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Edges, exponentials & education: disenthralling the digital

Technology is a key term in this book. How the term is used and understood matters. Usually, technology is thought of as material stuff, the physical artefact that is a printer or a mobile phone or an automobile. While this usage is convenient as a shorthand for talking about things, it is only when technologies are used to do things that it becomes less clear just what is or is not technology, i.e. where does it start and end; what are its boundaries? There is a significant literature that talks about technology more holistically for instance as hybrids/cyborgs (Haraway 1990, 1991, 1997), or as intimates (Turkle 2011), or as a global whole (Kelly 2010). Whenever a technology is in use there are always many other things that are present if not always visible and which, particularly in education, we tend to ignore (Sørensen 2009). So I want to extend the notion of thinking about technology holistically that I gestured to in the previous chapter and draw on sensibilities from actor-network theory or ANT to further examine schools, computing technologies and the patterns which were mapped in an earlier chapter.

Much can be said about ANT and there are now a large set of resources and publications that illustrate the way these ideas have been deployed to explore and examine everything from scallop fishing (Callon 1986), electrical vehicles (Latour 1996), atherosclerosis (Mol 2001), financial markets (Knorr-Cetina and Preda 2005), the law (Jasanoff 2007) and studying organizations (Jensen 2001). There are also a number of ANT informed studies in education (for example, Gorur 2008; Fenwick and Edwards 2010; Sørensen 2009; Rowan and Bigum 2011; Bigum and Rowan 2009).

Briefly, ANT offers a relational approach to thinking about technologies and schooling, as John Law (2008, p. 141) explains:

> Actor-network theory is a disparate family of material-semiotic tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactment of those relations. Its studies explore and characterise the webs and the practices that carry them. Like other material-semiotic approaches, the actor-network approach thus describes the enactment of materially and discursively heterogeneous relations that produce and reshuffle all kinds of actors including objects, subjects, human beings, machines, animals, 'nature', ideas, organisations, inequalities, scale and sizes, and geographical arrangements.

Realities, like schooling then, are enacted into being. But they are not enacted from nothing. Schools and schooling have a long history and practices that persist over time even after the origins of the practice are long forgotten. What is of interest are the persistent patterns of relations that are performed in schooling, what John Law calls the hinterland. As he puts it (Law 2004 pp. 33-34):

> The hinterland produces specific and more or less routinised realities and statements about those realities… The hinterland also defines an overall geography—a topography of reality-possibilities. Some classes of possibilities are made thinkable and real. Some are made less thinkable and less real. And yet others are rendered completely unthinkable and completely unreal.

I have traced some of the patterns of thinkables and unthinkables vis-à-vis computing technologies in the previous chapter. For computers to be 'real' in schools, they need to "draw on—and perhaps contribute to—an appropriate hinterland" (Law 2004, p. 28, 34). This means fitting in with the quotidian practices of schooling: classrooms, timetables, curricula, assessment logics and so on. So, in this way, it is perfectly thinkable to use computers to analyse data in a science experiment in class but in assessment, particularly high stakes assessments, it is unthinkable to obtain help from a machine. The influence of decisions taken in the past to allow and disallow actions in the present is not often drawn upon when we think about computers and schooling, yet, the role past ways of doing things have on what is not only on what can be done but also on what can be imagined is significant.

An example away from schools illustrates well the longevity of choices and decisions made in the past. Kevin Kelly (2010, p.179-180) recounts the story of the influence of Roman carts on roads and rail through time. Since the carts followed in the ruts of the war chariots the carts were built to the same specifications. The chariots were built to allow two warhorses to pull them side-by-side. In time, as the English began to use carriages, they too were built to fit the existing ruts which had become roads of similar width. When railways were built, the horseless carriages were also built with the same width of almost 5 ft. Laborers from England built the first American railway tracks and with their tools designed to build British tracks it resulted in rail track size in the US being also a little under 5 ft. More recently, the rockets which launch the space shuttle were brought via rail to Florida. They had to pass through a tunnel not much wider than the 5 ft wide track so their diameter could not be much greater than that same measure. Kelly quotes the conclusion of one wag who commented that: "So, a major design feature of what is arguably the world's most advanced transportation system was determined over two thousand years ago by the width of two horses' arse."

