Standing on the Outside: A Tale of How Technology Can Engage Those Working on the Margins of a Community of Inquiry

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This paper theorises an extension to a framework that structures students' interaction with technology through a series of metaphors: technology as master; technology as servant; technology as partner; and technology as extension of self. These metaphors provide insight into potential relationships between students' intentions, technological engagement and actions. The framework is conceptualized from within a socio-cultural perspective of learning/teaching mathematics and extends the Vygotskian principle of Zone of Proximal Development (ZPD) by elevating computer and graphing calculator technologies beyond that of simple cultural tools to that of quasi-partner or mentor. A component of the framework is used to analyse two episodes of student/student/technology interaction while working on a specific mathematical task. The extension to the framework has the potential to promote more sophisticated uses of technology in mathematics classrooms.

Through their inclusion as mandatory elements in Australian state syllabuses and assessment regimes, policy makers have authenticated the arguments of researchers (e.g., Morony & Stephens, 2000) in favour of the inclusion of mathematically enabled technologies and applications (META) because of their potential to transform learning and teaching in Australian mathematics classrooms. Similar change is evident outside of Australia in response to the influence of bodies concerned with curriculum reform in mathematics (e.g. NCTM, 2000).

Considerable research effort has been directed towards understanding how META can be used to enhance students' learning in mathematics (Dunham & Dick, 1994; Weber, 1998; Barton, 2000) and, in particular, how these technologies can act as catalysts for more active engagement in learning and, consequently, greater conceptual understanding (Barton, 2000). Other proponents (e.g. Asp, Dowsey, & Stacey, 1993; Templer, Klug, & Gould, 1998) have argued that these technologies can allow students the freedom to explore new ideas and concepts.

This paper outlines a framework that describes students' action and interaction with technology from a socio-cultural perspective and identifies META as an element, within this framework, that plays a role beyond that of a simple tool. It will be argued that META can play a vital role in leading those who position themselves on fringes of a participatory classroom culture into a confident engagement with a learning environment conducted according to the principles of a community of inquiry.

Theoretical Framework

Sociocultural perspectives on learning emphasise the socially and culturally situated nature of mathematical activity, and view learning as a collective process of enculturation into the practices of mathematical communities. A central claim of sociocultural theory is that human action is mediated by cultural tools, and is fundamentally transformed in the process (Wertsch, 1985). The rapid development of computer and graphical calculator technology provides numerous examples of how such tools transform mathematical tasks and their cognitive requirements. From a sociocultural perspective, technology can be regarded as a cultural tool — sign systems or material artefacts — that not only amplify, but also reorganise, cognitive processes through their integration into the social and discursive practices of a knowledge community (Resnick, Pontecorvo and Säljö, 1997). Amplification takes place when a tool provides a more efficient procedure or pathway for engagement in a task, for example, the use of a calculator or spreadsheet to deal with a series of tedious numeric calculations. Cognitive reorganisation, on the other hand, occurs when the use of technological tools mediates a qualitative change in an individual's way of thinking about a mathematical idea or concept, or their approach to a problem solving task. This type of transformation is evident when students are encouraged to develop the capacity to take a multiple representational approach to solving non-routine problems. The freedom to assign equal privilege to different problem solving approaches provides opportunity to break free of the straightjacket of traditional algebraic reasoning and represents a completely different way of thinking about how to initially engage with a problem solving task and then how to progress after this engagement.

While the approach taken here is essentially Vygotskian, Galbraith, Goos, Renshaw and Geiger (2001) have argued previously that the widely known definition of Vygotsky's Zone of Proximal Development (as the distance between what a child can achieve alone and what can be achieved with the assistance of a more advanced partner or mentor) can be extended to conceptualisation of the ZPD in *egalitarian partnerships* and by the way the ZPD concept creates a *challenge of participating in a classroom constituted as a community of practice*. The first extension suggests that peer groups of *equal* expertise can promote new learning via contributions from individuals with incomplete, though relatively equal, expertise that sum to something greater than their individual parts, and so through interaction collectively progress knowledge and understanding. This is different from the purely Vygotskian view in which productive learning arrangements require that at least one individual in a group possesses greater expertise in an area of learning endeavour. The second extension argues that through the establishment of a small number of repeated participation frameworks such as teacher-led lessons, peer tutoring, and individual and shared problem solving, students are challenged to move beyond their established competencies and adopt the language patterns, modes of inquiry, and values of the discipline. Such a classroom environment, representative of an active community of learners, is augmented by the availability of technology as a means to amplify and reorganise ways of communicating within the community; for example, by allowing students to contribute to collective discussions either as private individuals (via a computer screen) or publicly (via a display available to all participants). An important observation of this study was that students who were less prone to contribute to more conventional classroom discussion did so readily through electronic media.

