Mathematics and technological literacy

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Introduction

In putting together the words mathematics and technology, there are two associations which readily come to my mind. One is the use of technology in teaching and learning mathematics. Another is the mathematical basis of technological development, for example in engineering design. There are issues of social justice associated with each of these associations. With the first, there are questions of access to the technology, the cultural contexts for which the technology-based/ enhanced learning is designed, and the industrial and educational impacts of using technology-based learning, especially if it is to replace provisions of classroom-based interactions. With respect to the second association, there are questions about mathematical education acting as a gatekeeper to the expert communities of technologists, engineers, and scientists.

Without dismissing the importance of the issues I have raised above, I would like to focus on a different question about mathematics and technology which has occupied my fragmented mind as a part engineering educator, part adult numeracy teacher educator, part lapsed mathematician and part union activist. The fundamental question is *why* we should be interested in mathematics and technology in the context of social justice and education, in ways other than the sorts of concerns already mentioned. My starting point for exploring this question is the idea that mathematics can be more richly understood (and learned) in relation to the social and cultural contexts in which it is developed and used. So what are the social and cultural contexts that we should consider when we talk about the contexts of mathematics in "our" present world? I will develop the argument that part of understanding mathematics in the present social contexts means understanding how the world is increasingly shaped by complex technological systems. Ulrich Beck has coined the phrase *risk society* to describe how these technological systems are not only the products of human endeavours, but sources of global risks which are beyond the control of any further technologies that we can create to control them. (1996; 1998) What does it mean to be technologically literate in this "risk society"? What do we need to know about the role that mathematics is playing in the trajectory of this risk society in order to be technologically literate? And who are the "we" who need to be worrying about technological literacy?

I will attempt to sketch a tentative definition of technological literacy that reflects a concern for social justice. This will be derived from a combination of definitions of critical literacy, numeracy, competence, and technological systems. I will then try to test the viability of this definition by considering three case studies of technological systems.

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Technological literacy

In order to develop a definition of technological literacy, I will draw on some definitions of literacy, numeracy and competence which reflect some concern for social justice. In defining what is involved in critical reading, Freebody and Luke (1990) say that the reader has to assume four roles. They are:

- the text decoder - recognition of the "basic" technology of the text, for example phonics, letters, spelling and so forth of a text
- the text participant - comprehension and making meaning of the text
- the text user - recognising the significance of the text within the context in which it has arisen
- the text analyst - asking critical questions about the text, including how the reader is positioned by the text.

The role which reflects most clearly the social justice concerns in this definition of literacy is that of the text analyst where the reader is asking critical questions about the text in relation to their wider social concerns. It is therefore posited that people who have learned to assume these critical reader roles are better able to challenge and act on the social conditions in which they find themselves.

Literacy theories have informed the thinking of many of us who have been struggling to define numeracy. In one of our articles, my colleague Betty Johnston and I have said that numeracy is more than mathematics, and it is "the ability to situate, interpret, critique and perhaps even create mathematics in context, taking into account all the mathematical as well as social and human complexities which come with that process" (Yasukawa, et al, 1995; 816). In more sober moments, we have said it was a way of negotiating the world through mathematics (Johnston & Yasukawa, 2001). Again the intention of this definition is that being numerate better equips people to challenge the world around them, and to act on those injustices that they see.

Wedege (2000; 195) offers a holistic definition of competence which I also find helpful in thinking about a concept of technological literacy. She says that "competence is:

- always linked to a subject (person or institution)
- a readiness for action and thought and/or an authorisation for action based on knowledge, know-how and attitudes
- a result of learning or development processes in everyday practice and/ or education
- always linked to a specific situation context".

She also refers to a concept of competences for the "worker of the future which are: "(a) to see things in context; (b) to deal with people and nature in a caring manner; (c) to see one's own practice in the light of historical dynamics; (d) to handle problems of identity; (e) to show sensitivity in the face of exploitation and abuse; and (f) the competence to control technology at a level where the cohesion of general technological progress is visible" (from Negt, cited in Wedege, 2000; 195-196).

