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Educational Technology and Practice: Types and Timescales of Change

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ABSTRACT

This article identifies three uses of educational technology and evaluates their potential to change curricula and pedagogic strategies. The article is in four parts, with the first outlining a temporal model of change and discussing educators' expectations of continuities and discontinuities in practice. In order to distinguish minor modifications from culturally significant changes in practice, the second part recaps a variant of Merlin Donald's cognitive-cultural theory of human evolution. The third part adopts this theoretical perspective and classifies uses of multimedia-hypertext systems, generic software, and computer modelling software, as instances of functional substitution, delegation and innovation. The fourth and final part of the article evaluates the change potential of these types of use, with substitution sustaining existing teaching strategies and curricula, with delegation modifying practice, and with innovation prompting culturally significant change. The article concludes by suggesting that functional substitution and delegation dominate present-day uses of technology and that functional innovation will continue to present both challenges and opportunities to future generations of educators.

Keywords

Curriculum change, Evolution of learning, History of education, Pedagogic innovation

Technology and Change in Practice

Will the introduction of educational technologies significantly change curricula and pedagogic practice? According to Oliver and Price, the answer to this question depends on the level of analysis (Oliver, 2006). At the micro-level, their study of teachers starting to use a virtual learning environment (VLE) found that everything changed as keyboards and screens mediated interaction with students. Meanwhile, at the mid-level of pedagogic tactics, these remained familiar even though the teachers had to change, for instance, their methods of gauging student attention. Finally, at the macro-level, strategic matters such as curriculum planning, the monitoring of student progress and the provision of feedback were sustained rather than changed by technical innovations.

A model of change through time

This article expands on the three-level analysis of Oliver and Price, and sketches a temporal model of technology-related change in practice, as shown in Figure 1. The levels of analysis are translated into three sets of nested and linked practices, where the links can be indirect, subject to delays, or weak relative to other influences.

The indicative timescales, shown in italics in Figure 1, draw on experience and the following comments on educational change at the intersections of mathematics, computing and modelling. The first comment is from Judah Schwartz who cautions against expecting teachers to make simultaneous changes in practice. At the CAL89 conference, he suggested it was unrealistic to expect staff to adopt new technologies, to change curricula, and to change their teaching strategies in a single leap. Instead, he argued for a phased approach to change, as reiterated in his chapter on 'the right size byte' (Schwartz, 1995). The second comment laments resistance to fundamental change in education (Noss & Hoyles, 1996). Here, the authors close by analysing the waxing and waning of Logo 'as a fashionable means of learning mathematics' and, following Bernstein, implicate established systems of knowledge, position and power. The third commentary is from Hal Abelson who spoke at a research seminar (Riley, 1986), where he described MIT's educational computing projects and claimed the most important contemporary developments would be those seen 'two to three hundred years ahead, as significantly improving cultural consciousness'.

Together, these comments suggest that changes in curricula, teaching strategies and technology do not come easily or quickly, hence the timescales indicated in Figure 1.

