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Assessing Effects of Technology Usage on Mathematics Learning

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Computer-based technologies are now commonplace in classrooms, and the integration of these media into the teaching and learning of mathematics is supported by government policy in most developed countries. However, many questions about the impact of computer-based technologies on classroom mathematics learning remain unanswered, and debates about when and how they ought to be used continue. An increasing number of studies seek to identify the effects of technology usage on classroom learning, and at a time when governments are calling for 'evidence-based' policy development, many studies applying quasi-scientific methodologies to this field of practice are emerging. By analysing a series of conceptual frameworks for assessing the use of computer-based technologies to support school learning, this article emphasises the value of research into the relationship between technical and conceptual aspects of technology use in mathematics education and beyond, and challenges the usefulness of large-scale, quasi-scientific studies that focus on educational inputs and outputs.

The theoretical frameworks that we use in our attempts to understand and to evaluate educational practice can be seen as lenses that are selective in their point of focus, that impose boundaries on what we see, that afford particular points of view, and that foreground some aspects of the scene while obscuring others. This article examines a range of lenses, starting first with frameworks used by researchers working in the general field of educational computing, and then moving to work undertaken in mathematics education research on the conceptualisation of technology usage as *instrumental genesis* (Artigue, 2002). The discussion of these frameworks draws on Wagner's (1993) assertion that educational research ought to generate new knowledge. Wagner argued that "ignorance is a better criterion than truth for determining the usefulness of knowledge generated through different forms of educational research" (p. 15). In his analysis of ignorance, he distinguishes between what he calls *blank spots* and *blind spots*. Such metaphors have been used by others: Arnold (2004) uses "blindspots" to refer to areas of the school mathematics curriculum which have not received their due attention in terms of the nature and effects of handheld technology usage. Arnold's *blindspots* can be seen as a subset of those discussed by Wagner. Wagner's use of this term is quite specific and potentially more powerful than everyday understandings in that he challenges researchers to question their most basic assumptions, not only about the object of study, but those assumptions which underpin the research questions that seem most obvious and urgent to us. He wrote:

> Materials relevant to questions already posed can be seen as filling in *blank spots* in emergent social theories and conceptions of knowledge. Materials that

> provoke scientists to ask new questions illuminate *blind spots*, areas in which existing theories, methods, and perceptions actually keep us from seeing phenomena as clearly as we might. (Wagner, 1993, p. 16)

A focus on the effects of educational practice can perpetuate popular misunderstandings of what technology is and what it means to use technology. Often, the forms of educational research that are most visible and most persuasive to lay audiences and policy-makers are those that provide simplistic, sometimes misleading, treatments of technology usage. When discussing the ways in which particular theoretical constructs *frame* or allow us to see classroom technology use, this article interrogates these constructs in terms of their potential to reduce ignorance. Work in mathematics education research is identified as providing a view of educational technology usage that illuminates a blind spot in more popular understandings of what it means to use technology to learn. The conclusions made pose serious challenges for educational research in terms of its capacity both to provide analyses of the complexity of practice and to communicate findings to the public and to policy makers.

Qualification of Focus

This article focuses on classroom usage of technology and, in particular, on new electronic computing media. In the case of mathematics education, this category includes handheld graphing calculators, computer algebra systems, standalone computers running both generic and mathematical software, and (though still in the margins) networked and web-based learning environments. However, by focusing on classroom usage, other equally important questions or foci fade into the background. Questions about classroom usage assume that electronic computation media and requisite infrastructure are available for use in classrooms and that they are readily accessible to those teachers and students who need or wish to use them. Access to, and the distribution of, material resources is a critical issue in education, and access to electronic technologies is increasingly a central concern in terms of equity and human rights. Basic indicators of access to, and the adoption of, electronic technologies in developed countries present a picture of schools that are increasingly technology-rich. For example, the students-to-computer ratio in government schools in Australia ranges from 7:1 in Western Australia to 4:1 in the State of Victoria (Victorian Department of Education & Training, 2002). These figures are comparable to those for USA, the UK and Canada (OECD, 2002). Figures for developing countries are not as readily available as those cited above, but it is reasonable to assume that, in countries that experience problems such as poor communication infrastructure, unstable electricity supply and lack of hard currency (Hawkridge, Jaworski, & McMahon, 1990), mathematics classrooms are unlikely to be rich in electronic computation media. Though estimates vary markedly, some put the number of computers in Africa per head of population as low as 1:500 (African Internet Status, 2002). Questions about assessing the use of electronic computation media are meaningless in a context where the technologies are not available. Thus it is critical to be mindful of the assumptions behind the questions addressed in this article and of the issues neglected through the selection of a focus which takes the presence of new electronic technologies in schools as its starting point.