These definitions of literacy, numeracy, and competence place emphases on context, the position of the person in relation to the context, and a questioning attitude. It is tempting to now cut "text" or "mathematics" and replace these with "technology", or insert "technological" in front of "competence" to produce a definition of technological literacy or technological competence. Although this is in essence what I will end up doing, I first want to examine some ways of thinking about what technology is, or more specifically what is the nature of technological systems, to test whether such a cut and paste definition would make sense. I should also say that there is no shortage of definitions of technological literacy, and so shortage per se is not the reason why I am pursuing a definition. I am looking for a definition which will allow me to understand technological literacy in relation both to social justice and to mathematical knowledge or education.

In my development of a concept of technological literacy, I will focus on technological systems, and draw on some recent concepts of technological systems put forward by various social theorists of technology. A technological system might be the electricity distribution system of a city, or a surveillance system in an organisation, or an information management system in a workplace, or it might be a policy or set of procedure which governs the practices of a group. Hughes describes technological systems as a seamless web of "messy, complex, problem-solving components [including] physical artifacts, such as turbogenerators, transformers, ..., organisations, such as manufacturing firms, utility companies, and investment banks, and components usually labelled scientific, such as books, articles, and university teaching and research programs. Legislative artifacts such as regulatory laws, can also be part of technological systems" (1987; 51). A critical aspect of a technological system, however, is that the interactions between the numerous components are interdependent and work towards a common system goal; if one component is removed or changed, then the rest of the system is affected (Hughes, 1987). I suggest that technological literacy should be focused on an understanding of technological systems. This should involve more than knowledge about specific technical devices, processes or methods; it should include an appreciation of the various non-human as well as human components and their interactions that work to steer the system towards its goal. While Hughes uses the metaphor of a seamless web, Latour, Law and Callon have developed the metaphor of a network of heterogeneous actors in their actor network theory of technology (Latour, 1987; Law, 1991; Callon, 1987). According to the actor network theorists, a technological system evolves as human and non-human actors (the components in Hughes's seamless web) negotiate goals and are enrolled into a network that eventually finds some stable state.

With these views of technological systems, a definition of technological literacy which includes -

- an awareness of the humans and non-human components of the system and their interdependencies
- an appreciation of where one is positioned within or in relation to the technological system
- an appreciation of how the system is shaping the social fabric and the natural environment around them

may be viable. But I am looking for a technological literacy that reflects more than a passive critique, however intellectually sophisticated or ethically grounded or challenging the critique may be. I want to see a definition emerge which reflects people's willingness and confidence to transgress communities of practice and to interfere, intervene, or disrupt the trajectory of a technological system, if they come to understand that it is heading towards environmental or social injustices. Is such a definition viable? One interpretation of the idea of a risk society mentioned earlier, where technology of modernity is in some sense "out of control", would suggest that it is not. If technology is truly out of control, a manufactured "monster", then it would follow that we can learn to ask as many critical questions as we like, but nothing would nor could change. Such a view is an extension of the idea of technological determinism, where technology that is out "there" is the driver of human progress (or perhaps demise?). This is not a view of technology or technological system to which Hughes, the actor network theorists, or others belonging broadly to the constructivist school of thought would subscribe.

While there are many examples of technological developments that have proven to be harmful and which continue to threaten human existence, the technologies on their own do not tell the whole story. Theories from the social studies of technology suggest that humans can and do intervene in the trajectories of technological systems. The actor network theorists (and Hughes and others using different language) talk about the "translation" of goals that take place as different actors are enrolled into the network of a technological system. At each stage, the "goals" of the actors are renegotiated until a system is mobilised towards some agreed goal. If technological systems were understood as evolutionary, through interactions and disturbances by a number of human actors with different interests and non-human actors such as technical artifacts, computer programs, and so forth, then this offers the possibility for people to act in resistance to, or in support of certain trajectories of technological systems.

