us there. Getting off the plane, we might even be able to think of creating paths that loop around like a Mobius strip or fan out into a surface or sprout into 17 dimensions, only four of which we might actually be able to see. As with most of our thinking around education, such an approach, which embraces multiplicity, indeterminacy and nonsense, may be the best way to handle the complexity of digital technology use in mathematics education.

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In what follows, I have attempted to address the questions and prompts offered by the conference organisers, not in a way that is exhaustive, but that is opportunistic—drawing on my own research and research interests in technology. I will try to keep the provocation of anti-crosswords alive throughout, inviting readers to think less in terms of the image in Figure 1a and more in terms of the image in Figure 1b, which is a replica of the cover of Ingold's book.

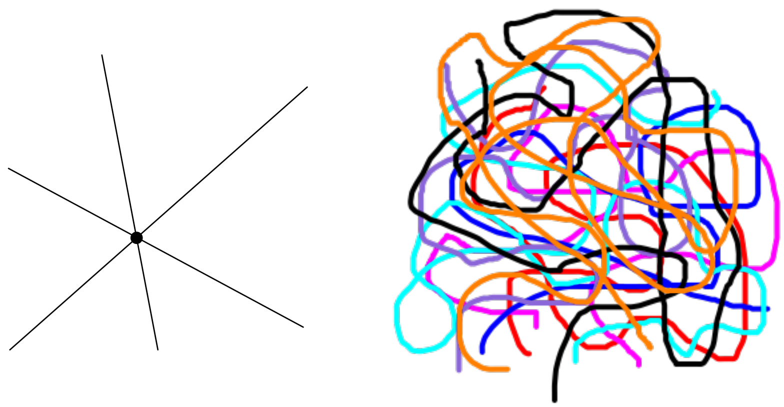

Figure 1. From transporting (intersections and crossroads) to wayfaring.

What we Have Learned from the Routes we Have Traversed

One way of seeing research in mathematics education is as an activity that enables us to answer questions, question such as: Should digital technologies be used in mathematics classroom? When is one technology better than another? What does a given technology change the way students learn? Another way of seeing research in mathematics education is as a practice of posing new questions, perhaps transforming the questions we started with so that they better respond to the complexities of the mathematics classroom. In this second kind of practice, the questions shift: new paths are created. Researchers have realised that the first question listed above, for example, depends less on empirical evidence than on assumptions about the goals of mathematics education. The second question may shift if one realizes that each technology might produce a different mathematical conception, in which case deciding on which is the best depends on many factors, ranging from aesthetic choices in mathematics to considerations of what might be evaluated on standardised tests. The third question listed above will also morph as researchers begin to appreciate that the student-technology dyad is a reductive focus, and that the role of the teacher, of the curriculum and of the classroom environment are also significant factors in what is learned.

To answer the question of what we have learned, it thus seems reasonable to consider how our questions have changed over the past few decades of research on the use of technology in mathematics education. I turn to the recently published *Second Handbook of Research on the Psychology of Mathematics Education* (Gutiérrez et al., 2016), which contains a chapter on technology (Sinclair & Yerushalmy, 2016) that considers the research published in the PME proceedings from 2006-2016. This is just one source—other Handbooks could also have been considered—but I have chosen it because it is international and because it explicitly compared research over the past decade with research conducted over the previous decade, which was reported in the first *Handbook of Research on the Psychology of Mathematics Education*, which was published in 2006.

The authors of the technology chapter report that while the 2006 Handbook had been structured into different topic areas (geometry, arithmetic and algebra), the research over the past decade was less amenable to such a categorization, in part because the research was *less explicitly concerned* with particular mathematical concepts. Instead, the primary concerns were theory, the role of the teacher, new technologies and the design of tasks and assessment. The authors found that while the majority of papers in PME proceedings were related to the use of well-known digital technologies such as dynamic geometry environments, computer algebra systems, graphing calculators and spreadsheets, these papers were less focused on the question of 'do they work?' than on questions such as: how do teachers integrate them? How might suitable tasks be designed for the use of a given technology? How might new theories help us understand the role that technologies play in teachers' and students' mathematical activity? Indeed, with respect to the first question, the authors remark on the attention not only to the teacher's role in using a given technology in the classroom, but to the challenge of orchestrating several types of resources: "Technology has opened up new challenges for teaching, not only in terms of their knowledge and beliefs, but also in terms of the complexities of integrating different kinds of resources" (p. 236). The shifting emphasis from the learner to the teacher can also be seen in the recently published edited collection entitled *The mathematics teacher in the digital age* (Clark-Wilson et al., 2014). This book was heavily oriented towards theory and professional development, but marked by a near absence of focus on mathematics. These new strands of research become entangled with prior foci of interest.

