# Master, Servant, Partner and Extension of Self: A Finer grained View of this Taxonomy

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This paper extends the work of an earlier study that theorised four metaphors for the way students made use of calculator and computer technology. Students' responses were obtained on three occasions during a two year teaching program in relation to the way they incorporated technology into their learning of new mathematical concepts and ideas or when solving problems set in both familiar and unfamiliar contexts. These responses were used to develop a finer grained taxonomy of behaviour than proposed in earlier work.

This paper reports on aspects of a three year longitudinal study that investigated the role of electronic technologies (graphics calculators and computers) in supporting students' learning in mathematics, especially in the way they can be used to explore new mathematical ideas and to mediate student/student and teacher/student social interaction. While there is now a significant body of work that has examined the effects of technology in learning mathematics (Durham & Dick, 1994; Weber, 1998; Barton, 2000) conclusions in relation to achievement remain inconclusive. Despite this there remains a sense, within at least some sectors of the mathematics education community, that these technologies can act as catalysts for more student active 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.

The majority of this research, however, has been based on quasi-experimental designs that sought to assess the effectiveness of teaching with technology in contrast to methods based on pen and paper approaches (Goos, Galbraith, Renshaw & Geiger, 2000). There has been little investigation into how technologies, such as graphing calculators, are used by individual students (Michelmore & Cavanagh, 2000) or how these technologies have affected teaching approaches (Penglase & Arnold, 1996).

This paper examines students' perspectives on the use of electronic technology to learn mathematics and to investigate new ideas and concepts. The categorisation of student responses to open-ended survey questions gives rise to the further development of a taxonomy of sophistication with which students work with technology - the subject of earlier work (Galbraith, Goos, Renshaw & Geiger, 2000).

## Theoretical Perspectives

The socio-cultural perspective of learning embraced by this study extends the widely known definition of Vygotsky's ZPD (Zone of Proximal Development) to the 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 (Galbraith, Goos, Renshaw & Geiger, 2001). This view suggests that there is the opportunity for the realisation of the learning potential of peer groups in classrooms where working on collaborative endeavours is a norm. This is relevant in the context of this study as students were regularly challenged to work as a group in bringing technological tools to bear on mathematical tasks that would expose their varying degrees of technological and mathematical expertise. The second view refers to the challenges that were inherent in the day to day function of the study group that over time adopted the modes of inquiry and methods of negotiation that characterise a classroom environment conducted in sympathy with the principles of an active community of learners. The environment was augmented, in this case, through the ready availability of technological tools which students integrated into their actions and interactions as individuals and in group settings. The interplay between the use of technology, student/ student and student/teacher interaction gave rise, on many occasions, to the unanticipated use of technology as part of the learning/teaching process.

To date, such unanticipated uses of technology have been given little acknowledgment by teachers who have, by and large, used new electronic technologies to enhance already established teaching methods (Ramsden, 1997; Thorpe, 1998). Ramsden (1997), however, argues that the unanticipated, or emergent, uses of technology are a natural outcome of learning environments in which the locus of power in the classroom has been shifted towards students rather than remaining totally with the teacher. Productive emergent uses of technology, he contends, must be encouraged if the intended culture of these types of classrooms is to be fostered. In support of this position, Shneiderman, Borkowski, Alavi and Norman (1998) describe classrooms in which an emergent outcome of the use of available technologies is the enhanced option for 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.

## A Framework for Analysing Students' use of Technology

While few studies have investigated how electronic technologies are used by students or what impact these technologies have had on instruction, there are studies which have sought to develop taxonomies of student behaviour in relation to the use of technology to learn 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 socio-cultural experience, however, that Galbraith, Goos, Renshaw and Geiger (2000) 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 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*. 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.

It is the purpose of this paper to offer an extended, more fine-grained elaboration of these metaphors.

## The Study

Consistent with the issues visited in the preceding discussion, as part of a larger study, evidence is sought that provides insight into the following:

1. Disposition of students towards using technology in learning mathematics.
2. Development of collaborative preferences (or not) by students as they work with technology in mathematics learning.
3. Choices of *specific* forms of calculator use favoured by students.
4. Choices of *general* strategic purposes for calculator use favoured by students.
5. Perceptions of students with respect to their global facility and confidence with graphical calculators as a personal resource.

This paper is concerned principally with 3-5 where a taxonomy, first described in (Galbraith, Renshaw, Goos & Geiger, 1999), has been extended on the basis of students' responses to open-ended questionnaire items.