Popular Lenses: Technology *into* Mathematics Education

The influx of computing technology into schools reflects policies that position such technologies as powerful tools for learning and for life, and to which all students should have access. In Australia, as in the UK and the USA, governments have promoted the integration of computer use across the school curriculum since the 1980s. In Europe, all countries now have official policy documents aimed at promoting the use of computer-based technologies for school learning. Since the late 1990s in Australia, computer integration has been formally mandated in government curriculum frameworks, and, using terminology such as *information and communication technology* and *e-learning*, state curriculum frameworks continue to promote the integration of new digital technologies. For example, in Western Australia, the integration of digital information and communication technologies into the curriculum is a significant aspect of the "Plan for Government Schools 2004-2007" (Western Australian Department of Education & Training, 2003). In Victoria, further to that state's curriculum framework, government schools are required to formulate policy documents that position computer technology as an integral part of school learning (Victorian Curriculum & Assessment Authority, 2002, 2005).

In mathematics education, the policy message is that electronic technologies can and ought to be used to enhance student mathematics learning. In Australia, the "Standards for Excellence in Teaching Mathematics in Australian Schools" (Australian Association of Mathematics Teachers, 2002) assume that excellent teachers of mathematics are purposeful and responsive in their use of technologies and are aware of a range of strategies and techniques for using information and communication technologies in mathematics teaching. In the USA, the "Principles and Standards for School Mathematics" explicitly state that "technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (National Council for the Teaching of Mathematics (NCTM), 2000).

However, progress in the use and understanding of electronic technologies for school learning has been long thwarted by technocentric assumptions (Papert, 1987). Popular discourses tend to ascribe more agency to the technological artefact than is warranted, and government policies tend to focus on the 'kitting out' of schools and classrooms as sufficient action for effecting improved learning outcomes. The expectation that the provision alone of new technologies will result in improved outcomes for learners can be seen in government spending patterns in Australia. For example, a national sample study of information technology resources in Australia found that schools spend more money on software, hardware and connectivity than on the professional development of teachers, within a context in which only a third of school principals surveyed agreed that professional development in their schools is adequate (Meredyth, Russell, Blackwood, Thomas, & Wise, 1999).

Popular lenses for understanding the role of new electronic technologies in school learning are often deterministic, based on an assumption that new technologies will have a unidirectional impact on what we do, how we do it and what the outcomes will be. This determinism is used to mount both utopian and dystopian prognoses of the effects of technology on school learning. Popular representations often position new technologies as agents that will either provide solutions to all the problems of modern schooling or lead to the downfall of all that is valuable and all that 'works' in schools (though in a context of increasing digital hegemony the latter position has become less tolerable). Deterministic assumptions centred on the view that educational outputs are a simple product of educational inputs also underlie government research funding policies that promote "scientific" research designs, and emphasise the value of large-scale, randomised control trials and "evidence based" research (Blackmore, 2002; Furlong, 2004; Lather, 2004).

In terms of the positive effects of new technologies on learning, commentators generally agree there is more rhetoric about the evidence than there is evidence to support the rhetoric. Much of the rhetoric that surrounds new technologies and schooling overestimates the degree of agency that a technological artefact may have and fails to account for the agency of human actors, the effects of existing systems and institutions, and the complexity of interactions that influence how new technologies are used. At the root of this failure is a fundamental misunderstanding or failure to comprehend the nature of technology and its role in learning. Technology is seen as a finished product that can be inserted into an educational setting to create a particular effect. In this article, this misconception is labelled an *input→output* approach, where the technology is injected into schools and classrooms and the learning effects result from this simple addition (Lynch, 2003).

An input→output approach to technology and schooling leads to very crude provision for, and assessment of, the status of computers in schools. In Australia and elsewhere, government targets in terms of the implementation of computers are usually expressed and assessed in terms of computer-to-student ratio. They focus on quantifying the material artefacts that will be injected into the system. In doing so, they construct teachers as recipients of technology and fail to acknowledge or respond to the complexity of technology usage. How technologies are used is usually the neglected part of the input→output equation and, as illustrated below, this neglect often extends beyond popular discourses to the frameworks developed by educational researchers. The focus on usage in this article responds to this neglect.