An entire section of the chapter is devoted to theorising. The authors cite Drijvers, Kieran and Mariotti's (2009) "plea for the development of integrative theoretical frameworks that allow for the articulation of different theoretical perspectives" (p. 89), especially ones that can extend and refine the two dominant theories found in European research: instrumentation theory and the theory of semiotic mediation. Sinclair and Yerushalmy report that while these two theories, which attend explicitly to the use of digital tools, were predominant, several other theoretical perspectives were used in the PME proceedings over the last decade, many of them *not* specifically attending to digital tools. The authors write that,

> With respect to the papers that do draw on theories, there has been significant development over the past decade, which suggests that the field of mathematics education related to digital technology has certainly matured; it has evolved from being an "experimentation niche" and has become an established domain of research that now carries a more solid message for the future (p. 251).

The authors go on to identify two issues related to theory use: first, they argue that theories related to the use of digital technologies need to be better coordinated with more general and established theories; second, while there has been a burgeoning of theory use and development, the concomitant development of associated methodologies has not kept pace. The idea of better coordination might imply some kind of intersections with other theories, but the simple crossing of one theory with another rarely does justice to the epistemological, ontological and axiological commitments of each.

One thing that we can say about "what we have learned from the routes we have traversed" is that the use of new theories has enabled us to ask different, more refined questions about the use of technology mathematical teaching and learning. For example, instead of asking "did the students learn fractions better?" an instrumental genesis approach might focus more on the new schemes that the students developed in using a given technology to work with fractions; a semiotic mediation approach might focus on the particular gestures that students made while using a technology and how they were transformed into mathematical signs by the classroom teacher. In both cases, there is not a revisiting of the initial question, but a re-layering of it. These questions focus less on the determining whether digital technologies should be used or whether they work better than other resources; they instead take technology use as a given and investigate the complex and often unexpected effects on how learners move their bodies, how mathematical concepts seem to arise and crystallise in new ways and how aspects of classroom activity, such as language use, student agency and material arrangements (of furniture, devices, bodies) change as well.

One final note on what we have learned relates to the evolution of research identified by Sinclair and Yerushalmy from the study of the use of "second wave technologies" [i], which are open in the sense that they do not contain embedded tasks, to an interest in *task embedded* digital technologies, "which direct the actions and uses to more specific purposes" and *evaluative* digital technologies, which "provide feedback on students' responses and actions" (p. 252). The inclusion of tasks and evaluative features may improve accessibility for teachers in that it takes care of some of the decisions that teachers would have to make with more open technologies such as identify and choosing problems and assessing student learning. Of course, the streamlining of open digital technologies may also have an adverse effect on classroom use, inasmuch as openness has often been taken as crucial for encouraging curiosity, expressiveness and agency. Nonetheless, we see in this evolution a complexifying of technology in which it is not simply the hardware/software device with strict boundaries, but instead a more amorphous entity that includes its associated tasks and modes of use. The question is less about technology A then it is about technology A using task B in setting C.

Addressing Issues of Access and Equity within Mathematics Education Today

For the most part, at least according to reports in the literature, the long-standing challenge of access—that is, whether students and teachers have access to computers and to software—is no longer the main hurdle in digital technology integration. Not only have computers become more common in classrooms, but many schools have embraced tablets; furthermore, the trend towards free software (including free versions of software programs that were originally licensed) has removed some hurdles for teachers, especially teachers in developing countries[ii].

As intimated above, the greater hurdle for technology integration relates to teaching practices, to curriculum and to assessment—and, in a sense to access to professional development (see Clark-Wilson et al., 2014). In terms of equity, there have been two main, different approaches to supporting diverse learners' needs through the use of technology. These seem to entail quite different understandings of what certain learners need in order to have more mathematical success. The development of new digital technologies addressing equity has focused mainly on students diagnosed with learning disabilities (MLDs), as well as deaf and blind students[iii]. In the area of the MLDs, for example, there have been several software programs created to help struggling children improve their number sense. These tend to be focussed on particular aspects of number and designed as *instructive*[iv] environment, which provide instant evaluative feedback and tend to target procedural skills. Such programmes aim primarily to address the deficits of the children; equity thus identifies the problem as belonging to the learner (rather than to the mathematics, the environment, etc.). Unfortunately, despite some promising results (Butterworth & Laurillard, 2010), researchers such as Goodwin and Highfield (2013) have shown that children working with the instructive digital technology were more focussed on receiving positive feedback than on discussing or reflecting on the embedded mathematical concept.