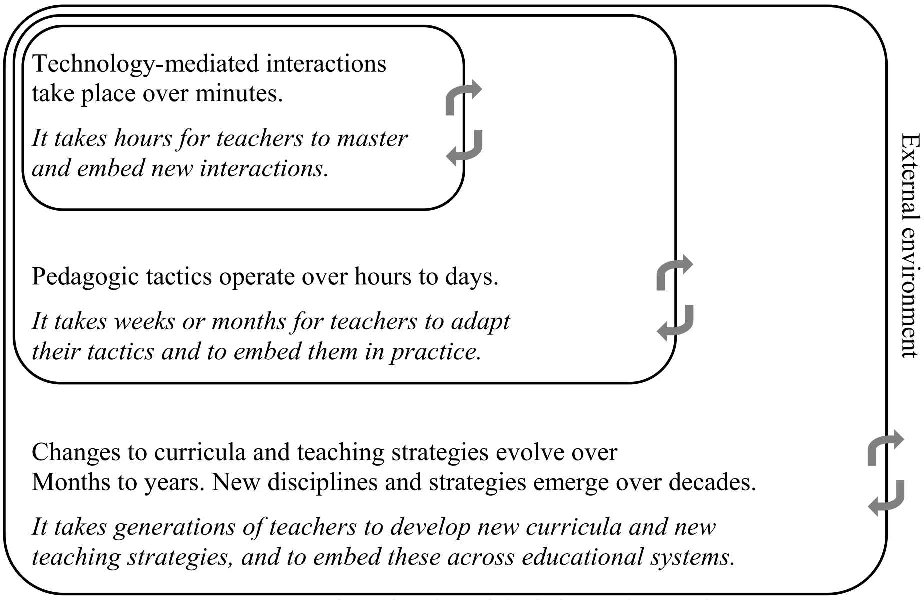

Figure 1. Three-level model of change in practice

Expectations of continuity and disruption

The model outlined above provides a basis for analysing expectations of continuity and change in practice. For example, those who expect new technologies to lead to new curricula and teaching strategies are likely to believe the three sets of practices are, or should be, closely-coupled (e.g. Papert and Strohecker, 2005). Whilst those more sceptical about change (e.g. Oliver, op. cit.), may believe the compartments operate more or less independently, and that continuity rather than change may predominate at the strategic level. A further factor to consider when comparing expectations is the timeframe, thus, a slow but prolonged change may pass unnoticed over the short-term and yet become prominent in the longer term.

Abelson's timescale of two or three hundred years reminds us that the field of educational computing, CAL or e-learning is still young; only some twenty years old when he spoke and some forty years old today (Smith, 2005). To better judge where educational technologies and practice may go in the future, we need to view our own times from a longer-term historical perspective. One such account of 'how education got here' was outlined previously (Riley, 2002a), and is recapped below before it is related to present day uses of technology, and to the prospects for long-term change in pedagogic practice.

An Evolutionary Account of Learning and Education

Several authors offer accounts of the co-evolution of human cognition and culture, including the familiar cultural forms of the performing arts, the humanities, religion, mathematics, science and technology (e.g. Mithen, 1996; Plotkin, 1997; Carruthers et al., 2002). Merlin Donald's account is adopted here as he discusses the origins of pedagogy, educational curricula and the impact of modern information technologies (Donald, 1991, 1997, 2002).

Three cognitive-cultural transitions

Merlin Donald's account of human evolution was prompted by his interest in the biological and cultural differences between our own species, present-day primates, and the inferred characteristics of ancestral apes some five million years ago. To account for the development of modern humans he proposed a theory of three major and accumulative transitions. He argues these were the minimum changes required to arrive at our present state, where we are able to act symbolically, and are able to express ourselves through body language, oral languages, and graphical or written languages.

Donald associates the invention of pedagogy with his first transition, the emergence of a 'mimetic culture' around a few million years ago (Donald, 1998). He claims the voluntary recall of memory, and the ability to control and share attention, enabled individuals to reflect on past events and to plan and rehearse for future ones.

The second and later transition is marked by changes to the brain, throat and hearing, enabling *Homo sapiens sapiens* to generate and comprehend complex speech. Donald argues that biological adaptations for spoken language took place during the last 500,000 years and led to changes in the subtlety, precision and abstraction of human thought, and to the chronological and narrative modes of reasoning characteristic of a 'mythic culture'.

Donald's third transition led to our present day 'theoretic culture', based on the manipulation of external symbols, and most clearly expressed in formal and logical reasoning. This cognitive and cultural transition was marked by the use of graphical images and written inscriptions over the last fifty to five thousand years. This period of evolutionary time has been too short for biological adaptation to occur and Donald proposes that the cognitive and cultural problems posed by inscriptions were solved by the development of lengthy educational curricula based on the '3 Rs': *r*eading, w*r*iting and a*r*ithmetic.

A fourth transition

Merlin Donald views modern information and communication technologies as important elements of theoretic culture, and believes they enhance collective memory and cognition. In contrast, two mathematics educators have argued for a fourth transition, on the grounds that computers externalise not only symbols but symbol processing (Shaffer & Kaput, 1999). Following Donald's schema of increases in cognitive capability triggering cultural change, they propose that autonomous symbol processing technologies are leading to a 'virtual culture' exemplified by computer modelling as a mode of thought and expression.