Interfering with the trajectory of technological systems

I take three examples of technological systems to illustrate what it means to act on the trajectory of technological systems. I will then suggest how this might link to a definition of technological literacy which can incorporate the idea of acting upon people's critical understanding of the workings of a technological system. Not all of these interventions can be said to have been "successful" if success means steering the system off course. The first case study I will describe is an example of a failure to alter the trajectory, but there is a lesson to be learned from it. The second example is where the system is still in an evolutionary state, and the third could be said to be a successful case study. All of these systems have mathematical actors interacting with the other actors of the system, and I will focus on these at the end of the paper to make some observations about what form mathematics education should take in relation to, or as a part of, ones development of technological literacy.

Example 1 -economic modelling of global climatic patterns

My first example of an intervention on the trajectory of a technological system is the effort by a number of groups to discredit an economic model which informed the Australian Government's policy on climatic change. The MEGABARE was an economic model commissioned by the Australian Commonwealth Government to model the impact on the Australian economy of reducing greenhouse gas emissions in the period leading up to the 1997 Kyoto Convention. Using the model results, the Government concluded: "to cut emissions by 15 per cent [as proposed by the European Union] would have the following effects:

- Australian wages would be reduced by 20 per cent below business-as-usual levels by the year 2020;
- GDP would be cut by 2 per cent by 2020;
- each Australian would lose $9000 from their savings accounts;
- tens of thousands of jobs would be lost;
- the economic cost for each Australian would be 22 times higher than for each European" (Hamilton, 2001; 61).

These conclusions were used by the Australian Government at the 1997.Kyoto Convention to argue against uniform targets of reduction, and in favour of "differentiated" targets. Like many computer based economic models, MEGABARE was a complex one, and one which is difficult for most lay-persons to penetrate, especially since details were deemed "commercial in confidence" (Hamilton, 2001). The model, backed by the Australian Government, complex economic arguments, and support from many of the big Australian industries gave powerful momentum for a climate policy which put Australia at odds with many of the industrialised nations, particularly European nations prepared to support uniform reductions. However, the trajectory of the Government's proposed policy was not a smooth one.

What got in the way of the trajectory of Australian Government's preferred policy of differentiated emission reduction targets? According to Clive Hamilton, Director of the independent think tank Australia Institute which itself critically scrutinised the MEGABARE model, a number of actors attempted to block the path pursued by the Government. These included a number of professional economists who questioned the accuracy and reliability of the estimates produced by the MEGABARE, and also the validity of the conclusions drawn from the model. These economists concluded that "policy options are available that would slow climate change without harming living standards in Australia, and these may in fact improve Australian productivity in the long term" (Professor Peter Dixon, Tor Hundloe, and John Quiggan, and Dr. Clive Hamilton, quoted in Hamilton, 2001; 56). This intervention was one by experts who had expert knowledge of economics, and economic models. They would have known, from their professional training and experience, what questions to ask, what levels of accuracy should be expected, and what constituted reliability of results.

What became a greater challenge to the credibility of the MEGABARE model and the conclusions drawn by the Government, however, came not from technical "experts". Members of a minority party (the Australian Democrats) revealed through sustained questioning of a Senator that businesses and business organisations in the fossil-fuel industry in fact largely funded the MEGABARE model (Hamilton, 2001). Early revelation of the business interests in the model was published in the press (Gilchrist, 1995). Following this and other criticisms, interrogations of Government politicians by minority political party members and revelations about the business influences on the development of MEGABARE gave added leverage to environmental organisations and other NGOs to discredit the Government position at the Kyoto Convention. The Australian Conservation Foundation sought investigation by the Commonwealth Ombudsman, whose report, which was not released until after the Kyoto Convention, criticised the bureau in charge of the MEGABARE for failure to disclose the sources of funding, thereby compromising the credibility of the model (Hamilton, 2001; 60).