A different approach has been taken up by researchers in Brazil (see Fernandes et al., 2011; 2013; Santos, et al., 2013), who have studied the use of digital technologies in inclusive classrooms (that may include deaf, blind, seeing and hearing students), and have developed more *manipulative* technologies. Their design and research process seeks to identify different ways of interacting with mathematics that may help all learners, and not just those diagnosed with disabilities. Such work requires re-thinking mathematics (as something that can be heard, for example, instead of seen through symbols or graphs) instead of merely simplifying traditional mathematics or breaking it down into steps. Their approach to equity identifies the problem as belonging less to the learner than to the mathematics (or the ways it is taught). A similar approach was taken in the study reported by Cohen et al. (2017), which involved the use of the *manipulative*, mutitouch iPad app *TouchCounts*

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with grade 1 children identified as low-achievers in the mathematics classroom. The app, which enables tangible, visual, aural and symbolic modes of interaction, was used both in the whole classroom situation, but also in a smaller group setting with the identified children. The use of fingers, which enabled these children to improve their subitising and awareness of place value, was also helpful for the other children in the classroom.

Returning to the metaphors of crossroads, it seems that one image that drives the choice of technology used with MLDs is that the children cannot take one road, so they must take the other, thereby setting off a chain of entailments about two kinds of mathematics, two kinds of learners, two kinds of technology. Such an approach fails to consider the extent to which the traditional technology of mathematics (paper and pencil) is implicated in the very nature of school mathematics and the possibility that new technologies may change what school mathematics looks (and sounds and feels) like, and what mathematical actions might be valued in the classroom.

Barriers within Research Traditions, Educational Policy, and Teaching Practice that Impede Researchers', Students' and Teachers' Success

In the first section, I identified the recent burgeoning of theory that was evident in the last 10 years of research published in the PME proceedings, as well as the current tendency for digital technology-specific theories to be isolated from other theories in mathematics education. A similar phenomenon—the segregating of technology and non-technology research—can also be seen in peer-reviewed journal publication. This is evident when comparing articles published in JRME, FLM and ESM (three of the top-ranked, long-standing international journals in mathematics education). As Table 1 shows, there are relatively few articles that focus explicitly on the teaching and learning of mathematics using digital technology. The frequency of publication seems to be quite stable when comparing articles published in 1996, 2006 and 2016.

One reason for this low frequency is the fact that there are several journals in which authors can choose to publish their work, journals where technology is an explicit focus (for example, IJCML (now TKL), DEME, IJMTL, CJMSTE). Publications in these 'technology journals' may not be in conversation with publications in journals such as JRME, FLM and ESM, thus leading to a group of theories that specialise in the use of technology and another group of theories that more or less ignore issues relating to technology[v]. This has been partially true for the influential learning trajectory research, which though tending to a more Vygotskian perspective, which recognises the central importance of language and tools in learning, continues to identify and disseminate trajectories that do not specify the use of digital technologies. If technologies were used in any of the tasks studied by researchers, it is assumed that the stepping stones from one concept to another could be made *no matter what* technology is used—but the default technology is almost always paper and pencil. This point of view contradicts the Vygotskian premise, but also reifies a certain vision of mathematics teaching and learning that makes it more difficult for digital technologies to be taken up more widely—and thus contributing to the continued debate around "the basics" (see Roth, 2008).

Table 1: Comparison of Articles Focused on the Use of Digital Technology Across Journals

	JRME		FLM		ESM	
	Technology	Total	Technology	Total	Technology	Total
2016	1	12	1	29	3	61
2006	0	13	2	31	0	50
1996	0	23	1	23	2	32
Total	1	48	4	83	5	143
	2%		5%		3%	

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The ignoring of technology has also tended to occur in the areas of curriculum design and assessment (some of which is based on learning trajectory research). While standards in most countries may have language that includes reference to the importance of technology, the actual concepts that are listed, and the order in which they are listed, are determined in a way that is absolutely independent of any particular digital technology. For example, in the area of geometry, which is my research focus, a curriculum or textbook that asks students to engage in geometric construction by drawing shapes that have numerically determined side lengths and angle measures is anti-dynamic[vi]. This after two decades of research showing the pedagogical benefits of using dynamic geometry environments in the teacher and learning of geometry.