This paper will argue that while technology plays a role as a cultural tool, as outlined above, it can, in the minds of students, assume a more active and interactive role in the process of cognitive reorganisation — that of an almost peer with expertise that can be drawn upon in the same way as other members of a learning community.

A Framework for Analysing Students' Use of Technology

There are a number of studies that have sought to develop taxonomies of student behaviour in relation to the use of technology while learning mathematics. Doerr and Zangor (2000), for example, in a case study of pre-calculus classrooms identified five modes of graphics calculator use: computational tool, transformational tool, data collection and analysis tool, visualisation tool, and checking tool. Alternatively, Guin and Trouche (1999) developed *profiles of behaviour* in relation to students' use of graphing calculator technologies. The modalities outlined in the profiles were characterised by random, mechanical, rational, resourceful, or theoretical behaviours in terms of their ability to interpret and coordinate calculator results.

It is from the perspective of learning as a sociocultural experience, however, that Galbraith, Goos, Renshaw and Geiger (2001) have developed four metaphors for the way in which technology can mediate learning. These metaphors, technology as *master*, technology as *servant*, technology as *partner*, and technology as *extension of self*, describe the varying degrees of sophistication with which students and teachers work with technology. While these metaphors are hierarchical in the sense of the increasing level of complexity of technology usage teachers and students may attain, it does not represent a developmental progression where once an individual has shown they can work at a higher level they will do so on all tasks. Rather, the demonstration of more sophisticated usage indicates the expansion of a technological repertoire where an individual has a wider range of modes of operation available to engage with a specific task. This means, for example, that a very capable individual may well use technology as a servant if the task at hand is mundane and there is no reason to invoke higher levels of operation.

A description of these metaphors is outlined in below.

Technology as master. The student is subservient to the technology — a relationship induced by technological or mathematical dependence. If the complexity of usage is high, student activity will be confined to those limited operations over which they have competence. If mathematical understanding is absent, the student is reduced to blind consumption of whatever output is generated, irrespective of its accuracy or worth.

Technology as servant. Here technology is used as a reliable timesaving replacement for mental, or pen and paper computations. The tasks of the mathematics classroom remain essentially the same — but now they are facilitated by a fast mechanical aid. The user 'instructs' the technology as an obedient but 'dumb' assistant in which s/he has confidence.

Technology as partner. Here rapport has developed between the user and the technology, which is used creatively to increase the power that students have over their learning. Students often appear to interact directly with the technology (e.g. graphical calculator), treating it almost as a human partner that responds to their commands — for example, with error messages that demand investigation. The calculator acts as a surrogate partner as students verbalise their thinking in the process of locating and correcting such errors. Calculator or computer output also provides a stimulus for peer discussion as students cluster together to compare their screens, often holding up graphical calculators side by side or passing them back and forth to neighbours to emphasise a point or compare their working.

Technology as an extension of self. This is the highest level of functioning, where users incorporate technological expertise as an integral part of their mathematical repertoire. The partnership between student and technology merges to a single identity, so that rather than existing as a third party technology is used to support mathematical argumentation as naturally as intellectual resources. Students working together may initiate and incorporate a variety of technological resources in the pursuit of the solution to a mathematical problem.

The Study

The research reported here describes one aspect of a three year longitudinal study although the data analysed in this paper are sourcedfrom a single mathematics classroom over a two year period (Years 11 and 12, the final two years of secondary schooling; students are aged 16-17 years.). The author was also the teacher of this class. The students were studying a challenging mathematics subject designed for students intending to pursue serious study of mathematics at a tertiary level. The intended culture of this classroom is one consistent with the sociocultural perspective of learning and teaching (see Goos, Galbraith, & Renshaw, 1999) including the acceptance of emergent uses of technology. This means a variety of interactions that involve mutuality are encouraged, including: student/student interaction; student/teacher interaction; sub-group and whole class investigation and discussion of specific tasks or of a variety of projects simultaneously. Interactions between participants and artefacts such as texts and more importantly electronic technologies also characterise the way students explore and investigate new mathematical ideas and concepts.