So too with computers in schools, the 'tracks' that have been laid down a long time ago continue to frame and shape what can run on them. Computer use which fits these tracks or long standing patterns in the classroom will be relatively easy to keep in place[1]. Practices which don't will require constant effort, most often from enthusiastic teachers, to be kept in place. To extend the analogy, it virtually means having to build your own, different tracks. Importantly, the places and spaces in which practices which are less constrained by the disciplining effects of the 'tracks' or the hinterland of schooling are always found at the edges, those spaces and practices that are deemed to be not sufficiently important or a part of 'real' schooling. It also means that for main stream schooling achieving anything other than a series of domestications, one for each new technology as it comes onto the market, is highly unlikely.

Does it matter if schools keep on dealing with these technologies as they have done for the past thirty years? Clearly, under the current cycle of doing computer related things in schools most people are happy. The vendors are happy. Schools are no longer the market key they once were but, in aggregate, schools still spend a significant amount on these technologies and the educational aura of each shiny new piece of computer equipment is in tact. The romance continues. Teachers are more or less happy. The enthusiasts keep getting their hands on the latest products and doing things with them in their classrooms[2]. The less than enthusiastic can either avoid them or find odd things for them to do in their classes. They remain a good, if expensive, reward to send students to for finishing their work early. The students are happy. They have adapted well to having a schooled experience of ICTs that is bizarrely different to what they have outside. Principals are happy. They

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1 There is an interesting parallel here with what Christensen et al. (2011) term sustaining innovation.

2 The current enthusiasm in schools for tablet computers like the iPad is a good contemporary illustration.

have managed to find enough funds to keep up the symbolic work these technologies do for schools. Parents are happy. Their school has a lot of the latest what evers so they must be doing good things with them. Governments seem happy as they find funds to build elaborate, locked down intranets that make the experience of the Internet even less like the Internet outside schools. So even though, as some critics might argue, this is a costly state of affairs, changing things does not appear to be an important matter to most of those involved. I want to disagree however and argue that maintaining such a position is not just unprofessional and wasteful but, in the broad scheme of things, dangerous.

As the previous chapters have already illustrated schools now operate in a world that is much changed to that of a decade or two earlier. The nature and size of the shifts that have occurred as the read/write web has played out is only a *tiny* indication of what will flow from computing and related technologies in future. The significant interest in and debates around the notion of education for the 21st Century is a key focus for this book, i.e. how do you future proof diverse groups of kids for what is (possibly) to come? The challenges go far beyond how to deal with various computing technologies in the classroom, they go to the role and purpose of schooling particularly when we consider the failure of long standing educational traditions to offer quality education to such large numbers of the population. To me, education now needs to be thought about in terms of two other E's: exponentials and edges.

Exponentials

If the current and future challenges posed by ICTs is not enough of a challenge for schools, there are other clusters of technologies that will powerfully shape the world in which the young of today will live. In particular, current developments in what Kelly (2010, p.260) calls GRIN technologies, G for geno, R for robo, I for info and N for nano technologies[3] point to significant challenges for future generations that will be orders of magnitude more disruptive than developments in computing and related technologies have been to date. How schools engage with such developments will be crucial if they are to retain any credibility as an essential element in the preparation of the young for a challenging and complex future. What is worrying about schools and schools systems is that the domestication habits they have developed in relation to ICTs are not good habits to have in the face of what is to come.[4] Maintaining the digital romance, enacting domestication after domestication in an era of accelerating change becomes neither sustainable, sensible nor ethical.

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3 The least familiar of the quartet, nanotechnology is concerned with engineering things at the scale of the atom. The properties of materials so engineered are like nothing we have seen till now. As Stevenson (Stevenson 2011, p. 110) puts it, "Nanotechnology is to matter what a phone booth is to Superman".

4 Ray Kurzweil (2001) argues that we won't experience 100 years of progress in the 21st century -- it will be more like 20,000 years of progress (at today's rate).