So what is the lesson here? The Australian Government succeeded in reaching its intended course of action by not agreeing to a uniform reduction target at Kyoto. In this example, the Australian Government formed a coalition with the fossil-fuel interest groups to develop a new, non-human actor in the form of the MEGABARE. This network of actors were determined and succeeded in their effort to steer Australian climate change policies away from the goals set by a larger network of European governments, Australian and other environmental groups, professional economists, and others equipped with their models, data and conclusions. The resistance to the trajectory set by the Government, came not only from economists who challenged the MEGABARE model and its results on technical grounds, but also from the politicians, the media and the environmental groups who challenged the credibility of the model based on the nature of the mutually re-enforcing links between the Government and the businesses in the system. It is preposterous for me to suggest ways in which the opposition to the Government's efforts might have succeeded. However, this story suggests to me that an understanding of how a technological system or network forms and gains momentum, who are the actors involved, and what interests are they negotiating in this network seem to be a critical one in developing how to begin to challenge its course. Equally critical is how this knowledge can help the opposition to enrol actors into their own network, rather than work as separate networks because the interests are not completely aligned. This is what I think I mean by transgressing boundaries in order to effect action on the trajectory of a powerful network.

Example 2 - modelling academic workload

This example is based on an ongoing study being conducted by my colleague Patrick Healy and myself (Yasukawa & Healy, 2001). In Australian Universities, academics' working conditions are largely set by local enterprise agreements between the University management and the union that has coverage of the academics. This is in contrast to all the conditions being set nationally by a central award. In Australia, the National Tertiary Education

Union has sole coverage of academics, and the Union is organised into individual Branches at each University. In the last round of enterprise bargaining, the process of negotiating these enterprise agreements, an Academic Workload Allocation Clause was negotiated as part of the Agreement at our University (UTS Enterprise Agreement, 2000; 41-42).

This is an example where an existing, management initiated formula and spreadsheet based system of teaching workload allocation in one of my own faculties is being disrupted by new actors who are enabling the evolution of a more "collegially agreed" policy. The existing system is based on measurements of New Load Units (NLUs) which replaced the original Load Units (LUs) and they stipulate how many hours a tutorial, lecture and other teaching related activities are "worth", based on formuale determined by the management. For example, one hour of face to face tutorial is worth 1.5 NLU.

Why is this seemingly neat and tightly managed policy being disturbed? The original workload model based on Load Units (LUs) was intended to assist the faculty to ensure that the existing staff could meet its teaching commitments. Prior to this, there was no instrument for measuring teaching load across the whole faculty. My own and some others' observations of the evolution of the LU and then the NLU system is that as since introducing a "uniform" measure of workload across the Faculty, people seemed to have be making comparisons between their own load and other people's load. It appears that this had then started to fuel concerns and complaints about some staff being allowed to obtain more LUs or NLUs than others who were teaching the same number of subjects. This and funding pressures in turn have appeared to provide a rationale for the management to allocate how many NLUs each subject could have, thus limiting the resources that each subject could have. This marked a significant shift in the use of the teaching workload metric. While previously, the NLUs (imprecise as they were) reflected what people did, now the NLUs dictate what people can do. By limiting the LU or NLU allocation to a subject (in no case that I am aware of has the allocation of a subject been increased), staff have had to change their teaching practices. In this way, the value that people placed on their practice seemed to have changed. For example, while staff have traditionally looked upon the quality of learning outcomes as a performance measure of their teaching practice (and no doubt many still do), there has been an emergence of cost effectiveness also being viewed as a measure of good teaching practice. In one forum, a colleague suggested that staff who succeed in teaching a subject for fewer NLUs than what they were allocated should be rewarded in some way.

Like the MEGABARE model, there were numerous criticisms of the validity of the LU and NLU formulae. Some argued on the basis of the weightings attributed to different types of activities; others argued on the basis of what was in and out of the formulae; and so forth. Each semester the formulae might be tweaked slightly, each time by management staff who did not widely explain why or how things were "refined". What has mobilised some potentially significant influence on the future trajectory, or indeed the survival of the NLU system in any form, is the provision of the Enterprise

Agreement clause on Academic Workload Allocation. This Clause states that "The development of the Faculty/ area workload allocation policy will involve the normal collegial processes of that Faculty/ area" (UTS Enterprise Agreement, 2000; 41). No longer can the management dictate what the policy or the model will be. The industrial requirement has forced all the staff concerned, including management to engage in a collegial, joint effort to develop a mutually acceptable policy. This may or may not in the end be based on complex formulae such as we have at present. However, groups of staff seem to have started to use the Clause in the Agreement as an ally to their goal of developing a different workload policy. The Enterprise Agreement is also an actor in among these groups of staff and management; it reflects the assumptions and interests which were negotiated between the University management and the Union during the enterprise bargaining negotiations. In this example, appreciation of the power and limitations of mathematical formulae will no doubt inform the workload model that eventuates, but equally important is the appreciation of the license for staff to take action into their own hands that the Enterprise Agreement provides.