Research Lenses: Looking for Learning Effects

Amidst popular speculation about the impact of technologies on school learning, a vast body of literature has developed that reports on research seeking to assess the impact of the different electronic technologies found in schools. Such research is referred to here as the *learning effects* literature. In order to raise critical questions about the quality of educational research and the way educational practice is framed, first, two large scale quantitative studies, taken from the broad field of educational computing, are contrasted. These studies differ significantly in what they allow us to see and what they offer in terms of reducing ignorance and informing educational practice. The first of these studies is described in detail. It has been selected for discussion for a number of reasons: first, it illustrates an input→output approach to assessing learning effects, being an extreme manifestation of the application of the input→output lens. Second, it has attracted the attention of popular media and is representative of the type of study that is likely to influence popular understandings of technology and learning. Finally, it fits into a sub-category of the learning effects literature, referred to here as the *no effect* studies, the implications of which are discussed later in the article.

Study One: Input → Output = No Effect

In 1994, the Israeli State Lottery sponsored a program that provided computers to many primary and middle schools in Israel, aiming to reduce the student-computer ratio in these schools to 10:1 by 1998. Angrist and Lavy (2002) compared the test scores of students in schools that received the new computers with those of students in schools that did not, focusing on the fourth and eight grades and concluding that the provision of computers did not appear to have any educational benefits.

The study used a quantitative survey to establish the frequency of computer use, asking teachers to rate their usage on a four-point scale from 'Not at all' to 'Almost always'. Teachers also rated their frequency of use of Xeroxed worksheets, Instructional booklets, Games, TV programs and 'Other audio-visual materials'. No data were reported on how students and teachers used these resources. And, importantly, no data were reported on how students and teachers used the new computers. When discussing types of educational use of computers, Angrist and Lavy use two crude categories to make a distinction between Computer Skills Training and Computer-Aided Instruction. These categories are presented as unproblematic and no discussion is provided as to what else computer use might look like.

Three main findings were reported. First, teachers in schools in receipt of the new computers reported an increase in frequency of classroom use of computers, particularly in elementary schools. A substantial increase was reported by fourth grade teachers; a smaller effect was reported by eighth grade teachers. Second, this increased use of computers did not appear to translate into higher test scores. Tests in mathematics and Hebrew were designed and administered by the national testing body that runs college admissions testing in Israel. Finally, fourth graders in schools in receipt of the new computers performed less well on their mathematics tests (this difference was reported as marginally significant) than fourth graders in schools not involved in the program.

Angrist and Lavy's study is a good example of what Wagner (1993) described as research that produces truth rather than reducing ignorance. Wagner argued that "some research projects are of little use to researchers or practitioners even though they reflect our highest ideals of truthfulness in data collection and analysis. When we judge a research project solely on the apparent truthfulness of its parts, we neglect its larger purpose: generating new knowledge about education" (Wagner, 1993, p. 15). The Israeli study is exacting in its methodological design and reporting of results; in terms of methodological rigour it rates very highly. Yet it fails to answer questions that are crucial if we are to improve educational practice. Had the study identified a significantly positive learning effect, we could not replicate this outcome in practice because we do not know how the computers were used. Nor can we predict the effect of input of computers into a particular educational context.

Study Two: Qualitatively Different Effects of Qualitatively Different Usages

A second study is now described. It is similar to the first in that it applies quantitative survey methods to determine the effects of classroom computer usage on (among other things) mathematics learning. However, the second study provides a more sophisticated analysis, identifying the different effects of different types of computer usage. The New Jersey-based Educational Testing Service, after conducting a large scale quantitative study, reported that eighth grade mathematics students who used computers for more time, but used them mainly for drill and practice, scored below average on a standardised mathematics test. While students who used computers for less time but used the time for specific applications and computer simulations of real world problems scored above average on the test[1] (Wenglinsky, 1998). Wenglinsky concluded that the greatest inequities in computer use are not in the frequency of their use, but in the ways in which they are used. The findings of this study provide us with a starting point for understanding and critiquing practice; they provide a challenge to popular positions of unqualified support for, and unqualified rejection of, computing technology in education, and they can be used to inform decisions about educational practice. The relative utility of Wenglinsky's findings is due to his sensitivity to the complexity of usage. His is not a simple input→output model, but accommodates the transformation that takes place when a technology is introduced to a teaching and learning context. Wenglinsky's study effectively compares the effects of two different learning technologies: computers used for drill and practice, and computers used to apply higher order skills. Although his categories of usage are still quite crude they allow us to see differential effects that are made invisible by Angrist and Lavy's subsumption of computer use for learning into a single category.