Data Sources

On average a lesson was videotaped every one to two weeks, or more frequently if a technology intensive approach to a topic was planned. Audiotaped interviews with individuals and groups of students were conducted at regular intervals to examine factors such as the extent to which technology was contributing to the students' understanding of mathematics, and how technology was changing the teacher's role in the classroom. At the beginning of the course and at the end of each year students completed a questionnaire on their attitudes towards technology, its role in learning mathematics, and its perceived impact on the life of the classroom. A final class interview/discussion reviewing the two-year program was videotaped. This paper presents two vignettes, drawn from observation and transcript data, as well as follow-up interviews of classroom events, to illustrate the role technology can play as a *Partner* in the generation and repair of new knowledge and understanding.

Vignette 1

Students (Year 12) were asked to develop programs for their calculators that found the angle between two three dimensional vectors as an application of the scalar product of vectors and as a means of validating results found from pen and paper techniques. The teacher provided only minimal instruction in basic programming techniques, and expected individual students to consult peers, who had varying degrees of knowledge, for assistance. Volunteers then demonstrated their programs via the calculator viewscreen, and examined the wide variation in command lines that peers had produced. This public inspection of student work also revealed programming errors that were subsequently corrected by other members of the class. For example, the class disputed the answer obtained by executing the program shown in the first part of Figure 1.

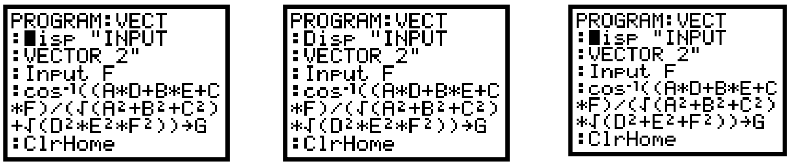

Figure 1. Correcting errors in a student program

Student 1: That is not the answer!
Student 2: Maybe he has it in radians?
Student 3: No it's just the wrong answer!

On the advice of fellow students, the presenter scrolled down through the program and replaced the plus sign in the denominator with a multiplication sign (Figure 1, second screen).

Student 4: The*re it is — that's the wrong formula…… That plus there (getting up and pointing) should be a times.*
Students 5: Yeah the plus should be a multiplication sign.

The amended program again produced an incorrect answer, and yet another correction (Figure 1, third screen) — suggested by students, not the teacher — was required before the correct output was obtained.

Whole class: Yeeaah! (followed by loud applause).

Vignette 2

In this episode we observe how one student consistently rejected the teacher's invitations to discuss his thinking with peers, participate in whole class discussions, and generally take some responsibility for advancing his mathematical understanding. For example, the teacher asked class members to participate in the development of a revision sheet for an upcoming exam.This involved each student contributing a question and model solution to the revision sheet that the teacher offered to organise, edit, and then print for each class member. The student under consideration here looked to avoid participation in the activity.

Teacher: So… what's your contribution going to be?
Student: Not much?

The teacher then chose to assign a section of work to the student in order that he develop an appropriate question and solution. The student expressed his opposition to this approach.

Student: But I wouldn't have a bloody clue.
Teacher: But that's part of the point … this is probably a really good way of revising.
Student: Yes but me revising one thing isn't going to help me much!

After some consideration, the student made one more attempt to avoid the activity.
Student: Does that mean if I choose not to take a revision sheet I don't have to write a question?
Several other students: Aw just grow up!

There appears to be at least two reasons for this student's objection to contributing to the class revision sheet. Firstly, the student does not believe that learning can be a collaborative activity and, as a result, he sees preparation for assessment as an individual responsibility. Secondly, he has very clear views on the roles of teachers and students in the process of learning. The student believes that content delivery and the development of review materials is the sole responsibility of a teacher, and the role of a student is that of passive recipient. In this instance, the student believes the creation of a revision sheet is a teacher's responsibility and finds it difficult to accept that this role should be made his.

The student's participation in classroom events began to change when he was drawn into participating in the activity described in Vignette 1. The student presented the program which included the initial screen illustrated in Figure 2 and then the second and third last screens (Figure 2, second and third screens).