Example 3 - open source and the protection of privacy

My third example is a subject of more detailed investigation by Ole Skovsmose and myself (Skovsmose & Yasukawa, 2000). Here we have an example which might be understood partly as a struggle for power between big government (the United States Government) and a social movement led by maverick hero Phil Zimmerman. In 1991, Zimmerman released a powerful encryption package, PGP (Pretty Good Privacy) on the world wide web for any interested party to download and use. Zimmerman claims that he wrote PGP because "PGP empowers people to take their privacy into their own hands. There has been a growing social need for it. That's why I wrote it." (1999). He released the package at a time when the US Government were trying to introduce a bill which would have forced manufacturers of encryption packages to insert devices which would enable the Government to read any messages encrypted by such packages (Zimmerman, 1999). The bill was eventually defeated, but there have been continued attempts by the US Government to control the use of encryption technologies so that parties perceived to be hostile to them would not be able to communicate with each other or among themselves confidentially.

PGP is a package of algorithms that includes one that is based on the mathematics of classical number theory. Encryption is a technology that is constantly faced with the tension of being defeated by faster computers. But Zimmerman did not try to defeat the US Government's effort by inventing a mathematically more sophisticated or "clever" encryption algorithm that those already in existence. He simply packaged available encryption algorithms based on clever and sophisticated, into a user-friendly form on the world wide web for free downloading. According to Zimmerman, the software is being used widely by a number of activist groups who would otherwise be subjected to US Government surveillance. For these and cyber-rights groups, Zimmerman is a hero. He has enabled the formation of powerful virtual networks by virtue of freeing an encryption software from their usual ties to commercial regulations, copyright, and standards. He has helped to disrupt the trajectory of surveillance embedded encryption tools that the Government tried to introduce. His success depended on a number of strategies: making his technology more accessible and cheaper (free) compared to the commercial technologies which were being forced to embed a device which was to enable Government surveillance, using the world wide web as the medium on which he released it, forming alliances with cyber-rights groups, and finally, having access to the technical know how to put a package like PGP together.

Back to technological literacy (and mathematics?)

So where does this leave me in what I set out to do - to formulate a definition of technological literacy which is valid and viable in our current contexts, and to consider the place of mathematics education in relation to it? Suppose it is sufficiently plausible that we live in a world where technologies (often intangible technologies such as a formulae, models, or algorithms) are acting in increasingly complex socio-technical systems - to the extent that some have used the term risk society to describe the era. What I have tried to illustrate through the three examples is that people can and do act upon their concerns about the trajectories of the technological systems, and can succeed in steering the trajectory differently. The course initially taken by a system is negotiated by the actors involved in creating that system; the system can be taken off course by other actors if they also are able to negotiate a common goal with respect to the system. People are shaped by technological systems; equally these technological systems are shaped by, and can be reshaped by people.

So what I am seeking in a definition of technological literacy is the willingness and understanding to engage in the shaping and reshaping of technological systems towards greater social and environmental justice. Many of these systems will have mathematics as core actors - the LU formula in the workload system, the equations in the MEGABARE model, the theorems that provide the basis of one of the encryption algorithm in PGP. In some, if not all of these cases, knowledge and ability to interpret, use, technically analyse and critique, and produce alternatives to the mathematics embedded in the system have been significant. But a demolition of the mathematical basis and the creation of an alternative, on its own does not generate enough momentum to interfere with the system which has already gained high momentum. There are alliances between the actors in the system which have to be exposed, analysed, and where possible broken, or reconfigured. This involves not technical or mathematical knowledge but political knowledge and skills.

