Learning and Technology? Technology and Learning? A Commentary

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Abstract Should we or can we understand learning better by working with technology, and then better support learning through technology? Research that compares learning with "low-tech" technologies (paper and pencil, models and metaphors) with learning with "high-tech" technologies (calculators, dynamic software environments, touch-interactive devices) promises contributions to this question. This commentary argues that learning uses technology while technology uses learning, as demonstrated by the studies in this section of Sourcebook. Researchers in these chapters resist a common tendency to conceive of technology outside of humanity, and in this way offer models of richly informed by the co-construction of humans and their technologies.

Keywords Technology • Curriculum • Reseach questions • Professional development

Can we understand learning better, and then provoke more, better, deeper, or a different sort of learning, by working with technology? How can teaching with technology help us to better learn about learning? Does it help to compare learning with "low-tech" technologies – paper and pencil, models and metaphors – with learning that transpires along with the use of "high-tech" technologies – efficient devices such as calculators, dynamic software environments, touch-interactive devices? If so, how/what/when? The chapters in Part II lead us into such questions by providing a variety of examples of classroom-based research where the collected and analyzed data focuses primarily on learners. The studies described in this part also offer opportunities to compare across different types of boundaries: the boundary of national, cultural context (chapter "Domains of Manipulation in Touchscreen Devices and Some Didactic, Cognitive and Epistemological Implications for Improving Geometric Thinking" by Bairral, Arzarello, and Assis, between Italy and Brazil; chapter "Integrating Arithmetic and Algebra in a Collaborative Learn ing and Computational Environment Using ACODESA" by Hitt, Cortés, and

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Saboya, between Quebec and Mexico), the boundary between low-tech and high-tech forms of technology (chapter "Graphs in Primary School: Playing with Technology" by Ferrarello, between paper and pencil and graphing calculators; chapter "Pocket Calculator as an Experimental Milieu: Emblematic Tasks and Activities" by Floris, between activities with and without calculators; chapter "The Street Lamp Problem: Technologies and Meaningful Situations in Class" by Gentile and Mattei, among paper and pencil, pictures and simulations, and dynamic software; chapter "A Framework for Failed Proving Processes in a Dynamic Geometry Environment", by Chartouny, Osta, and Raad, between paper and pencil and dynamic software; chapter "Integrating Arithmetic and Algebra in a Collaborative Learning and Computational Environment Using ACODESA" by Hitt, Cortés, and Saboya, between paper and pencil and calculators; and chapter "L-System Fractals as Geometric Patterns: A Case Study", by Alfieri, among paper and pencil, webquests, and technology-based presentations), the boundary between planned and implemented curriculum (chapter "Disclosing the "Ræmotionality" of a Mathematics Teacher Using Technology in Her Classroom Activity", by De Simone; chapter "L-System Fractals as Geometric Patterns: A Case Study", by Alfieri), the boundary between types of interactivity of touch devices (chapter "Domains of Manipulation in Touchscreen Devices and Some Didactic, Cognitive and Epistemological Implications for Improving Geometric Thinking" by Bairral, Arzarello, and Assis), the boundary between required and voluntary use of technology to pursue mathematical investigations (chapter "L-System Fractals as Geometric Patterns: A Case Study", by Alfieri), and boundaries across different stages of lessons (chapter "Domains of Manipulation in Touchscreen Devices and Some Didactic, Cognitive and Epistemological Implications for Improving Geometric Thinking" by Bairral, Arzarello, and Assis; chapter "Disclosing the "Ræmotionality" of a Mathematics Teacher Using Technology in Her Classroom Activity", by De Simone; chapter "Integrating Arithmetic and Algebra in a Collaborative Learning and Computational Environment Using ACODESA" by Hitt, Cortés, and Saboya; chapter "L-System Fractals as Geometric Patterns: A Case Study", by Alfieri).

One boundary left under-theorized by this collection is that between what we mean or might mean by "learning," and what we mean or might mean by "technology." The orientation of this collection, as with much research in mathematics education, frames the research around the following sorts of questions:

- Can we tame technology so that it promotes learning rather than discourages it from taking place?
- Can we understand technology better and then make more profoundly useful technologies, or use technologies in cleverer ways, if we study technologies through how learners interact with them?
- How can learning with technology help us to better comprehend technologies, and how to classify, categorize, exploit, and control them?

