Technology use and changes in teaching mathematics

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This paper argues that there is a need for pedagogical change in the teaching of mathematics when using technology, which would require a pedagogical shift towards learner focused practice rather than the use of technology as a computational tool. It briefly explores the background issues to pedagogical usage of technology in secondary school mathematics classrooms, examining stages of development in the use of technology, two theories of learning and associated pedagogical approaches, the 'intended' versus the 'delivered' curriculum goals, and the need for learner focused teaching. Barriers to change are examined and some possible ways forward are considered.

Introduction

To fully meet the requirements of the intended New Zealand mathematics curriculum (Ministry of Education, 1992), the effective pedagogical use of technology is necessary. New Zealand secondary mathematics teachers have access to technology, which includes class sets of scientific and graphics calculators and access to computers with Microsoft Excel as a minimum. In addition, many schools have other mathematical software packages available. Whilst there are equity issues, such as the significant differences between the resources available to teachers and students in different schools, the focus here is on making the most effective pedagogical use of the available technology. The reason for this focus is that the evidence suggests that the available technology, whatever it may be, is not being effectively used (Norton & Cooper, 2001).

Developmental stages of technology usage

There are many descriptions of developmental stages with regard to technology usage but here frameworks developed by Galbraith, Goos, Renshaw and Geiger (2001) and Lindsay (2002) are briefly summarised then equivalences are proposed.

Galbraith et al. (2001) describe four stages of technology usage: technology as master (the student trusts the output and has limited operational skills); technology as servant (the student trusts the output and has reliable operational skills); technology as partner (the student is able to judge the output and use the tool to investigate mathematical concepts), and technology as an extension of self (the partnership has developed so that the technology and student function as one).

Lindsay (2002) describes three stages of technology usage: the computational stage (output is copied by the student regardless of accuracy and there is no attempt to generalise), technician stage (student can make limited explanations and interpretations but is still unable to generalise) and the multi-representational stage (student can make detailed explanations and interpretations with a move towards generalisations). The first three stages of Galbraith et al. (2001) are similar to those of Lindsay (2002) (see Appendix 1) although the fourth has no equivalent. For example, the 'computational' stage (Lindsay, 2002) where output is copied implies a level of trust in the output as for the 'technology as master' stage (Galbraith et al., 2001).

Having briefly described the developmental stages of technology usage these will now be linked to the pedagogical practices that are required for the development of each stage.

Learning theory and associated pedagogy

Skemp (1976) draws attention to the fact that there are two completely different ways of understanding mathematics; 'instrumental understanding' – the application of rules without reason (which as Skemp points out does not necessarily involve any understanding at all), and 'relational understanding' – knowing what to do and why you are doing it (which requires an in-depth level of understanding).

The development of instrumental understanding can be achieved with technology usage at the computational or technology as master stage while relational understanding would require technology usage at the 'technology as partner' or 'multi-representational' stage. In order to develop relational understanding it is necessary that students must know what to do and how to do it, but most importantly why they are doing it. 'Extension of self' (Galbraith et al., 2001), the highest level of technology usage, appears to lie beyond relational understanding and probably links to, and is developed across, all curriculum areas. (See Appendix 1 which shows proposed connections between curriculum goals, the developmental stages of technology and teacher practice and informing theory.)

The Pirie-Kieren (1994) model of how people learn mathematics emphasises the recursive nature of learning with levels (doing, image making, image having, property noticing, formalising, observing, structuring and inventing) nested inside one another that are visited and revisited as learning takes place. If taught by a teacher with goals of instrumental understanding the student will be told the rule and how to apply it. This circumvents the learning process as theorised by Pirie and Kieren and does not allow the student to 'discover' the rule for themselves. Teachers with goals of relational understanding will create rich mathematical activities that allow the student to explore creating their own images, noticing properties of the images and discovering rules for themselves. Clearly, in the short term, the goal of relational understanding will require more planning on the part of the teacher and more time for the student than a goal of instrumental understanding.

Lindsay (2002) refers to the Pirie-Kieren theory with its focus on the highly individual nature of the learning journeys towards understanding (the multi-representational stage) as giving teachers an insight into the way students learn. This supports the development of a constructivist-aligned, student-centred pedagogy.

Norton and Cooper's (2001) case study of teachers at technology rich schools found that most teachers had relational goals for top stream students and instructional goals for less able students. In order to achieve relational understanding the pedagogical focus must be on the learner, rather than traditional transmission methods of show, tell, and explain.

The intended mathematics curriculum

The mathematics curriculum (Ministry of Education, 1992) states general aims that include 'concept development' and 'understandings', which clearly indicates that the intended outcome is relational understanding. This curriculum aim would appear to be met by students' achievement of Lindsay's (2002) multi-representational stage or Galbraith et al.'s (2001) idea of technology as partner. One of the more specific aims, however, is for students to "become confident and competent users of information technology in mathematical contexts" (Ministry of Education, 1992, p. 9) where technology is seen as a computational aide which would only require the 'technology as servant' or 'technician' stage.

The world in which the students will be living and working, however, will increasingly reward them for their ability to use technology as an integral part of their approach to work, i.e. as an extension of self. This suggests that the intention and delivery of the mathematics curriculum falls short of this expectation of society. However, technology usage as extension of self as a cross-curricular aim, rather than being subject specific, would allow this expectation to be met.