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1 Other key findings reported were: 1. Minority, poor and urban students were less likely to be exposed to computer use for higher order learning. 2. Poor and urban students were less likely to have teachers who have received professional development on technology use. 3. While significant effects were noted in the eighth grade; much smaller effects were noted in the fourth grade.

It is not uncommon to speak of technologies in terms of their affordances and constraints (e.g., Kerr, 1996). The same analysis can be made of the tools we use to view or assess classroom practice. In terms of allowing us to assess practice, the view afforded by Agrist and Lavy's lens offers very little. It tells us that the mere provision of computers is not enough to realise improved learning outcomes. In contrast, the Wenglinsky lens affords a more telling view and provides us with more generative insights.

Affordances and Constraints of Frameworks for asking 'How?'

There is a general consensus among mathematics education researchers that effects on learning depend on a whole range of variables that define how the technology is being used (e.g., Doerr & Zangor, 2000). In particular, most recognise that the role of the teacher is vital, and that different students will experience different outcomes (Tall, 2000). The *how* question is critical to understanding classroom use of computing technology, both in terms of learning effects and in terms of assessing the quality of teacher and student practice. We need to ask: "What types of usage enhance students' learning?" and "What types of usage inhibit learning?" Angrist and Lavy's (2002) reporting of the effects of the provision of computers made a basic distinction between usage that is focused on skills training and usage that is focused on technology as a learning tool. Many have gone further in the conceptualising of *computer as learning tool* by distinguishing between different types of usage. Wenglinsky (1998) distinguished between using computers to facilitate drill and practice and using them to apply higher order skills. This is consistent with earlier conceptualisations. For example, Olson and Eaton (1986) referred to *routine* usages that did not "appear to strain existing routines too far" (e.g., drill and practice), contrasting this with other "novel" usages.

A framework that has been developed explicitly for describing how computers are used in classrooms, and which can equally be applied to other computational devices, is the Computer Practice Framework (Twining, 2002). This conceptual framework responds to the technocentric, input→output focus that predominates in "big science" research (Furlong, 2004), such as the Isreali study. The framework distinguishes between three modes of using computers as a learning tool. It is useful to examine this framework because it accommodates the use of the same technology in qualitatively different ways, thus shifting the focus, so often on quantifying equipment or frequency of use, to how the technology is used. The Computer Practice Framework is intended as a conceptual tool for looking at and for planning classroom computer use. The framework distinguishes, first, between three objectives of computer use:

- using computers in ways that help students develop their computer skills (referred to as an IT focus, and similar to Angrist and Lavy's Computer Skills Training),
- using computers in ways that support aspects of students' learning other than developing their computer skills (referred to as a Learning Tool focus), and

- using computers in ways that are not covered by the IT or the Learning Tool foci (referred to as Other focus).

Twining (2002) then differentiates between three categories within the learning tool focus. Computers can be used to *support, extend* or *transform* learning:

- Computers *support* learning when the content to be learnt and the process of learning remain the same, but some processes are made more efficient or more effective through the use of computers. For example, using a calculator or spread sheeting program to perform multiplication as part of solving a problem makes the lower order processes that support problem solving more efficient.
- Computers *extend* learning when the content and/or the process of learning is changed and this change could have been made without the use of computers. The National Council for the Teaching of Mathematics (2000) gives an example of what Twining's framework would see as *extending learning*: using a graphing facility "students can examine more examples or representational forms than are feasible by hand, so they can make and explore conjectures easily" (NCTM, 2000, np). This example of computer use extends learning by more immediately facilitating a conceptual (as opposed to procedural/technical) approach to teaching and learning, than traditional pen and paper methods. This computer use changes the focus of the content, but a similar focus could be achieved without the use of a graphing program.
- Computers *transform* learning when the content and/or the process of learning is changed, and these changes could not have been made without the use of computers. For example, a multimedia authoring program can be used to create, and to explore, dynamic systems graphically in ways that would be very difficult to achieve without the use of computers.