To most, the notion of an exponential is something that belongs in a mathematics classroom or perhaps may somehow be related to home loan repayments[5]. Exponential change is not something with which we have had to become familiar, despite the fact of Moore's Law and other Laws that map the growth of various digital technologies and which tell us that the price of various digital technologies is halving roughly every 18 months to two years and that their performance is doubling on about the same time scale. For example, a measure of the computational power of the chips used in the manufacture of various computers is MIPS which is the acronym for millions of instructions per second. And while there are lots of qualifications of a measure like this, it is often used as a rough guide of computing power. This is doubling every 21 months (Kelly 2010, p.167). The chip in the laptop I am using to write this, an Intel Core 2 duo which was released in 2008, is rated at ~50,000 MIPS. In 2011, the most recent Intel chip is rated at 160,000 MIPS. These numbers are often difficult to relate to the experience of using a computer or related technology apart from a sense that newer computers seem to be faster. More controversially, but in my view, a useful measure that compares the rate of change of digital technologies in a less abstract manner, is to compare the calculations per second that the human brain carries out with that of computers now and into the future. Kurzweil (1999) argues that the human brain carries out about 20 million billion calculations per second. He estimates that around the year 2023 you will be able to purchase a $1000 computer with that computational power. By 2037, the same computer will cost about a cent. In 2049, he argues, that you will be able to buy a $1,000 computer that has the computational power (measured in instructions per second) of the entire human race. In 2059, he predicts that the price of this computer will be about one cent. These extrapolations may appear to be science fiction. If we had made similar projections at the time of the first moon landing they too would have seemed like fiction. It is a fiction I am using to write this book chapter. The fact is that the various digital technologies that end up in laptop computers, mobile phones, and an increasing number of things that we tend not to associate with computers, are still doubling their performance and halving their cost in fixed time periods, i.e. we are seeing exponential growth.

There is much controversy about what all of this might mean but for the purposes of this chapter I don't want to open the debates about Kurzweil's argument about the technological evolutionary point he calls the singularity (Kurzweil 1990), I simply point to a fast approaching world in which not just computing and related technologies are improving exponentially but a world in which the other three of

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5 To illustrate exponential growth let's imagine that we take a step and it is a metre of ground we cover. Then let's imagine that each step we take is double the last one. After nine steps we have covered a kilometre. In our 28th step we will have passed the moon. Step thirty four takes us past the sun.

the GRIN quartet[6] enjoy similar growth characteristics[7]. An important feature of this growth is that each technology draws on what has gone before. This is both limiting as I have just argued but it also means that you don't have to start from scratch to take the next step, i.e. in order to build a nuclear reactor you don't have to begin with a stone axe. Kurzweil's (2001) law of accelerating returns elaborates this point in some detail.

Another important property of all four groups or clusters of technologies is self-replication, that is the ability to make perfect copies of themselves or to improve subsequent versions. This is not a new idea. We have known about the replication of genes for a long time. What is new is the prospect of self-duplication in robotics and in nanotechnology: robots that build robots that build robots and which work to improve each successive generation; and nano factories, that build nano factories that build nano factories[8]. Taken together and without attempting to anticipate how any of these technologies will play out, it is nevertheless patently clear that doing school the way school has always been done or tweaking it around the edges will not prepare young people who will grow up in this world. And more importantly, school as school has always been, will continue to reproduce the patterns of disadvantage described in other chapters of this book.

This take on the challenges facing the young can easily lead to a kind of paralysis of the imagination and a loss of hope that things can be different. That is, we keep doing what we have always been doing because that is the only thing we have some control over, and, because the tracks are there it is easier to work within them than build new ones. Alternatively, we can work to explore or develop the mindsets that allow us to explore possibilities for schools and young people, some of which are mapped in this book. Experiments in doing school differently have become more common as the limitations of the mainstream system become more and more apparent. But even when we look to these sites and the inspiring folk who do this work, often against the odds, that there remain heavy traces of the ideas, assumptions, practices and beliefs to which those who work in education are in thrall, the stuff of the hinterland of education. Ken Robinson, speaking at the 2010 TED conference drew attention to a word that Abraham Lincoln used in an 1862 speech to Congress in which he (Lincoln 1953, p. 537) said:

> The dogmas of the quiet past, are inadequate to the stormy present. The occasion is piled high with difficulty, and we must rise—with the occasion. As our case is new, so we must think

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6 A readable account of the current state of these and other technologies is provided by Stevenson (2011).

