

Teaching Mathematics and Technology through Design Practice

Stephen Norton
Griffith University (Logan Campus)
<s.norton@griffith.edu.au>

Tom J Cooper
Queensland University of Technology
<tj.cooper@qut.edu.au>

In many schools throughout the western world teachers are observing increasing student disengagement with the study of mathematics and technology. The Queensland Education Department implemented a curriculum project designed to trial the use of design practice as a tool for integrating the teaching of mathematics and technology. This paper reports on the outcomes of the trial. It argues that differences in regulatory and instructional discourse adopted by the teachers resulted in different and pedagogically important outcomes.

This paper is set against two broad trends in mathematics and technology (M&T) education. The first is a distinct decline in participation in the more advanced learning in M&T, generating serious consequences for the national economy of Australia with a shortage of competent M&T trained graduates holding up critical infrastructure projects (Custer, 2003). Fewer students are taking advanced mathematics in Year 12 (Department of Education, Science and Training, 2003) and opting to study technology-based subjects such as Engineering and IT (Anderson & Gilbride, 2003; Kaiser, 2000). This appears to be caused by a decline in student enjoyment of M&T from Year 4 (Watt, 2005) affecting later participation (Khoon & Ainley, 2005); M&T is perceived by students as being dull, boring, difficult and inconsistent with wanted identity (Barrington, 2006). This connection between perceptions, participation and performance is supported by the findings of Norby (2003), Stepulevage (2001) and Thomson and Fleming (2004).

The second trend is a distinct theoretical shift in what it means to be mathematically and technologically literate from skill development to problem solving (Custer, 2003). With respect to mathematics, the focus on problem solving is excellently justified in the recent submission to the Australian National Numeracy Review by the Mathematics Education Research Group of Australia (Mousley, 2007) where it was stated:

People need to develop abilities to tackle, interpret and solve problems; to observe, describe, interpret and predict numerical and other sequences; to think abstractly and manipulate ideas; ... to analyse and reason about situations logically; to monitor progress and apply reality checks. (p. 2)

It has been suggested that this shift to problem solving also requires a shift in pedagogy, in particular, by placing an emphasis on connecting mathematical knowledge through investigations in a community of inquiry (Mousley, 2007; National Council for Teachers of Mathematics, 2004).

The shift to problem solving has been adopted by the Years 1-10 M&T syllabi developed by the Queensland Studies Authority (2003, 2004). The Mathematics Syllabus has termed "working mathematically" as an integral component of problem solving, investigation and application, and "connections" across all content strands (QSA, 2004, p. 1). The technology syllabus (QSA, 2003) focuses on design in both content and pedagogy, defining the technology practice strand as embodying the actions of investigation (identifying the problem and gathering information and data), ideation (planning and designing), production (creating and making), and evaluation (testing, judging, and refining).

The overlap of goals and methods in M&T provide clear indicators for the consideration of the learning of these subjects holistically rather than as distinct entities as they have been treated in the past. In order to capitalise on the potential benefits of learning M&T holistically, Education Queensland implemented trials of integrated M&T units of work of 9 weeks duration. Unfortunately, there is little research to guide the processes of curriculum development and implementation with this very specific emphasis in mind. Consequently, the objectives of this paper are to: (i) document and analyse their *regulatory discourse* (Daniels, 2001), a construct associated with the planning and management of the content to be taught, the key outcomes aimed for and the means by which they would be learnt, in particular what models of integration was undertaken; (ii) document and analyse their *instructional discourse* (Daniels, 2001) described as a construct associated with how the outcomes were taught, including learning activities undertaken and the various roles of the students and the teachers and how the students were supported in these activities; and (iii) draw conclusions from the implementation and evaluation processes to guide subsequent planning of integrated learning of M&T.

Method

The methodology was essentially a case study. The involvement of the researchers as active participants with the teachers in the trials also gave the methodology a participatory collaborative action-research element (Kemmis & McTaggart, 2000). However, the participatory role of the researchers was limited to providing a one day seminar on the technology syllabus implementation and some support with initial planning; in particular suggestions as to what types of technology based activities might be rich in opportunities to learn mathematics.

The participants in the trial covered by this paper were a teaching principal, “Alan”, (all names are pseudonyms) of a rural Queensland state school, “Granite Tors”, and 20 students ranging from grades 1 to 7. Only the Years 4 to 7 students participated in the project “Design a Sundial”. The other projects were “Design a Package”, Years 1 to 3; “Design a Bug Catcher”, Years 3 and 4; and “Design Proportional Puppets”, Years 5 to 7. The data were collected over the life of the 9 week trial. Sources of data included observations of the teacher and students’ classroom activity (videotapes, audiotapes, field notes) with particular attention focused on (i) elements of student and teacher activity including language and roles undertaken; (ii) the levels of autonomy and student ownership of the processes involved in the trial; (iii) the time, and the type of support, given to student learning; and (iv) teaching activities to make underpinning concepts explicit. Semi-structured interviews with the teachers at the beginning, mid-point and end of the trial focused upon their perceptions of the teaching potential of integrated teaching of T&M and how they went about implementing the projects. Artefacts including unit plans, lesson plans and student work were collected from the trial and analysed to provide rich descriptions of regulatory and instructional discourse.