This framework advances how we *view* computer use by providing a position from which to challenge simplistic, input→output beliefs about the impact of new technologies. It also provides a language for talking about studies that report different outcomes for different types of computer use (e.g., Wenglinsky, 1998). However, frameworks that classify practices in this way do perpetuate other ignorances. At this point, Wagner's (1993) distinction between blank spots and blind spots is useful. The Computer Practice Framework allows us to see different types of usage, but the categories that afford this view simultaneously obscure other views. For example, the IT Focus is given very little attention in Twining's framework, which privileges the Learning Tool Focus. This privileging is fundamental to Twining's framework; it is an advance on work that neglects the how question, and it can be seen as a step in the direction of redressing earlier fixations on the technology at the expense of attention to learning. However, a study using this framework to assess classroom practice might easily overlook the complexities of computer skills development and interactions of skills development with conceptual development in substantive content areas. The crudeness of a category of learning activity that focuses on developing students' computer skills, constructed in opposition to activities that support learning in the substantive content area, points to a blind spot that is discussed in more detail below.

Critiquing the Technical-Conceptual Binary

Furlong, Furlong, Facer and Sutherland (2000) point out that "the way in which technologies are accommodated into every day living has been far more complex than initially predicted" (p. 93). Studies in mathematics education that have looked closely at what happens when electronic technologies are used to support learning report unexpected complexities and emergent properties (Goos, Galbraith, Renshaw, & Geiger, 2000). Goos et al. (2000), after conducting a longitudinal study of technology-rich mathematics classrooms, concluded that the interaction between human and technological agencies often results in properties that cannot be predicted in advance, and that the relationship between technology usage and learning is not one of simple cause and effect. In mathematics education in particular, the explicit interweaving of technical and conceptual work has led to the development of sophisticated understandings of the role of technology in the mediation of learning.

To critique the technical-conceptual binary evident in the frameworks discussed thus far, and to illuminate this blind spot, I draw on a concept that has been developed within mathematics education research, specifically in the study of learning with computer algebra systems. The importance of technical and psychological tools to mathematics learning is widely accepted (Goos, et al., 2000; Meira, 1995). In fact, lay understandings of mathematics education usually conjure memories of symbolic representation, procedural techniques and technological objects as a primary element of mathematics learning. Artigue (2002) has argued that mathematical objects themselves are non-ostensive; it is only through the domain of technical skills and objects that we can work with mathematical ideas:

> Mathematical objects are not directly accessible to our senses: they are 'non-ostensive' objects; we worked with these through ostensive representations which can be [very diverse in] nature: discourse, schemas, drawings, symbolic representations, gestures, manipulatives... (Artigue, p. 270)

In discussing the relationship between technical and conceptual learning in mathematics, Artigue seeks to challenge the privileging of the conceptual domain over the technical domain in mathematics education research. Citing Lagrange, Artigue provides a critique of what she terms the *technical-conceptual cut*, drawing on studies of students' use of computer algebra systems and a process she terms *instrumental genesis*. She explains that "an instrument is a mixed entity, part artefact, part cognitive schemes which make it an instrument" (2002, p. 250). The process through which an artefact becomes an instrument involves a two-way shaping of both the artefact and the conceptual object.

The perceived divide between conceptual and technical domains (often implicit in research into educational technology) fails to account for the intimate relationship between these two domains. Twining's (2002) framework (along with those used by Wenglinsky and by Angrist and Lavy) is an example of a theoretical framework that fails to account for the nexus of technical work with conceptual work in school learning. His categories for understanding the focus of learning obscure the dialectic between computer usage as a learning tool and computer usage to develop computing skills. Whilst his attention to the ways in which computers can be used to learn substantive content provides a relatively useful tool for looking broadly at classroom practice, it is not sufficiently sensitive to detect the complex transformations that take place with all retooling of learning. Returning to the mathematics education examples given above to illustrate Twining's categories, and applying Artigue's conceptualisation of instrumental genesis, both the use of computational facilities to perform multiplication (supporting), and the use of graphing facilities to examine representations of functions or data sets (extending), would transform learning in very complex ways. Introducing a new technology necessarily transforms the task.

Assessing Practice: What Question Should we ask when Technology Usage means Transforming the Task?