7 George Church, a prominent molecular geneticist points out that the cost of DNA sequencing has been halving every four months over the past five years (Stevenson 2011, p. 51)

8 An early, large scale version of this kind of manufacturing is provided by the development of what is called 3D printing, or additive technology (http://en.wikipedia.org/wiki/3D_printing).

> anew, and act anew. We must disenthrall ourselves, and then we shall save our country.

Disenthralling ourselves is a lot easier said than done. Nevertheless, getting past the horseless carriage thinking that still characterises the way we think about computing technologies in education is an urgent first step. The term horseless carriage was used in the early days of the automobile to help smooth the transition from horse-based transport to one in which a horse was no longer required[9]. In education, thinking about computers as educational technologies, as tutors, as learning aids and so on is based upon a similar logic. Horseless carriage thinking is however a *kind* assessment. What has happened in schools more closely resembles horsey horseless carriage thinking. The horsey horseless carriage was a design in which at the front of the vehicle there was a carved wooden head and neck of a horse (Neil and Time 2007). It was argued that this vehicle would be less disruptive to horses with whom it shared the roads. So too in computing in schools, computers have to be domesticated so they don't disrupt the smooth running routines of the classroom and school. These are things to be preserved at all cost!

Disruption is never easy (a point made well by authors such as Gillespie, Walker, and Smith through this volume), particularly in the main stream of any set of practices and schooling is no exception. When we look for disruptions, because of the massively conservative nature of main stream schooling, we have to look to the edges, the fringes, the places and spaces that may not even be recognisable as school even though the educational outcomes from these sites are often more significant than that of a 'normal' school.

The disruptions I will briefly illustrate below (and others that are described in the next chapters of the book), are always accompanied by a disenthralling of some of the foundational ideas of schooling. Disenthralling ourselves of the ideas of formal schooling may seem like a return to the romantic days of deschooling (Illich 1973) in the 1960's and 70's. The challenge we face is neither romantic nor old. We have a very simple choice. We can either continue to prepare the young for a world that no longer exists or we can take seriously the huge challenges that will emerge as the GRIN technologies play into every aspect of human activity.

Edges

The edge is a way to talk about the places and spaces that are not mainstream. It is a label used to describe the boundary of things. In current debates about new economies, new ways of doing business and innovation generally, the edge is both a descriptor for and a symbol of things that are not mainstream. It is also a way to talk about the limits of what we know, what we can do and what we can think. It is

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[9] Carolyn Marvin (1988) makes a similar argument in her accounts of the introduction of technologies like the telephone and electricity in America.

a crude but useful distinction that, at the very least provides a marker for thinking differently about change in education.

To put it bluntly, edges are where novel stuff happens. The various systems that operate within the mainstream be they business models, governance structures, or accountability regimes, all serve to constrain what is possible. These things support what is more or less able to be anticipated and serves the interests of the organisation or business. This makes it nigh on impossible for innovations that could upset or disrupt the status quo to be allowed or even noticed. In actor-network terms, the hinterlands of well established organisations and businesses determine what can and cannot be thought, what can add to things and what can't.

To further develop this idea, I draw on what to some in education see as the 'dark side', that is the world of business. I take the view however, that with the changed and changing nature of the world that teaching and learning, in the broadest sense have become everyone's business, and particularly for those in business. If we use the notion of the emerging world characterised by exponential growth of the GRIN technologies as a kind of underground mine. It is dark. It is hard to tell what the next excavation will reveal and so on. Then business, because it has tougher metrics for success than do formal educational settings, can operate a bit like a canary[10] for education miners. That is, business will make mistakes faster and adapt quicker to the changed and changing circumstances they encounter. I am not advocating that education simply mimics the engagement business has with rapidly emerging technologies but that formal education needs to pay a lot more attention to what happens in this sphere. This, I need to add, is not a new idea. Doug Noble (1991) documented twenty years ago the influence of the US military in shaping most of the technologies dubbed educational in use in the average classroom.