Questions that I would like use to further consider as we reflect on the implications of the research reported in this collection include:

- What could it possibly mean to learn without technology? Or to have technology without learning?
- Are we inadvertently trying to tame learning so that it promotes appropriate rather than inappropriate technologies from taking hold in learning environments?
- How does what is considered technology influence what we say about technology?
- How does what one considers learning influence what we say about technology?

And I will conclude with what I see as the strengths of this collections for responding to implications of the learning-technology dichotomy for how we understand both learning and technology: when technology and learning are assumed prior to research to be distinct categories of things that can be defined, studied, and then brought into interaction, we find that technology in such research is already constructed, and hence reality is already predetermined to be created out of technology which is outside of human beings and humans "learning." Technology in this way is an add-on to a more fundamental notion of learning (and teaching/learning of course); this creates a sort of hierarchy, one way or the other, between learning with and without what is considered technology.

Can We Tame Technology?

A careful reading of the chapters in this part suggests that it might be possible that technology can be tamed and domesticated in order to nourish and support learning. My impression is that one approach to such domestication is to first of all keep all technology out of the classroom, and then to let it enter under careful scrutiny and in limited ways. By this I mean that learners who live in a technological-device-rich world outside of school are described as existing in a different world in the classroom. This is consistent with my own experience of many school mathematics learning environments in numerous countries: I rarely see learners with mobile phones, televisions, tablets, music players, fitness devices, and so on, coming together in classrooms in ways that are similar to how they interact outside of school, multitasking with entertainment, school assignments, social networking, and so on, all at the same time. What we see in such classrooms are a sort of sterile, technology-free environment into which calculators, tablets, dynamic software, or Internet exploration is introduced for examination and study. Technology becomes an intervention in the learning experience, analogous to a medical study of a drug for its effects on test subjects. Of course, it is questionable whether one can really establish a technology-pure environment, given that humans are technological beings. Technology as a tool that humans create in order to help them accomplish something far more challenging or impossible without the tool is a matter of semantics: pencil and paper is a technology for communication and learning as much as a touchscreen device; language is a tool for thinking and making sense of the world around us, for communication, for reflection, and so on; mathematics as a field of knowledge if a kind of technology. Still, there is something to be said for electronic technologies, such as calculators, touchscreen devices, dynamic software, and social networking, and that is what we are looking at in this part of this volume.

Once we domesticate technology it seems possible to imagine selective and controlled design, hybridization, and specialization, similar to the ways in which humans have carefully bred forms of livestock and plant life over generations and millennia to maximize perceived benefits. So we can and should ask, "Can we understand technology better and then make more profoundly useful technologies, or use technologies in cleverer ways, if we study technologies through how learners interact with them?" And the research collected here provides a strong "yes" in response. For example, calculators, spreadsheets, and dynamic software environments speed up the process of collecting specific cases of mathematical phenomena – values, variables, functions, shapes, locations along a graph, or properties of geometric constructions. Once this process of collecting specific cases is sped up enough, it is possible for learners to more efficiently consider at once the collection of cases rather than individual instances. This quite naturally supports a focus on collections of cases and generalizations, and in this way promotes a kind of learning that values consistent attempts to generalize, and to study the process of generalization itself as a learner. While this does not change the nature of learning – mathematics educators have always valued processes of generalization, it suggests that technology can indeed enhance the likelihood that learners can have more experiences with generalizing more often. In fact, the research collected here strongly supports the notion that dynamic software in particular models in its very form the idea of generalization, making dynamic software significantly rich in potential for promotion of a disposition to generalize.

