Development of an Instrument for Ways of Using Graphics Calculators: Preliminary Findings

Hazel Tan
Monash University
<Hazel.Tan@education.monash.edu.au>

This paper describes the development of an instrument aimed at measuring senior secondary students' ways of using graphics calculators as part of a larger study investigating the students' learning styles and their ways of learning and using the graphics calculators. The instrument uses the framework of four metaphors of technology use (Geiger, 2005): Master, Servant, Partner and Extension of Self. Preliminary findings of a pilot study involving 178 senior secondary students from Singapore are discussed.

Background

In Australia and elsewhere, graphics calculators have become an integral part of the national mathematics curriculum (e.g., Penglase & Arnold, 1996; Wong, 2003). Graphics calculator use has also been allowed in some high-stakes assessment used to determine students' entrance into university (e.g., the Victorian Certificate of Education); they have recently been introduced for student use in Singaporean examination courses. So there is a strong impetus to study the effects of graphics calculators for mathematics on a large scale.

Although there have been many studies on the use of graphics calculators for the teaching and learning of mathematics, some researchers have highlighted the pitfalls of overestimating "the degree of agency that a technological artefact may have" (Lynch, 2006, p. 32), and for not looking at the context in which the technologies are being used (e.g., Lynch, 2006; Penglase & Arnold, 1996). In particular, Penglase and Arnold (1996) cautioned that graphics calculator studies should "distinguish between the role of the tool from that of the instructional process" (p. 58) so that they do not become simply program evaluations. It is in this light that an instrument to measure students' ways of using graphics calculators was developed and administered to a sample of Singaporean students. Since the purpose was to develop a survey instrument for a large scale study, the instrument could not be too specific with respect to the use of particular mathematics topics or teaching instances. The challenge and aim of this study was to develop a measure of graphics calculator use that was meaningful and, at the same time, referred to the general ways of using them with which educators and students could identify.

Literature Review

While there are several instruments measuring students' attitudes and confidence in mathematics and technology use (e.g., Fogarty, Cretchley, Harman, Ellerton, & Konki, 2001), there are very few instruments measuring the way that students use technology, in particular, the graphics calculator.

Some studies on how students use technology are topic specific (e.g., Brown 2005, on affordances that technology provides when students learn functions) or technology specific (e.g., Lee & Hollebrands 2006, using Java). Table 1 shows a summary of some models of technology use in mathematics education, together with comments on the relevance of the model to developing an instrument for investigating graphics calculator use.

In R. Hunter, B. Bicknell, & T. Burgess (Eds.), *Crossing divides: Proceedings of the 32nd annual conference of the Mathematics Education Research Group of Australasia* (Vol. 2). Palmerston North, NZ: MERGA.

Table 1
Models of Using Technology in Mathematics Education

Models of technology use in mathematics education	Comments on relevance
Doerr and Zangor (2000): Found five patterns and modes of graphics calculator use: computational tool, transformational tool, data collection and analysis tool, visualizing tool, and checking tool. Results suggest "that nature of the mathematical tasks and the role, knowledge and beliefs of the teacher influenced the emergence of such rich usage of the graphing calculator" (p. 143).	Different types of tool use might be used more in certain topics; hence the modes might be more suitable for detailed investigations rather than a generalised instrument.
Goos, Galbraith, Renshaw, and Geiger (2000): Developed four metaphors to describe the roles of technology used by teachers and students: technology as Master, Servant, Partner and Extension of Self. Geiger (2005) divided the metaphors further into sub-categories on students' use of technology.	The metaphors can be used to describe both teacher and student use, and the sub-categories can be used as items in an instrument.
Kutzler (2003): Developed a "two-level framework for understanding, categorizing, and planning the use of technology" (p. 53), particularly computer algebra systems (CAS). The first level is how CAS can support teaching and learning: automation and compensation. The second level is pedagogical approaches: trivialization, experimentation, visualization, and concentration (p. 53).	Although there are some examples of students' use and teaching approaches, they are more related to pedagogical uses rather than usage from students' perspectives.
Lee and Hollerbrands (2006): Categorised features of a java applet into four sub-categories: "features over which user does not have any control and remain static, dynamic features that allow users to directly manipulate objects, dynamic features that update to provide feedback to users during problem solving, and features that activate parts of the applet" (p. 252). They investigated patterns in the features used to support the six problem solving goals: analysis, planning, implementation, assessment, verification, and organisation.	The features are specific to the java applet and are not as suitable for graphics calculators.