Clayton Christensen has been interested in canaries also. He does not write in these terms but he was curious about why some businesses that were operating well and were thought to be in control of their markets, failed. His curiosity led him to develop, with others (Christensen 1997; Bower and Christensen 1995) a model of disruptive technologies, later to be renamed disruptive innovations. In this model he makes a distinction between sustaining and disruptive innovations. Sustaining innovations improve existing products and services, ways of doing things, disruptive innovations change the nature of the business. Computers in schools can then be seen as sustaining innovations, added to improve things. That this claim is still a matter of considerable dispute (see for example, Cuban 2001) has not altered the persistence of the idea of a computer as an improver of things in education.

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[10] In the early days of coal mining, miners would carry a canary in a cage with them to monitor the quality of the air. If the canary fell off its perch the miners were warned of the presence of poisonous gases.

Sustaining innovations are deployed to improve market share, for instance, the embellishments that are commonly associated with wealthy private schools like swimming pools, rifle ranges and expensive computer equipment fall into this category. They are all intended to improve the product and hence, market share. Disruptive innovations always come from the edge or fringe, from places and spaces which dominant or mainstream businesses don't look at or if they do, don't recognise the innovation as a threat. They are not seen as a threat because initially they are often a lower quality or crude product or service and are not attractive to the existing users of the product or service. Thus for example, as Christensen documents (2003), telephone companies did not see the mobile phone as a threat. It was outside of the way they saw the world. It was also the case for the manufacturers of minicomputers like DEC when the first microcomputers appeared[11].

Typically, a disruptive innovation is simpler to use, costs less and attracts non-users of the technologies it will eventually compete against. It is also initially not as good as the technologies it eventually will disrupt. Those who can recall the early mobile phones which were often referred to as bricks because of their large size, is a good illustration. If Christensen's model can be applied to schooling, and he, Michael Horne and Curtis Johnson believe it can (2011), the current patterns of computer use will never achieve the kinds of revolutionary changes that some advocates have suggested. Moreover, an examination of educational practices that might be deemed to be at the edges may offer insights into how better prepare the young.

Doing school differently, education at the edges, 21st C schooling

Peter Senge (2007) once asked the question would we know what 21st C schooling looks like. He argued that we wouldn't given that we have had such a long involvement with mainstream schooling. What follows here then are not just examples of doing school differently but they also offer opportunities to think differently about what future proofing might entail.

What is on or at the edge will of course depend upon your vantage point. Whether some of what follows even registers as school will be an indication of how blinkered the debates about what it means to prepare the young for a future of exponential change have become. The examples included here are not intended to be a comprehensive list of all or most educational practices operating at the edge of mainstream education but rather are an indicative sampling. They are brief, at face value accounts and to which the characteristics of a disruptive innovation are lightly mapped. I am not arguing that the kind of rapid change seen in the business examples Christensen studied will spring from one or more of these, rather, I am interested in what can be learned from these approaches in thinking about future proofing the young.

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[11] Christensen's theory is not without its critics (see for example Danneels 2004).

In a recently publicised[12] series of experiments involving the placement of computers in holes in walls in India, Cambodia and Africa, Sugata Mitra (2006, 2003) has demonstrated that groups of children can learn to use a computer and the Internet to answer a broad range of questions. Mirroring what happens when children work together to play various video and online games (see for example Gee 2003, 2005), Mitra has documented evidence of peer tutoring, inquiry learning and a capacity to talk about the pedagogy used to help their peers. He argues that in terms of formal curriculum, only one portion of any given curriculum actually requires a teacher and that his model illustrates the key role of peer teaching and modest expertise to support the learning of novices. Importantly, the learning that he observed taking place was driven by questions. Not the kinds of questions asked in normal classrooms where the knowledge authority knows the answers but questions that lead to better questions in the pursuit of a goal (Thomas and Brown 2011). While his work is referenced to mainstream schooling, in terms of a disruptive innovation, his model taps a huge number of non-users of formal schooling.

To supply the missing third part of support that his model suggests, he has enlisted large numbers of volunteer mentor/tutors, his so-called 'granny cloud' which provide an hour a week to support to each self-organising cluster of students via Skype.

826 Valencia[13] is a project in the United States in which school age children work with writers after school hours on their writing. Help for writing ranges from help with homework through to writing and publishing books, novels, and newspapers, real tasks. The children have access to the mature insider forms of practice of actual writers, people who write for a living, something they can't get in a classroom. Computers are used for writing and publishing, i.e. to do work that matters to the children and to the audiences for whom they write. These children also are non-users, non-users of an educational service that gives them access to cutting edge expertise. Access to expertise is a consistent feature in all of these examples.