Nevertheless, we should be cautious to assume that technology forces generalization. Similar dreams have been provoked by educational tools throughout the centuries – whether the tools are pictures drawn on the sand, blocks grouped into tens of tens, pegs arranged in arrays on boards, or circles cut into various numbers of equal pieces. Adults who already understand mathematical concepts "see" the mathematics in these models of mathematical concepts, since the models were so nicely constructed to represent the concepts themselves. So a picture in the sand, base-ten blocks used to model the decimal system of numbers, geoboards upon which rubber bands can create shapes, and fraction circles, appears to the adults to scream the mathematics concepts at a high volume. What researchers have found is that, yes, these models can often be helpful in learning environments, but they can also simply reproduce the same issues with learning and teaching, since the learners do not bring the concept fully formed to their experiences of the materials. Instead, learners often mis-learn or un-learn concepts with the models, or mindlessly attempt to follow procedures for manipulating the models with no concurrent development of understanding. So it is not automatic that technologies that speed up the creation of specific cases, or which rapidly generate seemingly infinitely many examples of a geometric construction following certain properties, will force learners to generalize; it is rather those who approach a task with a propensity to generalize will readily grasp that generalization is indeed possible in such situations. What we can say based on these chapters is that learners who have been enculturated prior to experiences with technology to pursue generalization can take advantage of technologies that support generalization, and are likely to do so.

Can Learning with Technology Help Us to Better Comprehend Technologies, and How to Classify, Categorize, Exploit, and Control Them?

Here too we can use the research reported in this part to say yes. We have examples of researchers who have designed interventions to study differences that they have perceived between low-tech paper and pencil and dynamic software, drawing pictures and using calculators, different kinds of touchscreen devices, and software versus internet-based investigations. In each case, it is possible to identify important differences among the forms of technology. And in each case, a teacher can use these differences in their planning to design encounters that exploit the differences. On the one hand, it is worth pointing out that, on a certain level of analysis, there is little change in pedagogical techniques: if learners are engaging with paper and pencil, drawings, constructions on a screen, calculators, or dragging images on a touchscreen to create transformations, the critical pedagogical method is to facilitate reflection upon changes that can be observed when one looks at the changes that one is able to make happen through interaction with the mathematical objects. This can take the form of individual thinking, small group or large group discussion, reports by individuals or small groups to an audience (either the rest of the class or people outside of the class), or written reports for a particular audience (a private journal, a letter to the teacher, a video posted online, or an interactive online presentation).

I note two important points thanks to the researchers collected in this part. First, new technology requires educators to translate what they know and believe into new contexts, and this process alone might be the most valuable aspect of technologies for learning, because it provides ways for the teachers to promote what they value in the learning experience. Sometimes the learners surprise us in how they interact with the mathematics or with the technology, and in the process, clarify through their successes in achieving our goals for them whether or not our values for learning are consistent with our expectations. De Simone makes this paramount in her research onræmotionality in chapter "Disclosing the "Ræmotionality" of a Mathematics Teacher Using Technology in Her Classroom Activity". In this study we clearly see how a teacher's hopes, dreams and fears for her students are enacted in her decisions about technology in her classroom; it is in this study in particular that we can most easily consider as well how learning and technology are difficult to unravel from each other, because the learning experience influences how the technology is defined, experienced and exploited, or not; at the same time, we see in the discussion with teacher Silvia how the technology influences the learning experience, because it is enacted in the classroom in accordance with her emotional investments for her students.

But we also see the value of translation in the other chapters in this part. Chartouny, Osta, and Raad bring their interest in cognitive processes for the development of proof into the dynamic geometry world in chapter "A Framework for Failed Proving Processes in a Dynamic Geometry Environment". Because of their interest in stages of proof sophistication, they looked for this in their work with geometry learners. In the process, they highlighted important ways that teachers can use interaction with dynamic software to carry out ongoing assessment of specific kinds of misunderstanding within instructional experiences; in this way they suggest how teachers can plan for embedding such assessment within instruction, simply by interacting with learners as they are exploring open problems. Similarly, in chapter "The Street Lamp Problem: Technologies and Meaningful Situations in Class", Gentile and Mattei clarify the relationships among conjectures, exploration of cases, and argumentation through their own use of dynamic geometry environments with learners. Hitt, Cortés, and Saboya translate an interest in algebraic thinking as emerging from investigations into number relationships chapter "Integrating Arithmetic and Algebra in a Collaborative Learning and Computational Environment Using ACODESA"; Floris also demonstrates this aspect in chapter "Pocket Calculator as an Experimental Milieu: Emblematic Tasks and Activities", as do Ferrarello in chapter "Graphs in Primary School: Playing with Technology" with graphing calculators and Alfieri in chapter "L-System Fractals as Geometric Patterns: A Case Study" with explorations designed to help students appreciate that the reproduction rule is more important in determining a fractal than its seed shape.