The analytical framework for evaluating the interventions focused on the two major constructs, regulatory discourse and instructional discourse, described previously. The various data sources were examined for recurring evidence that allowed the authors to produce rich descriptions about the regulatory and instructional discourse enacted during the life of the technology based projects at the four schools. The results from these case studies were used to highlight pedagogically important differences between Alan’s teaching approaches and those employed by the teachers in the three comparison schools.

Results

The findings related to the nature and types of regulatory and instructional discourses employed at “Granite Tors” and the three comparison schools are summarised in Table 1. It is difficult to generalise across the three comparison schools, not least due to the variation of Year levels and the different project types involved, however, there was strong evidence for each of the descriptions tabled below.

Table 1*Summary of Regulatory and Instructional Discourse*

<i>Regulatory discourse for Design a Sundial project (Years 4 to 7) – Granite Tors</i>	<i>Regulatory Discourse – Other Schools.</i>
Student derived project based upon a genuine need of the school.	Teachers selected existing projects that might be rich in mathematics and technology learning opportunities and modified them. A travel based SOS project became “Design a Package”; science based insect collection project became “Design a Bug Catcher”, and a theatre based production became “Design Proportional Puppets”.
Framework of “thinking, discussion, planning, community involvement, making and evaluation, and publication” guided student negotiation of a new “useful project”, and student negotiation of design, investigation, ideation, production and evaluation processes.	Mathematics focus on space and measurement in design and production (and also ratio for the Years 5-7 project on puppets).
Mathematics focus on space and measurement in design and production of prototypes and a finance focus with the costing and manufacture.	Technology focus on production for the package and puppet projects. The Bug Catcher project also had a strong design element, but the focus was mathematical rather than on the design processes itself.
Technology focus on ideation, design and dissemination.	Completed projects shared with class, mostly print and art based display. ICT use auxiliary; limited design sourcing via www, some limited data collection and graphing in Bug Catcher project (Excel).
Project disseminated by students as a digital portfolio linked to school web site. ICT integration central to the project; evaluating various sundial designs and underpinning design theory from web sources analysis and displaying via ICTs.	Community involvement through guest speakers talking about the topic (postage and entomology).
High community involvement, e.g., equipment to clear site and local metal worker to construct according to student designs.	<i>Instructional discourse – Other Schools</i>
<i>Instructional Discourse – Granite Tors</i>	Many of the design decision taken by the teachers.
Extended student reflection and negotiation in design phases. High student ownership.	Planning proportionally less dominant phase, most time spent on production.
Considerable proportion of time allocated to planning, as well as making and evaluating prototypes, designing a final product, designing and supervising the construction of the base, negotiating with local fabricators to make their sundial design from metal, costing and managing the project, evaluating the effectiveness of the product.	Teachers worked “one on one” with students with an area of need. Mix of facilitator and explicit instruction.
Teacher worked “one on one” with students with an area of need. Mostly facilitation role adopted by the teacher.	Teacher exhibited high levels of question and critical analysis in “Bug Catcher”; that focused upon mathematical knowledge; and there was limited critical reflection beyond the material aspects of designs.
Teacher exhibited high levels of questioning that reflected a focus on developing student ability to be analytical in both mathematical and technological contexts.	

Models of Integration

Alan's description of the relationship between the technology based project and mathematics was as follows:

As mathematics can be a means of viewing the world, to investigate patterns, order, generality and uncertainty, it (the project) is an ideal subject to help students make meaning of the world, but more specifically the "place" they live in...I used the project to draw out their mathematics and two text books in support (*Signpost* and *Jigsaw Maths*) to fill in the light and shade. (Interview data)

Alan had a strong view on the purposefulness of mathematics and that student understanding needed to develop from engaging in "real" activity. The light and shade he refers to are those aspects of measurement and other mathematics that did not "grow out of" the project including much of the foundational number concepts which provide the basis for the other strands. Alan summarised his students' learning in the following words:

The students in this project see maths as having a purpose and have learnt to apply problem solving strategies. They were immersed in the process of technology practice, learnt lots about suitable materials, managing a project and seeking and transforming information. ICTs were used to access information and to publish their results as digital portfolios. In terms of ICTs, they are streets ahead of most kids their age and they are on their way to becoming autonomous learners.