The Lumiar schools in Brazil arose from the interest Ricardo Semler (of *Managing without Managers* fame) (1989, 1993) has in education. His philosophy of running businesses has been hugely successful. In his critique of the way businesses normally operate, he likened them to schools. So it is perhaps not surprising that he wondered about shifting his ideas into formal education settings. His schools offer a similar freedom to that which he gave his workers, a freedom uncommon in most mainstream schools. There are no classrooms, homework or playtime. While there

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12 http://www.ted.com/talks/sugata_mitra_the_child_driven_education.html
13 http://826valencia.org/

are features which may resonate with some aspects of mainstream schools, the basic thrust of the schools is to reinvent schooling so that it better meets the developmental needs of children and has none of the trappings of what is seen as industrial age schooling. The children work in multi-age groups led by a tutor or mentor. There are no teachers in the mainstream sense of the word. Masters come to the school as experts or subject matter experts to provide expertise that is driven by student interest.

The Khan academy[14] is not a school. It is a large collection of screen casts made by Salman Khan. It began when he was tutoring his cousin in mathematics using online notepad software. Friends and neighbours heard of it and to manage the demands on his time (he worked in the finance industry) he began to put them out as screen casts, short videos of him sketching on a computer screen while talking about the way he was tackling the problem. There are now over 2,000 of these screen casts covering mathematics, history, finance, physics, chemistry, biology, astronomy, and economics from elementary ideas through to ideas taught at the lower end of university. I've used a number of them. They are excellent. Probably the best of this genre I have seen. Khan has since quit his job and with the support of the Gates foundation works full-time for the Academy. The content is free. Many would probably say it is not as good as a face-to-face experience. It is, in terms of mainstream schooling, the stuff of mainstream schooling. The interesting point of this example is that it is providing the service that usually occurs in a classroom. For the poor in the world the Khan Academy provides an excellent teacher in places where there isn't one[15], for the home schoolers it provides high quality materials at no cost and for schools, apart from providing auxiliary help for students, it poses interesting challenges for teachers and their content-based expertise.

There are many other examples of schools which might be categorised as having the potential to be disruptive to main stream schooling. The MET schools movement, now under the umbrella of Big Picture Learning[16], the Buck Institute's[17] promotion of project-based learning, High Tech High's[18] emphasis on students producing work for real audiences, the KaosPilot schools[19] of Denmark are just a few examples of the many experiments occurring around the world in doing school differently. All of these 'experiments'[20] in doing school differently make for a messiness in the education landscape. It's a robust messiness as each project in its

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14 http://www.khanacademy.org/. Currently over a million students a month are being supported by these materials.
15 This is one of Mitra's motivations also.
16 http://www.bigpicture.org/
17 http://www.bie.org/
18 http://www.hightechhigh.org/schools/HTH/
19 http://www.kaospilot.dk/
20 Mainstream schooling also needs to be seen as experiment, a very long standing one that has inappropriate metrics and a misguided notion of accountability.

own way aims to cater for diversity, difference and the desires of the young. In every case, there is a measure of disenthralling going on. Not all of the tracks of schooling have been relaid, replaced or removed but there are signs in all of these sites at the edges that the needs and interests of the young are not being assumed, that preparation for the future is not the straightforward task that main stream schooling implies and that new kinds of knowledge work are not only possible but are a key part of future proofing the young.

GRINning at Education

It is clearly the case that mainstream schooling will be with us for some time to come. However schools change, diversify or morph into something else there are a number of considerations that need to be at the front of any practice that is associated with preparing the young for the future. These considerations derive from taking the challenges of the GRIN technologies seriously. They might be thought of as two opportunities to become disenthralled with some long standing educational ideas.

In a world in which the growth in the numbers of computers and their inter connection grows rapidly, there will necessarily be an ongoing delegation of work to these machines. As Robert Constable (2007, np) argues: "Digital information, now measured in petabytes, is expanding rapidly; already most of it will never be examined by any human."