David Shaffer and the late James Kaput claimed this present-day transition generates novel educational opportunities and demands. For instance, they suggest that existing mathematics curricula aim to improve students' mental manipulation of passive images and written inscriptions, and were intended to meet the needs of theoretic culture. Curricula appropriate for a virtual culture should prepare students for a world where many computational tasks are off-loaded to machines and, where computer-based modelling is an increasingly widespread and important practice.

Technology, educational practice and the four transitions

Merlin Donald's theory, as elaborated by Shaffer and Kaput, proposes a succession of four hominid and human cultures, each of which appropriated, reinterpreted and built on its precursors. These cultures, along with the origins of pedagogy and of institutionalised education, are summarised in Table 1.

This perspective on educational technologies and practice is likely to be unfamiliar for several reasons. Firstly, the criterion of significant change in practice is cultural, in the sense of Shaffer and Kaput's transition to a 'virtual culture'. Secondly, the timescales are extremely long, compared with the life cycles of university curricula and the life cycles of educational technologies. Thirdly, computer modelling is given prominence, despite being relatively rare in practice (Laurillard, 2002; Riley, 2002b). Finally, the metaphor of orchestration is introduced, to stand for the mediated manipulation of symbols in computer models. Orchestration is used here, as an alternative to 'instruction', because of objections to this term in the earlier conference presentation (Riley, 2005). The first objection came from participants who viewed learning as a process of construction, and argued the didactic associations of 'instruction' were distracting. The second objection, from an empirical modelling perspective (Beynon, 2007), was that 'instruction' had particular connotations in conventional computer science and these were best avoided.

Three Idealised Uses of Educational Technologies

This part of the article adopts Shaffer and Kaput's cognitive-cultural perspective and identifies three idealised, or canonical, types of use of educational technologies. In the final part of the article, these three types will be related to current practice and the prospects for culturally significant change.

Table 1. An evolutionary perspective on learning and education

Type of culture	Cultural agents, and new forms of practice	Associated developments in learning and institutionalised, formal education
Episodic	Apes act skilfully within 'episodes': no conscious use of symbols or voluntary recall of acts outside of these episodes.	Individuals learn by instinct and some mimicry. Minimal group and inter-generational learning, and extremely slow rates of cultural change.
Mimetic	Hominids invent body language and act symbolically: dance, gesture and mime. Performing arts and pedagogy emerge.	Individuals learn to recall, reflect, rehearse, and coach. Two-way, 'tutor-tutee' interactions are invented and the beginnings of pedagogy facilitate social and cultural change.
Mythic	Early humans invent oral languages: sing, speak and narrate myths. A wide range of social-cultural practices emerges and is elaborated.	Our species adapts biologically and individuals learn to think chronologically and abstractly, to teach with and about language. Narrative invention, rhetoric, and abstraction drive learning and accelerate cultural change.
Theoretic	Humans invent written language: draw, inscribe, write, count and compute. Agriculture, art, commerce, defence, education, governance, industry, law, mathematics, medicine, philosophy, religion, science and technology develop as complex specialisms and culturally inter-related practices.	People adapt culturally (not biologically) and learn to use external symbol systems, to master specialist discourses and practices. The '3 Rs' entail lengthy tuition, and specialist fields require subsequent apprenticeships. Specialisation, made possible by long periods of 'cloistered' formal education, reinforces and accelerates cultural change.
Virtual	Humans invent computer modelling languages: construct and investigate models, treat them as expressive devices and sources of knowledge. Models act as mimetic agents: move or gesture, draw, compute, read, write… and respond to other agents. Computer science, informatics and new forms of mathematics emerge and, influence other disciplines and specialist practices.	People learn to 'orchestrate' external symbols using computer models, to enter discourses and practices of *indirect* symbol processing. O*r*chestration, the '4th R', is appended to existing curricula and new curricula emerge, e.g. in genetic and biological engineering. Three-way, 'tutor-tutee-computer' interactions are invented and extend existing pedagogies. The '4th R' and three-way pedagogy impact on human learning and cultural change.