By comparison the following quotes were typical of the reflections of the remaining three teachers with respect to the relationship between the technology project and the mathematics learning:

(Bug Catcher) I tended to teach the normal maths number (strand) in the morning...that way we would not miss key concepts... but we would also look at other strands such as measurement. We would develop the concepts in the morning and have an opportunity to apply them in the afternoons (when students were working on the technology projects).

(Puppets) I was looking at ways of incorporating what I wanted to teach in mathematics. I wanted to teach quite a lot on measurement including length and area, as well as to introduce the concepts of ratio and proportion in a concrete way. The ratio was taught previously using other materials such as blocks, paint and mixing cordial drinks up, to set up (an understanding of) proportion. The students readily transferred the ideas to puppet production including the patterning and making of puppet cloths. I parallel taught other mathematics concepts.

Discussion

All the teachers reported that the students in each respective trial were highly engaged and on task throughout the project, and the integration of M&T worked to harness students' enthusiasm to be creative and constructive for the purposes of learning mathematics. This assertion was supported by evidence from classroom observations.

Mathematics Learning

What was common to each of the four trials was that the teachers had the perceptions that by linking the learning of mathematics to the technology projects, students could see the value in learning mathematics, that is, mathematics has a purpose. All four teachers believed that seeing mathematics as purposeful and useful was a factor in the high levels of student engagement. If we assume the models proposed by numerous authors are correct in that student perceptions are central to their participation and learning of subjects (Ethington, 1992; Khoon & Ainley, 2005; Markku, 2002; Murphy & Gibbs, 1996; Thomson & Fleming, 2004; Wigfield & Eccles, 2000) and that these perceptions are formed early and that early experiences are important (Thomson & Fleming, 2004), the above findings are encouraging. In addition, the regulatory and instructional discourse was reported by all the teachers to have furthered the attainment of mathematical literacy in ways consistent with reform definitions of mathematical literacy (Anderson, 1999; Mousley, 2007; NCTM, 2004).

However, the findings including those in Table 1 indicate that there was a difference between Alan and the other teachers with respect to the manner of developing of understanding. The dominant regulatory and instructional discourse used by the three comparison teachers resulted in the use of an approach that involved parallel instruction, that is, mathematics concepts were taught explicitly in the morning either using textbooks or other resources and this knowledge was applied and built upon in the afternoon session when technology practice was enacted. Alan's approach was somewhat different. The problem based technology project became the focus of mathematical learning and supporting textbooks were used to provide "light and shade", "extension work", "cover missed concepts", and as a resource for one-to-one tutoring of concepts that particular students struggled with. As previously signalled, the integration model used by Alan in teaching mathematics through engagement with the technology project had the added dimensions of seeing mathematics as a tool to "make sense of the world" and in seeing the integrated M&T project as "providing a platform to explore the world of maths". This made Alan's trial and project different in that while integrated M&T projects were seen as opportunities to essentially apply mathematics to authentic contexts in the other three schools, they were seen more as opportunities to generate mathematical understandings at Granite Tors State School.

For both Alan's and the other teachers' models of integration, the effect was increased time and opportunities for students to engage in mathematical activity in addition to time that would normally be spent upon mathematics lessons. All teachers cited examples of the use of mathematics concepts while students planned and constructed their artefacts. Further, the teachers in each trial reported that the harnessing of teaching mathematics with and through technology made mathematics more "fun" and more "understandable." It is likely that the two are intertwined since, as reported above, students consider learning that is "too hard", is also "boring". Put simply, students like to have the tools to understand.

In constructing their artefacts, the students were using mathematics in planning and working with materials that they might not normally engage with in more formal mathematics teaching and learning episodes. Thus, it was evident that the integrated teaching of technology and mathematics gave teachers increased representational opportunities to explore mathematical concepts in very practical situations. An example of this was the use of proportional reasoning in the puppet construction, in addition to representations with blocks, mixing cordial drinks to set ratios and ratios of colours or objects, as well as ratios in purely numerical representational forms. The successful linking of a number of representations is central to the Queensland mathematics syllabus (QSA, 2004) and to reform mathematics learning in general (Booker, Bond, Sparrow, & Swan, 2004; Mousley, 2007; Van de Walle, 2007). In this study, the increase in both time and representational opportunities was accompanied by increased frequency of student engagement with specific mathematical concepts. All teachers were aware that it was important to make the connections between representations explicit. However, in Alan's trial these links were made more obvious to the students as they worked on their projects, in part through their greater participation in the ideation and design actions of technology practice which afforded greater opportunity to engage with spatial concepts, in particular. A simple measure of this is that the students spend more time working with mathematical concepts during the extended design process.