Lines can be dangerous. Lines can begin as imaginary paths to be followed, but once carved, they can become troughs that are hard to escape. Research in the use of digital technologies can sometimes reinforce troughs, when it focuses more on how technologies make concepts more efficient or quick to learn, rather than underscoring the sometimes unexpected conceptual shifts that innovative digital technologies can occasion.

The issue of assessment may be particularly important in high school and undergraduate contexts, where the use of digital technology on tests is often disallowed, meaning that students may be learning with a given technology but are being assessed as if that technology was a disposable scaffold to learning. Sangwin et al. (2010) argue, "if a teacher encourages students to make extensive use of tools in a course but does not allow their use on the end-of-course test, are students being given the opportunity to show what they learned with the use of such tools?" (p. 229). The issue is complex, however: in a study of secondary school teachers in Canada, Venturini (2015) found that teachers were reluctant to use digital technology assessment tasks because they were concerned that the students would learn as they used the digital technology, which was seen to contradict the purpose of assessment.

In terms of teaching practices and teachers' success, there has certainly been a dearth of research in this area. As Sinclair and Yerushalmy write, "Compared with research on student learning with technology, research on the teacher has not been as well developed" (p. 260). Nascent theory development began with the framework of TPACK, which describes the different types of knowledge that teachers may use in their teaching practices, adding technology to the well-known pedagogical and content knowledge aspects. As a theory, it is rather limited. More recently, theories that provide a more analytic lens on the role of the teacher in teaching with digital technology have been developed, based on theories of instrumental genesis (such as instrumental orchestration). Ruthven (2014) has also proposed a framework for analysing the teaching expertise that underpins successful use of digital technology in the mathematics classroom. His framework highlights the tensions that arise for teachers when trying to integrate technology, that relate to the lack of articulation between digital technologies and other resources such as textbooks, curricula and assessment. Worth studying would be situations in which this articulation has been attempted (perhaps with a high-quality e-textbook (see Pepin et al, 2015) or with trajectories that have been elaborated using digital technologies).

Laying the Groundwork for Future Crossroads or Intersections Among Theory, Research, and Practice

When thinking about future crossroads or intersections, two recent, related developments in educational research come to mind, both of which are highly relevant to technology. One is the association of mathematics with computational thinking (CT) and the other is the emergence of the idea of STEM. Both developments have received substantial funding over the past decade (and have given rise to specialized conferences, journals and special issues) and will likely shape future discussions around the role of technology in mathematics education. In both cases, the role of technology shifts quite significantly from the way it has been conceived in research over the past two decades. Before commenting on whether or not we are at a crossroads, I would like to look more closely at each new development in turn.

In the case of CT, the research initiatives most closely associated with mathematics education have involved studying the use of computer programming as a means to support mathematical learning, much in the tradition of Papert (1980). For example, Benton et al. (2017) as well as Gadanidis et al. (2016) explore the use of Scratch programming in relation to concepts that are recognizably mathematical (e.g., angle, binomial theorem). In these two cases, the digital technology in question is one that was not designed specifically for the teaching and learning of mathematics, and that entails practices and values that are specific to the domain of computer science.

In the case of STEM, the nature of the "T" seems to be less precise than in CT, involving not so much the use of programming (or coding), but instead the use of digital tools. For example, in the STEM videos published by the Teaching Channel[vii], students use scientific tools such as digital thermometers or calculators as well as simulations (a programme for building and testing rollercoaster). In these cases, the technology is not vectored towards the learning of mathematics, but rather to the completion of what is essentially a science or engineering project. Whereas the CT connection privileges computer programming as the primary mode of engagement with digital technology, the STEM agglomeration features the use of digital technologies that are oriented towards their pragmatic value rather than their epistemic value (see Artigue, 2002 for a discussion of the distinction between these two values).

I bring up these two examples because of the stress they will likely place on the way digital technologies are used and researched in mathematics education. They displace technology from being constitutive of mathematics (à la Rotman, 2008), which may result either in the displacement of technology to something you do in your CT lesson, not in mathematics, or in the isolating of technology as one element in a STEM fruit salad of disciplines that shares little disciplinary value with mathematics. Again, a crossroads view of things encourages us to think about choices, about going this way or that. But, at this moment in time, what we may need more of is attending to the multiple threads in which mathematics education is entangled and how the choices that seem on offer are already the consequence of a set of assumptions and commitments—and to think, what could things look like before the crossroads?