Functional substitution

The first type of use of educational technologies, called 'functional substitution', is associated with typical uses of multimedia, intranets and Internet technologies. These technologies and their derivatives are widely used in higher education and, in part, substitute for previous media. One can imagine, for example, that a Palaeolithic cave-artist or ancient Egyptian stonemason would marvel at streamed video but, they would comprehend the intent. Similarly, a Sumerian cuneiform scribe would recognise the pedagogic purpose of an online written task in accountancy, commerce or law.

Functional substitution sustains the exchange of images and inscriptions between students and teachers, a practice inherited from theoretic culture and based on ancient pedagogic roles and rhythms. When students and teachers use online discussions, Weblogs, Wikis and multimedia depositories, the underlying computer technology is meant to remain invisible or 'transparent', and traditional two-way, tutor-tutee relations are maintained. Similarly, it is proposed that changes to curricula are more likely to be superficial than fundamental, when 'old wine is transferred to new bottles'.

Functional delegation

The second type of use of educational technologies, called 'functional delegation', is commonly associated with word processors, spreadsheets, databases and other generic software. These technologies are widely used in higher education and enable people or 'users' to delegate routine symbol processing tasks to computers acting as agents or clerks. For instance, teachers may use VLEs in this way to track low-level student 'attendance', to record performance on quizzes and to provide conditional feedback on their answers. The teaching of computer science and cognate fields is an exception here, as the technology is a sustained focus of attention for these students.

For most students and teachers, functional delegation involves the passing of symbol-processing tasks to computers. The computers are responsible for the execution of clearly defined tasks whilst students and teachers are responsible for selecting or specifying the appropriate algorithms. Thus, functional delegation introduces a triangular relationship between the teacher, student and computer although the latter is assigned a subsidiary role. Functional delegation leads to new 'skills' being added to curricula but, with the exception of computer science and closely related fields, curricula remain much the same as before.

Functional innovation

The third type of use of educational technologies, called 'functional innovation', is epitomised by computer modelling. A symbolic model can serve as a way of thinking, a means of expression, and a subject of investigations, although it differs in kind from the subject of a scientific experiment or a device in an engineering test rig. A model can play a key and sustained role in student learning with a three-way, if unequal, relationship between teacher, student and computer. Learning to model also may lead to a '4th R', as outlined in Table 1, and prompt significant changes across a wide range of disciplinary curricula as people put their 'heads and computers together'.

To understand what functional innovation may mean in education, take the parable of Daisyworld as an example (Watson & Lovelock, 1983; Lovelock, 1988). Lovelock's Daisyworld simulations demonstrate the reasoning and systems principles underpinning the Gaia Hypothesis and illustrate the expressive possibilities of computer modelling. Versions of these models have subsequently been reproduced in environmental science texts for students to investigate, elaborate and discuss for themselves (e.g. Ford, 1999; Hardisty, et al., 1993; Henderson-Sellers & McGuffie, 1987).

One reason why it is difficult to describe the character and scope of functional innovation is that it amounts to cultural work-in-progress. We are yet to develop adequate terms, discourses and shared understandings to explain its features and applications. For instance, commentaries on professional practice yield a range of views on what computer modelling is, and what modellers do (Dowling, 1999; Galison, 1996; Morgan & Morrison, 1999). Similarly, commentators on learning by modelling imbue their books and papers with a sense of unfinished business and of history in the making (DiSessa, 2000; Mellar et al., 1994; Noss & Hoyles, op. cit.), or of a present with roots in an ancient past (Roth, 2001).

Reflections on the three uses of technology

The three types of use of educational technologies are idealised and do not map onto particular tools or combinations of practices. For instance, a teacher using a VLE may engage in a series of written interactions with students (functional substitution), and set an online quiz with conditional feedback (functional delegation). Or, a student might use a spreadsheet to record and graph experimental data (functional delegation), and then extrapolate the results by creating a statistical or causal model (functional innovation).