It seems that we are still at an early stage of classifying technologies. So far we have paper and pencil and other picture-creating tools; calculators and spreadsheets and other similar tools for carrying out repetitive calculations – whether arithmetical, tabular, or creating a static graph; dynamic environments, in which it is easy to drag and change elements while holding others static; social networking, incorporating extensive opportunities to research what others have already done; and touch-devices, in which the ways in which one interacts with the screen might, according to Bairral, Arzarello, and Assis in chapter "Domains of Manipulation in Touchscreen Devices and Some Didactic, Cognitive and Epistemological Implications for Improving Geometric Thinking", have significant impacts on the epistemologies that are carried through the learning experience. Sensorial process, motion and manipulation on-screen take an important cognitive role in this research; in their movement into existence, in which they become objects of thought and consciousness, geometric concepts are endowed with particular determinations, which are in turn actualized in sensuous, multimodal and material activity. On the other end of the experiential dimension, we might have the webquest activities described by Alfieri in chapter "L-System Fractals as Geometric Patterns: A Case Study". Because the students volunteered to pursue these beyond what is ordinarily expected of learners, and for an outside audience as part of a regional presentation competition, the learners carried their own expectations for learning into the experience, rather than being manipulated by the technological encounter into a particular form of thinking or learning.

Learning with/out/for Technology?

I want to return to the image evoked earlier, of a technologically pure environment into which we inject technology as an intervention. Could we have learning without some form of technology? This rhetorical question makes it clear that humans do not really exist independent of technologies. The history of humanity is one of co-evolving with our technologies, in ways similar to other animals with which we share our planet (including birds, mammals, dolphins, octopi, etc.). So it is important to tease out what the research highlighted in this section on learning can help us to think about in this broader context. Technology runs the risk of being understood as a prosthetic device – an enhancement either for the teacher to more powerfully trigger learning, or for the learner to more powerfully see, hear, and sense in general, the mathematics (Haraway 1991). This has positives and negatives in terms of giving superpowers – in terms of what we can accomplish in a given amount of time, what we can perceive in one glance, what we can produce, and so on; but also in the process creating super-power-related weaknesses (for example, in the rush to generalize about functions as exponents change, we overlook the nuances of a change in constants; or, in the rush to find patterns in shaped numbers, we no longer see patterns within the same shapes of numbers of objects; or, in our attempts to explore geometric relationships, we rely on argumentative fallacies as in chapter "A Framework for Failed Proving Processes in a Dynamic Geometry Environment"). Sometimes educators want to slow down rather than speed up processes, because the volume of information is overwhelming for the learner. At other times, technology narrows our focus too much, or not enough. In these instances, technologies understood as enhancing powers of perception turn into disabilities of oversensitivity to too many stimuli (Appelbaum 2007).

We sometimes inadvertently limit "technologies" to devices outside of people. What about language, knowledge, and specific terrains of subject expertise such as mathematics itself, as technologies? (Keitel et al. 1993) When we reduce technologies to tools outside of people, we also reduce learning to perception, and we exploit metaphors of perception (often reduced to an ideology of vision) to describe learning; in these ways we miss out on other forms of learning not captured by perceptual discourse. How might we help learners feel, taste, smell, and otherwise experience mathematics? Or, more fully, are their ways of comprehending learning outside of the metaphors of seeing and touching mathematical objects and mathematical relationships? What else is inherent to mathematics not captured by our ways of thinking about technology? (Appelbaum 2007).