We have become used to having machines help us do things or do things completely for us not only in the material world where our existence has become almost totally dependent upon an array of machines which we tend not to notice until they stop doing their work, but also in digital space where we can duplicate files with the click of a mouse, Google a word or phrase to determine its meaning, analyse a huge data set via a graphical interface, or have our phone record an incoming voice message. In all of the myriad tasks in which machines have a role there is a distribution of competences between the human and non-humans (Latour 1992, p.158). The distribution is, as Winner argued a long time ago, always political (Winner 1985). That is, that delegation of certain tasks to machines in particular ways can discriminate against particular groups of humans. As I have argued in the past, consideration needs to be given to the distribution and to identify those complementary skills that humans now are assumed to have. To take a simple example, a hand calculator is a device in which the arithmetic work of a calculation is delegated to the machine. For calculations with large numbers involved, being able to estimate very roughly what the answer should be is an example of a complementary skill. For some calculations knowing about significant figures or perhaps how the processor rounds up or down could also be important. In effect, the calculator can discriminate against people without those skills. Computer use in schools is devoid of these kinds of considerations. I suggest that developing a keen sensibility about the delegation of work to machines and assumptions about complementary skills ought to be a key element in any future proofing agenda.

Complementarity is a broad principle that can usefully be deployed when thinking about what is done in schools and elsewhere. As the spread and use of various technologies occurs apace outside schools, asking how these patterns might be complemented inside schools rather than should we domesticate or not would allow schools to play a much more proactive role in terms of issues like access and role. More importantly, as the rest of the GRIN quartet begin to play out, complementarity provides a robust basis for thinking about and acting on issues of difference and disadvantage.

The second consideration is linked to the first and can be stated as a question: why do we teach children to do things that machines are good at or soon will be? Schools have had an unhappy history about allowing students to use machines to do some of the routine work of schools. The long running debates about being able to use calculators[21] in mathematics, the concern that Mum or Dad were writing essays when students turned in word processed assignments, or the anxiety about students using Wikipedia as a reference source underline the difficulty schools have had in coming to terms with the role of computing technologies. There has been little interrogation of curricula in terms of what machines can now do and what they will be capable of in the near future.

Douglas Thomas and John Seely Brown (2011, p. 92) describe an experiment Thomas conducted following the publication of a report in 2006 that found that 63% of Americans aged between 18 and 24 could not find Iraq on a map. Thomas gave a group of students a computer instead of a map and asked them to find Iraq. They all could but offered a great deal more options of how the country might be viewed, aerial, satellite, conventional map etc. The shift from 'what' to 'where' as Brown and Thomas suggest is an important characteristic of working with machines.

I am not arguing here that simply because a computer can do a task that it ought to do that task (Weizenbaum 1984) but that in a world in which there is a delegation to computers on such a massive scale that clinging to old curriculum and assessment practices is galactically stupid.

This second consideration underlines the shift that is occurring in the way that knowledge is produced, preserved and disseminated. The intimate association of the disciplines with computing technologies was underlined by a recent report on the state of 'computational thinking' (Committee for the Workshops on

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21 Which distracted the debate from the more important question of complementary skills in calculator use.

Computational Thinking 2011) which, among other things, details examples of the role that computers have played in solving problems in fields as diverse as criminology, archeology, psychology, astronomy and proof construction in mathematics. In schools there is still an ongoing emphasis on doing the 'grunt' work in problem solving rather than encouraging students to develop problem formulating skills. The recent exhortation of Douglas Rushkoff (2010) is apt here: program or be programmed.

The current world already favours those quickest to adapt. Managing the fine balance of what machines do and what humans do will not be simple but it cannot continue to be ignored and needs to be a crucial component in any education that claims to future proof the young. To do this we can't continue with the mainstays of conventional schooling. It is a matter of letting go, of becoming disenthralled. As Thomas and Brown (2011, p.81) suggest:

> We propose reversing the order of things. What if, for example, questions were more important than answers? What if the key to learning were not the application of techniques but their invention? What if students were asking questions about things that really mattered to them?

The chapters that follow provide a range of examples of educators asking questions about what they are doing in order to allow students to ask questions themselves. In the following chapter Rowan explores the ways in which this kind of thinking can be accompanied by a commitment to educational justice characterized by both robust hope and modest ambition.

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