With regard to instructional discourse, the main mathematics implication is the relationship between mathematics and technology teaching. Alan's use of mathematics as a support and extension to the project, not a preparation, meant that he was able to bring the mathematics to bear when the students needed it. His approach was much more a "just-in-time" use of mathematics teaching as against the other teachers' "just-in-case" use. This approach built stronger connections between representations, particularly in relation to artefact design and, thus, potentially deeper mathematics understanding. Observations indicated that making appropriate connections was far from fully refined in the other trials, particularly with regard to technology concepts.

Technology Learning

The difference between Alan's trial and those of the other three teachers is more evident with regard to technology learning. Although all four teachers reported encouraging progress, it was clear that the other three teachers (overall) struggled as to how to go about assisting students to learn technology practice processes and technology concepts, particularly those associated with the design (ideation) and evaluation actions. At Granite Tors State School, Alan was more explicit with linking technology practice as enacted by the students and the actions of technology practice outlined in the technology syllabus (QSA, 2003). He achieved this by having his students use the framework of "thinking, discussing, planning, community involvement

(and making), and evaluation and publication”. Alan and the class invested a considerable proportion of the allocated time to investigation and ideation (planning). This was a negotiated process and students’ input was valued and critiqued by each other with scaffolding provided by the clearly documented instructional discourse that Alan developed and worked with. The student activity was consistent with recommended technology education practices that have moved from a skills focus towards the development of more generic problem solving skills (Custer, 2003; NACCCE, 1998; QSA, 2003). In addition, in Alan’s trial, there was a conscious effort to document and critically examine design process through the use of ICTs. The processes of making technology practice explicit were facilitated by student construction of digital portfolios.

The ICT policies and processes of the Granite Tors State School with respect to accessing and processing information stand as a model for the integrated use of ICTs as part of the information strand of the technology syllabus and for integrated M&T projects. Alan’s students’ proficiency with the use of ICTs was acknowledged when they were invited to the local high school to mentor secondary students in ICT learning. However, despite this finding, the researcher found little evidence of planning by Alan to make explicit key concepts associated with the other strands of the technology syllabus (QSA, 2003) such as systems and materials. For example, while concepts associated with materials were used, the theory behind the nature of materials and their uses was not discussed or assessed. Hence, even with the excellent progress being made by Alan’s students, it is likely that key technology concepts remained implicit and that more technology learning opportunities could have been utilised which may have increased the generalisability of the concepts studied.

The differences between Alan and the other three teachers have implications for M&T learning and projects. In terms of regulatory discourse (planning management), the principal implication is the importance of an explicit focus on ideation and evaluation actions. The investigation of existing plans and appreciation of materials and production techniques were largely missed as prominent opportunities to develop creative problem solving and design opportunities in the three comparison schools. The major technology implication is the importance of allowing students to make decisions in design. In the other three trials, the teachers determined the project focus and to a greater extent provided the design plans. The teachers taking responsibility for these processes in these trials limited students’ opportunities to engage in authentic design. Alan’s opposite policy led to greater in-depth design and technology learning.

Conclusions

In summing up, the following appears to be evident from the study. First, all four teachers believed that the integrated M&T teaching could: (i) potentially facilitate powerful mathematics learning, in part, by offering a multiplier effect through greater time, exposure to additional representations, and increased frequency of engagement with mathematics concepts; and (ii) do so in ways consistent with emerging definitions of what it means to be mathematically literate. Carefully planned regulatory and instructional discourse is necessary to capitalise on these opportunities. Alan’s approach in allowing the students control in the selection of the project and resultant design of the artefact appears to offer the greatest potential.

Second, two models of regulatory and subsequently instructional discourse were identified. The three comparison teachers used an integration model which involved teaching the mathematics primarily as they had previously, and used the technology design project as an opportunity to apply in “authentic” contexts what students had previously learnt. In contrast, Alan’s model was one of learning mathematics through engagement in the design process and “just-in-time” mathematics teaching. While both approaches are likely to enhance transferable skills and generic problem solving (Anderson, 1999; Mousley, 2007; NCTM, 2004), Alan’s model potentially offers stronger connections between mathematical representations (including authentic experiences in the technology project) and deeper understanding of design and technology, in part due to the more extensive engagement in the investigation and ideation actions of technology practice and the use of mathematics in these processes.

Third, it was evident that all the teachers in this study needed assistance in implementing the technology syllabus as they missed opportunities to connect technology syllabus outcomes (QSA, 2003) to a coherent schema based framework. However, this assistance was of greater need for the three comparison teachers to prevent them continuing to empty their technology tasks of creative and innovative opportunities for the students. Their teaching oversights tended to have the effect of developing more craft based technological literacy rather than a more generic problem solving technological literacy. In contrast, the technology practice

framework used by Allen (thinking, discussion, planning, community involvement, making and evaluation, and finally publishing) was evidence of the actions of technology practice being made explicit and was more successful. This was particularly so for the student construction of a digital portfolio to record the concepts and processes involved in the project.

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