I suppose we could say that the co-evolving humans and technologies are both influencing each other, so that our notions of mathematics, technology, and learning are all buttressing each other (Puech 2016). But there are also ways in which mathematics education might benefit from challenges to our natural ways of thinking. What if we assume that technology and learning are inseparable concepts? The technology-learning nexus, if you will, collapses all distinctions between technology and learning. What this means is learning is a technology; and technologies are a form or a crystallization of or a promise of certain “learnings”. Learning leads to acting with technologies to continue learning; technologies provoke learning how to further use the technologies to further learn to yet further use technologies. There is circularity to the overlapping and mutually defining nexus of learning and/of/with/through/for technology. The critical point is that there is no learner without the presence of some kind of technology, and no technology without a learner using the technology. Technology-learning is a collection of characteristics that are essential to mathematics education. We can similarly state what might seem obvious but which is lost in its obviousness when we try to come up with fancy research-based “results”: the learning-technology nexus is at once both personal and social, in that it is apparent in private, intimate and personal moments, both in solo explorations, and in experiences that are emotional and raemotional, and also in group activities, such as those that take place in classrooms and in small and large numbers of teachers, learners, and audiences.

None of the researchers collected here have attempted the folly of trying to isolate learning or technology outside of a culturally rich and institutionally defined form of learning-technology. That way of approach is nothing more than a trap where technology ironically becomes a form of taming learning, capturing learning in the grip of technological constraints. We might want to proceed with caution, and ask, “Who/what are we serving when we carry out research with technology?” Are we merely serving a technology outside of ourselves when looking for reasons to value the technology? This is occurring when we translate our values for mathematics into our research and desperately search for them in the learning/technology context that we have created. This is present when we introduce technologies as prosthetic power enhancers in an otherwise pedagogically dead classroom. In contrast, we are critically examining our learning-technology nexus when we explore with the technology at hand what might be possible in terms of the values that we hold for the mathematics that is being learned. Is the technology supporting the learning that is supporting further use of the technology to support learning? Do we have evidence of this circularity? When educators seek a pure idea of learning and/or a pure idea of technology independent of time, place, culture, or institutional context, I believe they misunderstand the nature of the learning-technology co-evolution that characterizes humans who are learning mathematics and creating technologies for learning mathematics, and using things at hand as technologies to learning mathematics, and in turn structuring learning to be grounded in technologies.

It is important to clarify whether the learning-technology experience is technology-driven or curriculum-driven (Bromley 1997). When confronted by a teaching/research project, we can ask:

- How did this project come about?
- Why is this initiative taking place?

If an answer to one of these questions is to insert some cool technology into a learning environment, then the project is technology-driven and is likely to lead to little significant change in learning; I would expect more of the same, as in digitized forms of exercises that could easily have been accomplished through paper and pencil worksheets, digital collection of data on student performance rather than learning, or soon-outdated equipment purchased for a large sum of money. On the other hand, if the responses to these questions involve discussion of forms of social interaction tied to goals that educators have for learning, then there is great potential that learning and technology are together carrying social values that are crucial to educational transformation. In the projects described in Part II of this volume, we have seven examples of learning-technology that are curriculum-driven rather than technology-driven and therefore demonstrate powerful forms of social transformation: Bairral, Arzarello, and Assis (chapter "Domains of Manipulation in Touchscreen Devices and Some Didactic, Cognitive and Epistemological Implications for Improving Geometric Thinking") create opportunities for the learner to be active sculptures of geometric objects and their transformation using GeoGebra and Geometric Constructor software; the secondary school students become active strategists whose gestures touching the screen physically drag through multiple cases of a possible construction. Ferrarello (chapter "Graphs in Primary School: Playing with Technology") establishes primary school students as explorers in a mathematics laboratory, who exploit technology to efficiently gather observations so that their comparisons can carefully test their own conjectures. Learners in the contribution from Floris (chapter "Pocket Calculator as an Experimental Milieu: Emblematic Tasks and Activities") establish learning milieus through anticipating actions that they then carry out, in the ongoing negotiation of the didactic contract of the classroom. Whether expectations are confirmed or met with surprising feedback from the technology, the important component of the learning-technology nexus is the ongoing construction of the possibility for "adidacticity", specifically, something to learn as an inescapable characteristic of the learning milieu.