The three types merely serve to discriminate between uses of technologies which align with the 3Rs and the two-way interactions of theoretic and earlier cultures, and uses which align with the 4th R and the three-way interactions characteristic of virtual culture.

The Prospects for Culturally Significant Change

This part of the article relates the three idealised uses of technology, and the earlier model of temporal change, to the prospects for significant change in educational practice.

Functional substitution is interpreted as being culturally conservative. There is continuity in the strategic mission of sharing learning between individuals, groups and generations. In accordance with Oliver's comments, these types of use of technology maintain and replicate familiar pedagogic strategies and curricula, even if the specific, technology-mediated acts are new. The roles of tutee and tutor remain much the same and their interactions follow ancient dual and dialogical beats.

Functional delegation for most students and teachers introduces changes or reforms in pedagogy at a tactical and curricular level, as illustrated by the introduction of courses in 'IT skills' over recent decades. Previous generations of students and teachers did not possess autonomous symbol processing agents or have to learn how to harness their capabilities. Thus, functional delegation introduces a three way pedagogic relationship but the computer plays a subsidiary role and does not fundamentally change disciplines or their core curricula.

Functional delegation has a more radical impact on teaching strategies and curricula in computer science and related fields, where new disciplines and curricula are being generated over timescales of decades. Beynon is better placed to comment on this (Beynon, op. cit.), although it is tempting to speculate that the instrumental use of computers to perform tasks characteristic of theoretic culture, may map onto his dominant conception of computation. Empirical modelling and an alternative conception of computation may better map onto the notion of functional innovation.

Functional innovation, typified by computer modelling, could lead to significant change both because of its three way pedagogic interactions and its cultural novelty, which may translate into a 'fourth R' in educational curricula. However, making sense of modelling remains a challenge to professionals and commentators (e.g. Keller, 2002; McCarty, 2005), and to teachers and students. For example, as O'Sullivan asks in relation to complexity:

> "How models may be used to learn about the world – if at all – is a critical epistemological question."
> (O'Sullivan, 2004).

Functional innovation, as envisaged here, encompasses the educational ambitions of previously cited educators such as Shaffer and Kaput, and Noss and Hoyles. Their comments on computer modelling could be interpreted as a call for a new form of mathematical literacy, a view that resonates with the ideas of DiSessa. However, these ideas and practices are emerging slowly, and the timescales of educational change may be measured in generations of educators rather than in decades.

Do the temporal model and functional types match recent history?

Abelson's proposed time span of two to three centuries would support a reasonable evaluation of the model of change and the three types of use. The best we can do now, however, is to compare the model against the available forty-year history. So, one might argue that if the model is sound, then functional substitution should have dominated in the early years with functional delegation appearing next and functional innovation being the latest to emerge, if at all.

Paradoxically, personal experience suggests the reverse pattern. Computer simulations, games and modelling software were prominent amongst the supply-led developments of the 1970s and 1980s, well before the appearance of multimedia and the Internet. So is this judgement of the forty years flawed, or is the model of change faulty?

A sound historical judgement would require research beyond the scope of this article but the model of change can be defended on the grounds that the computers of the mid-1960s to 1980s lacked the memory, processing power, storage capacity, display and communication capabilities to support functional substitution. The technologies needed to become more versatile, cheap and pervasive before the use of multimedia systems and the Internet could flourish in education.

This reading of history suggests there were technical reasons, amongst others, for regarding the first twenty years as anomalous in the mix and balance of the functional uses of educational technologies. The take-up of educational technologies over the second twenty years may be a better indicator of institutional priorities and of practitioners' preferences and of demand-led developments in the coming decades. Viewed from this perspective, it appears that functional substitution, delegation and educational continuity will prevail for some time to come, whilst functional innovation takes a slow-burn revolution over much longer timescales.

Prospects

This article has adopted an evolutionary perspective and discussed a temporal and functional model of technology-related change in educational practice. It concludes by supporting Oliver's contention that much remains the same when educational technologies are introduced into higher education, thanks to historical or even pre-historical momentum. At the same time, the first inklings of significant change are emerging and offer opportunities for present and future generations of educators to make pedagogic history.

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