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Endnotes

[i] Sinclair and Jackiw (2005) describe three ways of technology evolution in mathematics education. The first wave focused on learners' interactions with technology (such as Papert's research with Logo); the second wave shifted from programming languages to technologies that were more transparently related to the school mathematics curriculum, such as graphing calculators, computer algebra systems and dynamic geometry environments; the third wave was concerned with technologies that attended to the social context of the mathematics classroom.

[ii] But this should not necessarily be seen as a positive development for mathematics education. Paying software programmes were maintained and came along with teacher support and, frequently, curriculum materials; they could be expected to be developed by professional software designers, and to last for long periods of time.

[iii] As far as I am aware, there are very few examples of digital technologies that have been designed for other groups of students who have been identified as under-achieving, based on gender,

race or socio-economic status. One exception, which dates back to the 1990s, was Klawe's E-GEMS project (see Inkpen et al., 1995), which was targeted specifically for girls. A small number of researchers have also explored the use of digital technologies with bilingual learners, who also face particular challenges in the mathematics classroom (see Ng, 2016).

[iv] Goodwin and Highfield (2013) distinguish three types of digital technologies: instructive, manipulable and constructive. Sinclair and Baccaglini-Frank (2014) describe each as follows:

> Instructive digital technologies tend to promote procedural learning, relying on evaluative feedback and repetitive interactions with imposed representations. Manipulable digital technologies enable the imposed representations to be manipulated so as to engage students in discovery and experimentation. […] Finally, constructive digital technologies are ones in which learners create their own representations, which are often the goal of the activity, thereby promoting mathematical modeling and what Noss and Hoyles (1996) characterize as expressive uses of technology. Goodwin and Highfield argue that while instructive technologies may be well-suited for procedural learning, manipulable and constructive technologies better support conceptual learning.

[v] That is it possible to do this strikes me as quite interesting, but coherent with the view that mathematics—and thus the learning of mathematics—can be separated from its technologies.

[vi] And example of this can be found in the New York State Common Core Mathematics Curriculum.

[vii] See, for example: https://www.teachingchannel.org/videos/teaching-stem-strategies and https://www.teachingchannel.org/videos/stem-lesson-ideas-heat-loss-project. An analysis of these STEM videos is currently in preparation (Bakos et al, in preparation).

References

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.

Bakos, S., Chorney, S., Ford, J., Gilling, S., Hare, A., Pimm, D., Rouleau, A., Sinclair, N. (in preparation). How STEM frames, segregates and trivialises mathematics.

Benton, L., Hoyles, C., Kalas, I., & Noss, R. (2017). Bridging Primary Programming and Mathematics: some findings of design research in England. *Digital Experiences in Mathematics Education, 3*(1).

Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscaclulia: Identification and intervention. ZDM—The International Journal on Mathematics Education, 42, 527–539.

Clark-Wilson, A., Robutti, O., & Sinclair, N. (Eds) (2014). *The mathematics teacher in the digital era: An international perspective on technology focused professional development*. Dordrecht: Springer.

Cohen, R., Chorney, S., Sinclair, N. (2017). Equity and Access to the Complexity of Number: A Multimodal, Digital Approach. In S. Celedon-Pattichis, D. White & M. Civil (Eds), *Access and Equity: Promoting high quality mathematics in grades K-2*. Reston, VA: NCTM.

Fernandes, S.H.A.A.; Healy, L.; Martins, E.G.; Rodrigues, M.A.S.; Souza, F. R. (2011). *Ver e ouvir a Matemática com uma calculadora colorida e musical: estratégias para incluir aprendizes surdos e aprendizes cegos nas salas de aulas.* In: Pletsch, M. D.; Damasceno, A. R. (Org.). Educação Especial e inclusão escolar: reflexões sobre o fazer pedagógico. Seropédica, RJ: EDUR, 2011, p. 97-111.

Fernandes, S. H. A. A., Santos, C. R., Bezerra, C. (2013). EaD e Educação Matemática Inclusiva: desafios e possibilidades In: *O uso de chat e de fórum de discussão em uma educação matemática inclusiva.*1 ed. Rio de Janeiro: EDUR, 2013, v.5, p. 19-36.

Gadanidis, G., Hughes, J. M., Minniti, L., & White, B. J. G. (2016). Computational thinking, grade 1 students and the Binomial Theorem. *Digital Experiences in Mathematics Education*, 3(2).