A common blind spot central to the argument presented here is the assumption that a technological artefact can be used in a teaching and learning context without affecting what is learnt and how it is learnt. If we take as our starting point the assumption that introducing a new technology necessarily transforms learning, this affects the type of questions that it is sensible to ask. No longer does it make sense to ask whether a technology will have an effect, and no longer is it sensible to come to a "no effect" conclusion. The proposition that learning, both in terms of what is learnt and how it is learnt, is changed when the tools are changed, poses serious challenges to the pursuit of quasi-experimental, "big science" research. The authors of the Isreali State Lottery study clearly position their research within a quantitative empirical tradition and a scientific paradigm, noting that, "there are few empirical studies [of the effectiveness of computer-assisted instruction] that meet a rigorous methodological standard" (Angrist & Lavy, 2002, p. 736). This concern is echoed in reports that covered this study in the popular magazine, *The Economist*, in which educational researchers are asked to conduct 'proper' studies with randomised samples and control groups. The complaint is that "hardly any studies compare classes of children taught with and without the help of computers - and none randomly allocates children into differently taught groups, as a medical trial would do" (*Screen it out - No real help and sometimes harmful*, 2002, p. 13). The Israeli study meets the standards of the "big science" model of research increasingly encouraged and rewarded by governments (Blackmore, 2002; Furlong, 2004; Lather, 2004). However, as discussed earlier, the study can be criticised for its failure to inform educational practice or improve our understanding of the role and effects of technology on learning (Wagner's criteria). This type of study may also be criticised for its presuppositions: if you take two classrooms and equip one with computing technology and the other with more conventional technologies (e.g., pens and pencils, protractors, log tables), then you are not comparing two similar pedagogical environments with the same types of activities making use of different tools. Rather, you are comparing the use of two different types of technology and you are comparing two teaching and learning environments that may well (and likely do) have very different foci in terms of what is learnt and how.

The dominant approach to researching technology use in mathematics learning has been to treat technology as a variable, comparing sites that do and that do not use a particular technology, an approach that seems to be ignorant of the presence of technologies in "traditional" classrooms. Penglase and Arnold (1996), in their review of research on graphics calculators, noted a predominance of the use of performance on traditional, skills-based assessment tasks as a measure of learning effects. They recommend caution when interpreting such studies because the use of the technology is often noted as being associated with changed pedagogical approaches that do not focus on skills development. They suggest that instead of comparing classrooms that use the technology with classrooms that do not, quasi-experimental research would do better to compare instances of tool use where pedagogical or other contextual factors differ. Goos et al. (2000) implied a critique of quasi-scientific approaches, advocating that study designs be sensitive to "the diversity of teacher and student interactions in the technology-rich [classroom]". Similarly, Tall (2000) argued that we need to be open enough in our investigations to observe what students actually learn when technology is used to teach mathematics. In a review of research into technology in mathematics education, Kaput and Thompson (1994) explain that studies that "did their post-tests independently of the technology that was used in the intervention" (p. 667) tend to report weak impacts of the technology. This trend is contrasted with studies where "the educational activity was more deeply affected by the technology, the researchers were more oriented toward students' mathematical conceptualisations, and they placed less emphasis on controlled comparisons" (p. 667). Of the two types of study, Kaput and Thompson conclude that the latter are both more generative and more feasible. Studies that provided close analyses of performance tended to lead to new questions and new perspectives; that is, they illuminated blind spots.

Input→output models fail to account for the complex of transformations that occurs when technology is used and the unpredictable properties that emerge, so the comparisons that are made (classrooms with and classrooms without the technology) are misleading in that such study designs cannot really see what is being compared. If retooling necessarily affects what is learnt and how it is learnt, rather than asking *whether* electronic computing technologies affect learning, we should ask: *How* do they affect learning, what is learned when they are used, and under what conditions is learning enhanced?

More Radical Questions: *Not*, How Does Technology Effect Learning? *But*, How Does Learning Effect Technology?

The simplistic, input→output approaches seen to predominate in popular understandings of, and in government policies on, new technologies and schooling, and the analysis of instrumentation offered by Artigue, seem worlds apart in terms of their levels of sophistication and the projects of which they are a part. In many ways a comparison of the two seems unnecessary, but it is illustrative to attempt to crystallise the key difference between the two extremes of understanding the same field of practice. The two point to fundamental differences in the conceptualisation of technology and the nature of technology use.