The four metaphors framework developed by Goos, Galbraith, Renshaw & Geiger (2000) was chosen to be adapted into an instrument for several reasons. First, Goos et al's. (2000) theoretical orientation lends itself to the development of a large scale survey instrument for students. They addressed "technology usage as an integral component of the learning environment" (p. 306) rather than investigating "the effects of different instructional strategies (both with and without technology) and teacher attitudes towards technology" (pp. 305-306). Second, the metaphors cover the roles of technology in a broad and logical manner. The model is not topic specific and adequately covers various uses of the graphics calculator. Although the metaphors represent increasing levels of sophistication, this does not mean that, once attained, students will always use the higher levels for all tasks. Rather, a higher level of sophistication of use indicates an "expansion of a technological repertoire where an individual has a wider range of modes of operation available to engage with a specific task" (p. 370). Hence students' responses to items based on the four metaphors could give an indication of the extent of use represented by each metaphor, and would provide a richer description of student use than by aggregating calculator use at a given level. Third, since the metaphors and sub-categories were grounded in students' responses (Geiger, 2005), it is relatively easy to transform them into items to include in an instrument. Table 2 outlines the four metaphors framework presented by Geiger (2005), describing the ways students made use of technology.

Table 2
Four Metaphors of Technology Use by Students

Metaphor	Description
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. Sub-categories: lack of technology skills, mathematical dependence, unfamiliar conventions.
Technology as Servant	Here technology is used 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. Sub-categories: looking after large calculation and tedious repetitive methods, performs calculation more quickly and efficiently, reduces errors in calculation, presentation, checking answers.
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 student verbalise their thinking in 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. Sub-categories: for exploration and different perspectives, looking after cognitive load, facilitating understanding e.g., via visualisation, scaffolding.
Technology as 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. Sub-categories: mind expander, freedom.

Adapted from Geiger (2005, p. 371).

Methodology

The findings of a pilot study that is part of a larger study on students' learning styles and their ways of using graphics calculators (GC) are presented in this paper. When complete, the results of the main study will be reported elsewhere.

Based on the selected framework, a survey instrument was developed with the items taken from the descriptions of the students' calculator use representing each of the four metaphors, and from Geiger's original questionnaire used in his study. These descriptions were modified into survey items that corresponded to the sub-categories found by Geiger (2005). For an example, the representative student comment for GC as Master category and sub-category "Lack of Technology Skills" was "Technology can also cause confusion if you are not competent enough with the machine to understand why it may make mistakes" (p. 373). This was adapted into the survey item statement "I do not know why sometimes the GC does not give me the answer that I want" and coded according to category (e.g., M1 to M3 for GC as Master). A 5-point Likert-type response format, from "Strongly Agree" to "Strongly Disagree", was used for all items.

Table 3
Items According to Metaphors (Adapted from Framework by Geiger, 2005)

Metaphors	Sub-category	Item
GC as Master	Lack of technology skills	(M1) I do not know why sometimes the GC does not give me the answer that I want.
	Mathematical dependence	(M2) I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.
	Unfamiliar conventions	(M3) I find GC confusing because it uses different conventions and symbols than normal maths.
GC as Servant	Reduces errors in calculation	(S1) I use GC for basic calculations because it is more accurate than working by hand.
	Performs calculation more quickly and efficiently	(S2) I use GC for calculations because it is faster than working by hand.
	Looking after large calculation and tedious repetitive methods	(S3) I use GC to look after large calculations and tedious repetitive methods.
	Presentation	(S4) I copy the graphs on the GC in my answers because they are more accurate than drawing by hand.
	Checking answers	(S5) I usually use GC to help me check my answers.
GC as Partner	Scaffolding	(P1) I use GC to solve problems that I usually cannot do by hand.
	Looking after cognitive load	(P2) I use GC to help me simplify steps in a complex problem.
	Different perspectives	(P3) I use GC to help me look at the same problem or concept in different ways (e.g., using graphs and tables to understand the process of differentiation in addition to algebraic method).
	Facilitating understanding	(P4) GC helps me understand concepts better.

Metaphors	Sub-category	Item
GC as Extension of Self	Freedom	(E1) I often use GC to explore maths even before the teacher tells me to.
	Mind Expander	(E2) GC allows me to expand my ideas and to do the work my own way.