A change in pedagogy is required

Currently many students are taught using 'traditional' pedagogical practices (Klein, 1998) that encourage instrumental understanding, which is in conflict with the intended curriculum. While many teachers are using technology in the classroom it is more often being used as a computational tool rather than a tool for investigating and developing mathematical concepts (Norton & Cooper, 2001). Another complicating factor is that even when concept development is a teacher focus the teacher's pedagogical practice can be student, class or lesson specific. For example, teachers may have relational understanding goals for the top students/classes, and instrumental understanding as the goal for everyone else (Norton & Cooper, 2001). Such practices conflict with the aims of the curriculum which are for all students equally. Hence teachers' pedagogical practices need to change to better and more consistently reflect the aims of the curriculum.

Three possible ways to facilitate change could be introducing assessment specifically designed to influence how students are taught (an acknowledged method of promoting change), the provision of professional development, and attempting to change the beliefs teachers have about mathematics and teaching mathematics. Beliefs and consequent attitudes about teaching mathematics are paramount, as teachers with goals of instrumental understanding will, in general, not progress students beyond the technology as servant stage. Whilst professional development can successfully inform teachers of the potential of available technology, changing beliefs is harder to facilitate. Teachers require accurate and comprehensive knowledge of the technology (including software packages and graphics calculators) that is available for them to use within the school environment. Understanding the potential of technology usage and the aims of the mathematics curriculum (the development of competent users of information technology able to use it in investigations and problem solving) in relation to technology and mathematics teaching is also required. Learner focused pedagogies that use the available technology to assist students' development of concepts (relational understanding), are required for students to reach the goal of technology as partner.

Norton and Cooper (2001) propose three categories of teacher usage of available technology: rejection, calculational and conceptual. The first category is composed of teachers who reject the use of technology and actively resist the use of the technology available. They do so for two main reasons: comfort with and faith in the efficiency of traditional teaching pedagogy/methods which they see no reason to change, and/or a lack of the required knowledge to be able to use the available technology and a consequent rejection of its use in their teaching. The second category, calculational users, promote the use of the available technology as a computational aid but their goals are that of instrumental understanding only. Teachers as calculational users have pedagogical practices that are generally teacher focused. The third category, conceptual users, use the available technology as a tool to investigate mathematical ideas and promote relational understanding. Teachers as conceptual users have pedagogical practices that are primarily learner focused.

Barriers to change

Teachers' beliefs and attitudes can be a barrier to change; some teachers fear relationships changing within a classroom when a learner focused pedagogy replaces a teacher focused pedagogy. This can essentially be a fear of losing power and control. The teacher's beliefs about mathematics teaching and pedagogy have a direct effect on their use of technology in the classroom. Teachers who believe that the use of technology (eg. computers) hinders mathematical growth in students will generally practise show and tell (and explain) teaching methods which are predominantly teacher focused (Norton & Cooper, 2001).

Another barrier is insufficient resources such as time and support for teachers to develop the necessary new skills. As part of this, teacher workload is also seen as a significant barrier, as unfortunately teachers are frequently not allocated enough time or support to become familiar with the technology available or to incorporate it into their classroom practice. This results in teachers ‘turning a blind eye’ (McInerney & McInerney, 2003, p. 201) or using technology in very ‘safe’ and traditional ways. In such situations students would only be supported to develop to the computational or technician stage of technology usage.

Possible ways forward

Teachers whose pedagogical practices encourage instrumental understanding often structure teaching with assessment in mind, therefore if use of technology to investigate mathematical concepts was assessed it would be taught (Norton & Cooper, 2001). Indeed assessment may be a more powerful tool for implementing change than the curriculum as evidence suggests teachers tend to interpret the curriculum to suit their beliefs.

Engaging teachers in classroom based research can be used to facilitate self reflection much more successfully than simply requesting that they reflect on their teaching practices. Norton and Cooper (2001) stress how important it is to provide teachers with the support they need to adopt new practices, arguing that “effective professional development needs to involve the entire mathematics community” (p. 392). In contrast, top down approaches seldom produce the desired results, as teachers are alone in the classroom with students and will hold to their existing beliefs; if they have faith in the pedagogy they have used for the last ten years they will not change it simply because they are told to change.

The need to engage the whole mathematics education community positively is highlighted by Goos’ (2002) study of teachers in Queensland and their use of technology. A theoretical framework building on the Vygotskian concept of the Zone of Proximal Development (ZPD) was used to describe a beginning teacher whose skills were developing and the collegial environment they were in. The Zone of Free Movement (ZFM) and the Zone of Promoted Action (ZPA) were additional zones that Valsiner (1987, in Goos, 2002) developed. The ZFM suggests which teaching actions are possible whilst the ZPA represents the active involvement of associate teachers and fellow professionals. Where a beginning teacher lacked collegial support, because of prevailing traditional views, they had a consequently limited ZFM. This seriously restricted the beginning teachers' ability to promote the appropriate use of technology to develop relational understanding. The potential of their ZPD was not allowed to develop as it might otherwise.

In summary the positive actions that can be taken are as follows: work on changing beliefs; change assessment to better reflect the aims of the curriculum, especially in relation to technology usage; manage teacher workload; provide adequate resources and time for teachers to develop new skills; and aim for a mathematical education community involvement that is positive.

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Appendix 1

Connections between the curriculum and developmental stages of technology and pedagogy

Curriculum	**Technology use**			**Teaching and Learning**	
Mathematics (Ministry of Education, 1992)	**Galbraith, et al. (2001): Developmental stages**	**Lindsay (2002): Developmental stages**	**Norton and Cooper (2001): Technology usage**	**Norton and Cooper (2001): Teaching style**	**Skemp (1976): Ways to understand mathematics**
	technology as master	computational stage	rejection [resistance or lack of knowledge]		
delivered curriculum	technology as servant	technician stage	calculation	teacher focused	instrumental understanding
intended curriculum	technology as partner	multi-representational stage	conceptual	leaner focused	relational understanding
cross curricula and societal expectation	technology as extension of self				