Goldenberg, E. P. & Cuoco, A. A. (1998). What is dynamic geometry? In R. Lehrer & D. Chazan (Eds.), *Designing learning environments for developing understanding of geometry and space.* Mahwah, NJ: Erlbaum.

Galindo, E., & Newton, J., (Eds.). (2017). *Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education.* Indianapolis, IN: Hoosier Association of Mathematics Teacher Educators.

Goodwin, K., & Highfield, K. (2013). A framework for examining technologies and early mathematics learning. In L. D. English and J. T. Mulligan (Eds.), *Reconceptualizing early mathematics learning* (pp 205–226). New York: Springer.
Gutiérez, A., Leder, G., & Boero, P. (2016). *The second handbook of research on the psychology of mathematics education*. Rotterdam, The Netherlands: Sense Publishers.
Ingold, T. (2007). *Lines: A brief history*. Abingdon, Oxon: Routledge.
Inkpen, K., Booth, K., Klawe, M. & Upitis, R. (1995). Playing together beats playingapart, especially for girls. Proceeding of CSCL '95 *The first international conference on Computer support for collaborative learning* (pp. 177-181), Bloomington, IN: Indiana University.
Larkin, K. (2016). An App! An App! My kingdom for an App: An 18-month quest to determine whether Apps support mathematical knowledge building. In T. Lowrie & R. Jorgenson (Eds), *Digital games and mathematics learning* (pp. 251-276). New York: Springer.
Ng, O. (2016). The interplay between language, gestures, dragging and diagrams in bilingual learners' mathematical communications. *Educational Studies in Mathematics*, 91(3), 307-326.
Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.
Roth, W-M. (2008). Where are the Cultural-Historical Critiques of "Back to the Basics"? *Mind, Culture, and Activity*, 15, 269-278.
Pepin, B., Gueudet, G., Yerushalmy, M., Trouche, L. Chazan, D. (2015). e-textbooks in/for Teaching and Learning Mathematics: A Disruptive and Potentially Transformative Educational Technology. L. English, & D Kirshner. *Handbook of International Research in Mathematics Education. Third edition* (pp.636-661), New York: Taylor & Francis.
Roth, W.-M. (2008). Where are the cultural-historical critiques of "back to the basics"? *Mind, Culture, and Activity*, 15, 269-278.
Rotman, B. (2008). *Becoming beside ourselves: The alphabet, ghosts, and distributed human beings*. Durham: Duke University Press.
Sangwin, C., Cazes, C., Lee. A. & Wong K.L. (2010). Micro-level Automatic Assessment Supported by Digital Technologies, Chap. 10 in the *17th ICMI Study*.
Santos, C. R., Bezerra, C., Fernandes, S. H. A. A. (2013). Contribuições de alunos cegos e de alunos surdos resolvendo problemas matemáticos em Fóruns de discussão. In: *O uso de chat e de fórum de discussão em uma educação matemática inclusiva.*1 ed. Rio de Janeiro: EDUR, 2013, v.5, p. 65-88.
Sinclair, N. & Baccaglini-Frank, A. (2015). Digital Technologies In The Early Primary School Classroom. In L. English & D. Kirshner (Eds.), *Handbook of International Research in Mathematics Education*, 3rd edition (pp. 662-686). New York, NY: Taylor Francis/Routledge.
Sinclair, N. & Jackiw, N. (2005). Understanding and Projecting ICT Trends. In S. Johnston-Wilder and D. Pimm (Eds.), *Teaching Secondary Mathematics effectively with Technology* (pp. 235-252). Open University Press.
Sinclair, N. & Yerushalmy, M. (2016). Digital Technology in Mathematics Teaching and Learning: A decade focused on theorising and teaching. In A Gutiérrez, G. Leder and P. Boero (Eds.), *The Second Handbook of Research on the Psychology of Mathematics Education: The Journey Continues* (pp. 235-274). Rotterdam, The Netherlands: Sense Publishers.
Soury-Lavergne, S. & Maschietto, M. (2015). Number system and computation with a duo of artefacts: The pascaline and the e-pascaline. In X. Sun, B. Kaur, & J. Novotna (Eds.), *The Twenty-third ICMI Study: Primary Mathematics Study on Whole Numbers* (pp. 371–378). Macau, China: ICMI.
Venturini, M. (2015). *How teachers think about the role of digital technologies in student assessment in mathematics.* Unpublished PhD dissertation. Burnaby, BC: Simon Fraser University.