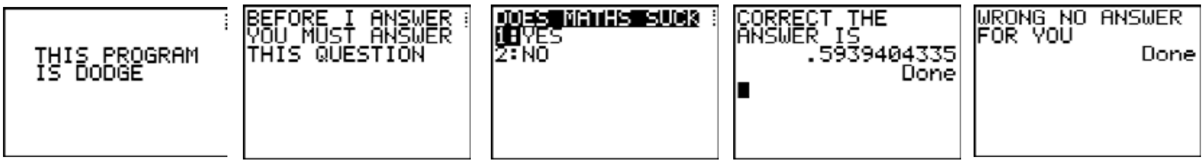

Figure 2. Presentation of the Dodge program

The choice of option 1, in response to the question posed in screen 3, resulted in the display of the answer to the calculation the program was designed to deliver (screen 4). The choice of option 2 resulted in no answer being provided (screen 5) in the manner of a taunt.

Now while the student had used the task to demonstrate dissent in relation to his current experience of mathematics, his clever use of the very method of discourse that the teacher has been encouraging the student to use persuaded the teacher not to issue a reprimand of any type. The student responded, over subsequent lessons, by increased involvement in classroom presentation whenever technology was used to mediate discussion. This included the presentation of improved, and increasingly sophisticated, versions of his initial program. This was followed by an animated program he created that depicted the adventures of mathematical objects (various irrational numbers) as human-like characters — *Dodge: The Movie*. The enthusiastic and admiring response to his "movie" (and the sequel — *Dodge II: The Revenge of Dodge*) was significant in drawing this student into the kind of mathematical discussion he had previously resisted, and he became a willing participant in subsequent discussions both technology-focused and otherwise.

Discussion

Technology is often viewed as a neutral tool useful for the illustration of mathematical ideas and concepts but with little potential for mediating interaction. Doerr and Zangor (2000), for example, found that the use of the graphics calculator as a private device led to the breakdown of small group interactions. The two vignettes above demonstrate the potential of technology, including associated presentation tools, for drawing in students who are initially reluctant to engage in, or in some cases resist, the social and cultural norms of a community of learners.

In the first vignette, technology supported the interaction of peers of roughly equal expertise in repairing a faulty calculator program. The technology not only provided the medium in which the students worked but it also stood alone to make public a particular student's work; holding it up for scrutiny and providing the opportunity for supportive critique. In this case, technology has assumed the role of almost equal partner in the interaction. It has offered to the group a skill or expertise that they lacked in order to get the job done. Once injected into the interaction it allowed the group to progress the development of an individual who had encountered difficulty in progressing by himself. The significant contribution technology has made in this episode is more than that of a simple tool; it is an instance where the boundaries between tools and human learners is blurred.

The second vignette features a student who uses the method of discourse he had previously resisted to register dissent in relation to the way mathematics classes were conducted in this course. Having received positive reinforcement from his peers (and no negative feedback from the teacher) he is slowly drawn into the ways of interacting with his learning community that he has previously shunned; initially when technology was involved and then, eventually, at other times. Technology, again, has acted as more than a simple tool. Firstly, it acted as a partner that assisted him to express the personal frustration that lay in a conflict between his view of how to learn and do mathematics and the social and cultural norms for doing the same in this particular classroom. Technology had acted as a *partner in crime* in this instance. Secondly, however, technology has almost acted as a *supportive go-between* that has encouraged him to move from the fringes of his learning community into the mainstream.

Implications for Learning and Teaching

The conceptualization of technology as a quasi-peer offers the following insights into the process of integrating META into mathematics classroom.

Technology can be regarded as more than a passive cultural tool to be appropriated by teachers and students to enhance mathematics learning and teaching. Rather, META can make contributions to social and cultural activity beyond that of merely mediating interaction. The vignettes presented above highlight instances where technology has played a far more important role than that of a simple presentation tool that assists in mediating discussion and interaction. In these instances, technology has almost taken on its own persona and has offered contributions to these learning episodes that students, by themselves, would not have been able to replicate. This is emphasized, particularly in the second vignette, where a student is empowered by a technological partner to voice a controversial view via a method of expression sanctioned by the learning community from which he had excluded himself. Further, he was then led by the same technological partner back into a human community from which he had previously dissociated himself.

The notion that META can be regarded as quasi-peer within a community of practice extends Vygotsky's notion of a ZPD to include technology as contributing member to a group of learners rather than merely a cultural tool. This implies that META should be afforded even greater attention in terms of its pedagogical power than has been previously assigned and so has implications for both teacher pre-service instruction and for in-service professional development.

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