Prior to the 1970s, definitions of technology arising from fields such as engineering focused on the material elements of a machine or a technique (Mitcham, 1978). The technology was seen to be complete when it arrived at the site where it was to be consumed; it had been produced elsewhere. It was defined by its material components (e.g., hardward and software) and intentionality that is built into these through the design process. Usage was seen as the implementation of someone else's idea. Assessments of use (implementation) were made by designers with reference to intentions that are hardwired into the product. Usage that did not comply with the intentions of the designer or initiator was seen as misuse. Within this framework, the technological artefact, together with the intentions of the design, is seen as a product, and the user of the artefact is constructed as a receiver or consumer of this product.

Critiques of this notion of technology (as an already-completed product) have come from many directions. Sociological (Bereano, 1976; Pacey, 1983) and feminist (Berg, 1994; Hacker, 1989; Wajcman, 1991) accounts of interactions between technology and users, suggest that the notion of technology-as-product provides an inadequate explanation of what happens when a technological artefact is introduced into a field of practice. Socio-cultural perspectives, on the other hand, of which Artigue's work is an example, draw on Vygotskian principles to see the technological artefact as a tool that is appropriated within a socio-cultural context and whose meaning is co-constructed within that context. Doerr and Zangor (2000), in a study of the use of graphing calculators, drew on Lave and Wenger's work in their conceptualisation of the calculator as a tool: "the features of a tool are not something in and of themselves, but rather are constituted by the actions and activities of people" (p. 146). They describe how the meaning of the graphing calculator as a tool was constructed through the interactions of students and teachers, suggesting a critique of previous research that positions the graphing calculator as an already finished product, in their words, "[research] which often appears to take the features and nature of the tool to be given or self-evident, as the details of how and why the tool was used are often not reported" (Doerr & Zangor, 2000, p. 146). In contrast to the notion of technology as an already finished product, from these perspectives, the technological artefact is viewed as an object that is inscribed with meaning in use. In this way, the artefact does not become a technology until it is put to use, at which point it becomes subject to ongoing negotiations of meaning.

This conceptualisation is fundamentally different to the notion of technology-as-product, and it leads us to construct users and usage in very different ways. If we see technology as a product, then users are constructed as receivers of technology and usage is seen as a very straightforward enterprise. Within this framework, usage is either correct usage (that ideal usage desired by designers) or it is misuse, and correct usage will produce the desired effects. In contrast, if we see technology as a process, as continually being produced, then users are positioned as producers who have qualitative effects on the nature of the technology. Within this framework, usage is a very complex phenomenon that requires study via very subtle tools. Within this framework, the mere provision of technology would not be expected to produce a particular (good or bad) effect.

Conclusion

This article has discussed several conceptual frameworks through which classroom technology usage and its effects on learning might be viewed, starting with the most simplistic and finishing with the most sophisticated in terms of what each allows us to see. Input→output approaches to understanding and assessing technology use have been criticised for their neglect of the context of usage and questions about how technology is used. The Angrist and Lavy study distinguishes only between what is termed Computer Skills Training and Computer-Aided Learning, where the latter is focused on what is assumed to be the substantive content area of a discipline (e.g., Hebrew or Mathematics). Both the Wenglinksy and the Twining frameworks attend more closely to how technology is used for learning: Wenglinsky distinguishes between computer use for drill and practice and computer use to apply higher order skills: Twining distinguishes between computer use to develop computer skills and computer use for other learning outcomes, where the focus on non-computer skills learning can manifest in three qualitatively different ways. However, the analysis offered by Artigue offers something quite different, challenging the skills-concepts binary that is evident in the other studies cited and in popular understandings of classroom technology use.

Work carried out in mathematics education suggests that technology use necessarily transforms learning, both in terms of what is learnt and how. This supports sociological and feminist theories that assert that the meaning of a technological artefact is indeterminate until it is appropriated to a particular purpose within a social context. Such findings raise questions about the usefulness of large-scale quasi-scientific studies that purport to determine generalisable differences between learning outcomes attained in traditional classrooms, and those where electronic computing technologies are used, by administering the same test in different settings. Such studies assume that technology either will, or will not, affect learning. However, the qualitative work discussed here suggests that, not only does technology usage necessarily have qualitative effects on learning, but that learning affects technology such that inputting the same *artefact* at different sites or at different times does not necessarily result in the implementation of the same *technology*. These findings pose serious challenges to researchers at a time when governments are calling for an increase in large-scale quasi-experimental research to inform educational policy.

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