The impact that a technological system has on people's lives and practices has to be understood as well. This involves listening to stakeholders, for example, the academics whose work is being measured, the social activists and other virtual communities who have an interest in maintaining confidential communications, the Australian citizens whose livelihood are being affected by the Government's climate change policies. This means giving voices not just to the experts, politicians, managers and the big businesses who are moving their

agenda forward, but the other groups whose lives are being put at risk in different ways by the trajectory of various technological systems. Enabling these other voices to come out and be heard raises issues about how the "public" understand technology, who they trust to form alliances with, what they consider "expert" knowledge, and how they value their own power and knowledge. This suggests to me that we should be looking carefully at some of the literature on risk communication, public understanding of science and technology (Slovic, 2000; Franklin, 1998; Flynn et al, 2001; Irwin & Wynne, 1996; Dierkes & von Grote, 2000; Margolis, 1996). We should also be examining the opportunities of the reflections being undertaken by some professions. For example, in the engineering profession in Australia, there has been a review of engineering education suggesting such the need for a shift so great that the report has been named "Changing the Culture". One of the recommendations of this national review was the following:

> That engineering schools demonstrate that their graduates have the following attributes to a substantial degree:
>
> • ability to apply knowledge of basic science and engineering fundamentals;
>
> • ability to communicate effectively, not only with engineers but also with the community at large;
>
> ...
>
> • understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;

There is a growing interest in developing better communication skills of engineers, particularly in relation to risks (Herbert, 1994; Beder, 1998; Swearengen & Woodhouse, 2001; von Gorpe & van der Poel, 2001). Part of this is appreciating that risk is not just about the probability of a potentially hazardous (or beneficial) event occurring, but it is that coupled with the severity of the event's consequences - the severity will be perceived and experienced differently by different people. Being able to calculate probabilities is important, but it is not enough.

Conclusions

I feel that I have avoided making a statement about mathematics or mathematics education, when surely I should be saying something like "So in conclusion, the importance of a good mathematics education in the development of technological literacy is ...." Afterall, this is a mathematics education conference.

I have not consciously avoided talking about mathematics education. But I have a difficulty in convincing myself that mathematics education is critical for each and every person for a technologically literate society, or saying that "if only person x had the maths, they could ..." I believe that in order for a technological literacy which involves transgression, resistance, and/ or in some other way shifting the trajectory of an existing technological system, the focus must be on collective knowledge, skills and action. That is, people who have interests or concerns about this trajectory need to be able to recognise why and how the system is affecting their lives and concerns, and identify others who have concerns, not necessarily completely aligned to their own. So it requires stepping out of ones normal community of practice - whether that is a group of academics in the same area with similar goals, or a social activist group, or an environmental group, or a group of economics professors. It requires them to negotiate ones interests and goals with the others, to negotiate the different knowledge, skills, experiences and risks that each brings to the problem, and to develop a strong network which can diffuse and perhaps replace the momentum of the existing network. In some cases, it may involve all of these groups networking, and overwhelming the existing network to steer it away from its original goal. Technological literacy, in this sense is a collective intelligence, not something that makes sense as an individual ability, skills or attribute.

And I am still not getting to any conclusion about mathematics education! In my definition (or is it a vision?) of technological literacy, there are different types of mathematical knowledge needed. They include:

- recognising what mathematical actors exist in a technological system, and what their intended and unintended roles are, especially in relation to the impacts of the system on people's practices and lives, and the environment;
- understanding the technical function served by the mathematical actors, and its significance in relation to the system's goal;
- being able to identify, use, and in some cases develop mathematical techniques or models to produce alternative components in the technological system which can lead to a more desirable goal;
- appreciating the connections between the mathematical components and the various human actor groups and the political significance of these connections; and
- being able to generate and ask the questions which bring the points listed above to the surface.

These skills and knowledge cannot all be brought to bear by people acting as individuals, or a group of people operating only within their traditional community boundaries. If education is about brining about social change, then the focus of education cannot be divided up between different discipline knowledge, or on individuals' intellectual development alone; there must be a focus on making connections between different types of practices and knowledges which exist in different and changing communities.

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