### *Classroom Context*

The research reported here describes one aspect of a three year longitudinal study although the data analysed in this paper is sourced from a Mathematics C classroom over a two year period (Years 11 and 12). This classroom was situated in a coeducational non-government school where the author maintains a position on staff. The author was also the teacher of the class that was the focus of this study. Mathematics C is a challenging subject option for students intending to pursue serious study of mathematics at a tertiary level. The intended culture of this classroom is one consistent with the socio-cultural perspective of learning/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.

Both graphing calculator and computer technologies were used in a variety of settings and for a range of mathematical activity. These technologies were used as *Tools* (Taylor 1981) and as *Catalysts* (Willis & Kissane 1989). Technologies were used as *Tools* to perform mathematical activities they would have otherwise conducted in some other more time consuming way or to perform tasks that would have been beyond their capabilities without the assistance of computer or calculator technologies (eg calculations involving operations on large matrices). Calculators and computers were used as *Catalysts* to encourage mathematical explorations and discussion or to promote the use of problem solving skills (eg the search for conditions associated with population stability in an exploration of the logistic equation). Students were encouraged, in their individual and collaborative activities, to utilise technology in any way that they saw fit and were able to justify or defend.

### *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 draws on data from all three questionnaires. Sixteen students completed the questionnaire at the beginning of Year 11. Of these twelve also provided corresponding data at the end of Year 11 and fifteen at the end of Year 12. Students enter Year 11 with a variety of backgrounds, and during this year the culture of the classroom is established (see Goos, Galbraith & Renshaw, 1999), the various technologies, teaching approaches, and learning formats are experienced, and the expectations of the teacher made clear. By the end of Year 11 students are able to respond in an informed way to the questionnaire items. While the stability or change in student opinions and assessments over time is also of interest, restriction of space will not permit the discussion of this topic in this report. The questionnaire contained structured Likert items together with a section inviting open responses. It is these open response items that are the subject of analysis. A sample of these is provided below – abbreviated for convenience. They invite reflective comment on identified aspects of the program.

- Are there any advantages (disadvantages) in using technology instead of pen and paper? Use examples to illustrate how it helps (gets in the way) of learning.
- Are there ways in which you believe technology helps you to think differently e.g., ways of approaching unfamiliar problems or an investigation?
- Are there benefits in students presenting their calculator work to the class via a viewscreen and OHP? Benefits for presenter? For class? For teacher?
- Does using technology change the teacher's role in the classroom? In what way(s)?
- Which description best fits the way you use technology in the classroom?

### *Extended Taxonomy*

Responses were initially categorised into one of the four overarching metaphors by matching the response to the descriptor of a relevant metaphor. The partitioned responses were then re-examined leading to the emergence of the sub-categories described below. Examples deemed to represent each position are also presented.

*Technology as Master*. Students' responses indicated that their relationship with technology was one of subservience in some way for the following reasons. Firstly, a lack of skills with technology being used could restrict their capacity to make progress with a task that requires the use of some facility. The manipulation of large matrices, for example, is very difficult using pen and paper methods alone and a lack of facility with the matrix module on a graphics calculator would restrict a student's progress on such a problem. Secondly, students' comments indicated that there was a danger of developing a dependence on technology that supplanted the need to understand the underlying mathematical process. This reflects the concern, expressed by educators, that the use of technology can be simply a "black box" approach to the study of mathematics. Thirdly, the input and output conventions (syntax) used by different technologies were identified as a negative influence on students' confident use of calculators and computers. Each of these sub-categories appears below together with an example of a representative student comment.

*Lack of Technology Skills*
- Technology can also cause confusion if you are not competent enough with the machine to understand why it may make mistakes
*Mathematical Dependence*
- Some times you can rely on it too much. And then not understand the full process
*Unfamiliar Conventions*
- Technology can often confuse the issue because it uses different conventions and symbols than normal

*Technology as Servant*. In this category students identified a range of ways in which technology could be used as a fast reliable replacement for mental or pen and paper algorithms. It should be noted that these are not approaches to technology that transform the task or significantly change how a student attempts to solve a problem. Rather, technology is used to do the task more quickly, more neatly or more efficiently rather than more creatively. The only possible exception to this description is the final sub-category of *checking answers* as students were often observed working interactively with the calculator over a series of checks adjusting their initial solutions on the basis of the output they received from the technology. While students are essentially using technology as a *servant* in this case there is a sense of partnership in the way they progress toward a solution. Operating with technology in this way may well be an indicator that the student is in transition to using technology at a more sophisticated level. Sub-categories with representative examples appear below.