Gentile and Mattei (chapter "The Street Lamp Problem: Technologies and Meaningful Situations in Class") raise the question of situations posed by the teacher in the classroom; the learners in this study represent the situation with GoGebra, and in the process become what the teacher describes as.

> . . .very interested and involved, working seriously on the task given, arguing and justifying their solutions in an accurate way. I felt very involved in this activity; they worked with interest and curiosity. . . (Gentile and Mattei, this volume, p. 208)

This in turn led the teacher to describe herself as transformed by the observations of her students: ". . . this gave me a great satisfaction and an incentive to repeat in the future this kind of experience." In this case, designing a social learning context in which technology is used to translate an open situation into a representation changed the forms of participation and relationships among the teacher and the learners. Similar changes in the adults are discussed in chapter "A Framework for Failed Proving Processes in a Dynamic Geometry Environment" by Chartouny, Osta, and Raad; once the teachers identify three stages of the proving process – the construction and manipulation of the figure; the formulation of the conjecture; and the proof itself – they become students of the learners, understanding the kinds of (perhaps faulty) reasoning that learners often employ, and how these kinds of reasoning can be the result of the interaction with the technology that is meant to help them learn. What we see here is a nuanced comprehension of learning with technology and technology with learning, a relationship with learners that recognizes the need for a nonlinear path toward a teacher's objectives. What learners will create as products of their learning is not always mathematically perfect; instead, forms of proving that would be labeled failures by a seasoned mathematician are evidence of learners doing just what they should be doing: learning.

Such changes in the teacher in response to the changed learning-technology world that is created by the research project are echoed in chapters "Disclosing the "Ræmotionality" of a Mathematics Teacher Using Technology in Her Classroom Activity", "Integrating Arithmetic and Algebra in a Collaborative Learning and Computational Environment Using ACODESA" and "L-System Fractals as Geo metric Patterns: A Case Study": De Simone (chapter "Disclosing the "Ræmotionality" of a Mathematics Teacher Using Technology in Her Classroom Activity") describes how a teacher thinks with potential integration of technology about how to make her dreams for her students to be more possible. As she experiments with GeoGebra and Java applets, she becomes increasingly creative in the ways that she can make it possible for learners to use their imagination to construct mathematical concepts; as students demonstrate that the dynamic software does in fact support their imagination in such ways, the teacher relies more and more on dynamic software to validate the students as constructors of mathematical concepts. Hitt, Cortés, and Saboya (chapter "Integrating Arithmetic and Algebra in a Collaborative Learning and Computational Environment Using ACODESA") place the learning-technology nexus in support of collaborative learning, scientific debate and self-reflection, a pedagogical approach that has come to be known as ACODESA; they noted, for example, how spontaneous representations impacts on three different forms of social action – individual work, teamwork and large group discussion. Finally, Alfieri (chapter "L-System Fractals as Geometric Patterns: A Case Study") turns her learners into special members of a mathematical community who self-select to pursue further investigations into interesting mathematics beyond the regular curriculum; as they pursue mathematics with technology, and as they readily make use of technology because they are learning, they become members of a new community of mathematics learners that interacts with students in other schools, and adults who are interested in what they can learn from these students.

What I find missing from this collection – and surely any small number of studies cannot reach all relevant areas of research – is attention to how the learning-technology nexus created differential curriculum-driven opportunities for different learners. Who was best served by the various forms of learning-technology that unfolded in these contexts? (Bowers 2001; Leigh 2002) Social class, ethnicity, immigration status, or other important learner communities means different opportunities in the same learning-technology world that is established in a school or classroom. What we find in these chapters is an assumed, normalized learner who interacts with a generic teacher. So I ask us to strive for further analysis in this direction.

What the research in Part II shares nevertheless is the pursuit of complexification worthy of mathematics education practice and theory, rather than an empty but rational simplicity. Learning uses technology while technology uses learning in each of these studies: I see this positive circularity in each of these chapters, and for this reason alone I applaud my colleagues, and thank them for the chance to contribute this commentary, and thus to share in their important work. Here in these chapters are researchers strongly resisting the pull to conceive of technology outside of humanity; here are researchers critically embedding themselves in the learning-technology nexus, and reflecting on that process.

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