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| *Looking after large calculation and tedious repetitive methods*<br>- It gives you something to blame when things go wrong. It does all the small calculations you can't be bothered to do.<br>*Performs Calculation more Quickly and Efficiently*<br>- I much prefer technology because of its efficiency. The work can be done much quicker.<br>*Reduces Errors in Calculation*<br>- less chance of error in calculations<br>Presentation<br>- Displays everything in a neater and more succinct manner. You can illustrate eqns graphs etc.<br>*Checking Answers*<br>- When graphs or functions are needed or to check answers of $\int$ or derivative |

*Technology as Partner*. Responses in this category indicated that student's believed there were four different ways that technology assisted them in approaching mathematical tasks. These sub-categories describe the capacity technology provides to look at a problem in a different way or to transform the task so that it becomes more approachable. Further, there was acknowledgment of the role technology can play in scaffolding a student through a task even when they lack a particular pen and paper skill. This was sometimes observed, for example, when students were challenged by a problem in which algebraic facility was required but was not the focus of the task. Students who were not strong users of algebra were sometimes able to achieve success through the use of the symbolic manipulation system available on their calculators for the part of the task that required such facility.

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| *For Exploration and Different Perspectives*<br>- With the learning of integration and differentiation, the seeing of the examples graphically helps understand the whole concept, and thus makes you think on a wide scale (graphically and manually) when doing a problem.<br>*Looking after Cognitive Load*<br>- Yes – it quite often helps to simplify steps in a complex problem<br>*Facilitating Understanding eg via Visualisation*<br>- The study of chaos theory would have been virtually impossible as the graphs enable us to visualise the functions more clearly<br>- *The computers inhibit visualisation*<br>*Scaffolding*<br>- Can do problems that I usually cannot do myself because of lack of basic skills |

An interesting counterpoint to the generally positive responses to the deployment of technology in this classroom was the student response that states computers inhibit visualisation. This is perhaps a reference to the previously mentioned concern that acquisition of skills can be retarded if technology is used exclusively to perform a task, that is, if technology is used to replace a skill instead of being used to amplify a skill already developed by an individual.

*Technology as Extension of Self*. While the sub-categories within this metaphor received relatively low frequencies of response (2 each) this shouldn't be surprising as this represents the highest level of function within the taxonomy. These sub-categories represent the level of operation described by Templer, Klug and Gould (1998) and others who have advocated that the genuine promise of working with technology lies in the potential for students to explore and investigate new mathematical ideas and concepts. This is firstly by expanding a student's repertoire of available cognitive resources that now include the use of technology. Further, technology also offers students the opportunity of exploring, more freely, conjectures that are the product of their intuition. There is again, however, an interesting counterpoint by way of the second comment under the sub-category of *mind expander*. The student in this case reminds us that, ultimately, potential uses of technology are only limited by the creativity of the human mind and that this cannot be replaced by technology alone.

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| *Mind Expander*<br>- Technology allows you to expand ideas and to do the work your own way.<br>- Think differently? No – act differently yes. To work out unfamiliar problems you must first figure out what type of process you need to solve it, then execute the process. What you use is irrelevant<br>*Freedom*<br>- You have much more freedom. |

## Conclusion

Goos and Cretchley (2004) in a review of research on the use of computers and other non-calculator technologies in mathematics education argue:

> If technology is assumed to change the nature of classroom learning environments, the awareness of students' attitudes towards technology becomes a central concern in evaluating the impact of computers on learning

The extension of the metaphors of *master*, *servant*, *partner*, and *extension of self*, proposed here, is intended to capture some of the diversity of students' attitudes toward, and perceptions of, their interactions with electronic technology within the context of a mathematics classroom.

While it has been observed that it seems natural for teachers to use new technologies such as graphing calculators and overhead projection panels in ways that are consistent with preferred teaching methods (Goos & Geiger, 2000), students' responses in this study indicate that electronic technologies are not passive or neutral objects in the learning/teaching process. Rather, at least some students perceive these technologies as interactive tools with the potential to transform tasks and their own actions in relation to how they seek both solutions and understanding. Implicit in this view are a number of challenges for teachers, none-the-least of which includes attention to the pedagogical issues that will allow the accommodation of student driven approaches to learning. It seems that this is an essential prerequisite for students to be afforded the freedom to explore new ideas and concepts in mathematics in unanticipated, *emergent* ways. To meet this challenge a clearer understanding must be developed of the ways in which students can make creative uses of technology and the learning environments in which such approaches can be fostered. The analysis in this paper highlights students' perceptions in the subtleties that exist in the interaction between technology and the learning/doing of mathematics.

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