Fourteen items were created based on the sub-categories of Geiger's (2005) four metaphors of technology use. The items were then reviewed by a panel of 3 teachers and 7 students from Singapore who were asked to comment on any phrasing ambiguities and on the appropriateness of the items. Items were modified based on the comments received. The final version of the instrument, shown in Table 3, formed part of a larger set of items tapping other dimensions of interest for the main study. The instrument was piloted from October 2008 to January 2009 with students in one pre-university (junior college) in Singapore via an anonymous online survey, and another junior college via a pen-and-paper survey. The first junior college is considered above average amongst the 17 junior colleges in Singapore, whereas the second college is considered below average.

Analysis and Discussion

There were 178 Singaporean students (95 females, 83 males) who completed the survey, including 5 students who did not answer some of the 14 items. The data from students whose responses to each item were identical were excluded from the analyses. Statistical analyses were conducted using the SPSS Graduate Pack 16.0. It must be taken into account that the small sample size (< 300) limits the generalisability of the findings (Tabachnick & Fidell, 2001). Pallant (2001) cited the use of the Kaiser-Meyer-Olkin measure of sampling adequacy and the Bartlett's test of sphericity to assess the factorability of the data. For this sample, the Kaiser-Meyer-Olkin measure was 0.716, which was more than the minimum recommended value of 0.6 (Tabachnick & Fidell, 2001), and the Bartlett's test of sphericity yielded significance ($p < 0.001$, $df = 91$, approx. $\chi^2 = 667.495$), suggesting that the use of exploratory factor analysis in this study was still appropriate.

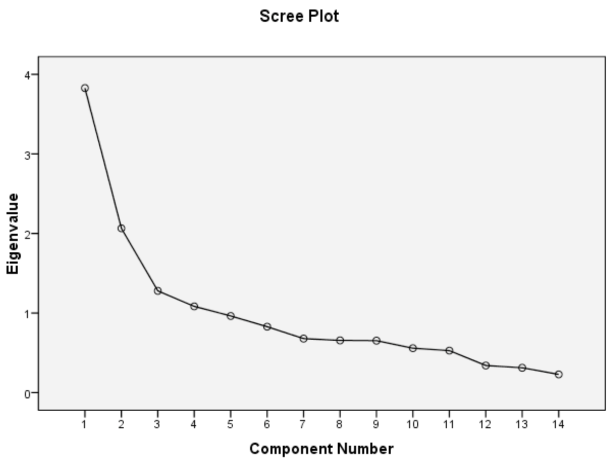

Figure 1. Scree plot showing four eigenvalues > 1.

The solution of the initial exploratory factor analysis using principal components extraction and varimax rotation, revealed four orthogonal components accounting for 59.0% of variance. The scree plot for the initial exploratory factor analysis is shown in Figure 1, and shows that there were four eigenvalues > 1. The original rotated component matrix, with factor loadings less than 0.3 removed (Pallant, 2001), is shown in Table 4.

Inspection of the four components indicated that the first component seemed to be made up of GC as Extension of Self and GC as Partner items, component 2 of GC as Partner and GC as Servant items, component 3 of GC as Master items, and component 4 of GC as Servant items. Item P1 was the only GC as Partner item loading on component 2, and item S5 had loadings across components 1, 2 and 3. Item S3 also loaded across components 2 and 4, both of which are comprised of GC as Servant items. This suggested the possibility of a three component solution rather than four. An examination of the scree plot (Figure 1) also indicated this three component possibility, as a straight line can roughly be drawn through the first three points before levelling off (Tabachnick & Fidell, 2001).

Cronbach-α reliability coefficients for the originally hypothesised subscales were found to be: GC as Master (0.542), GC as Servant (0.677), GC as Partner (0.675), and GC as Extension of Self (0.792). Although the reliability coefficients for GC as Master, Servant, and Partner are less than the ideal of 0.7, Pallant (2001) cited the possibility of low Cronbach-α values (e.g., 0.5) due to short scales of fewer than 10 items, as was the case here. Schmitt (1996) also argued that “there is no sacred level of acceptable or unacceptable level of alpha. In some cases, measures with (by conventional standards) low levels of alpha may still be quite useful” (p. 353).

Elimination of poorer performing items was conducted through an iterative process of examining the inter-item correlations, Cronbach-α values if items were removed, the communalities, and the solutions generated by factor analysis with varimax rotation. The solutions were also compared with the theoretical four metaphor model for consistency. The final solution, with P1 and S5 were removed, has three orthogonal components accounting for 53.8% of the total variance – see Table 4 for final rotated component matrix.

Table 4
Rotated (Varimax) Component Matrices Before and After Removing Items P1 and S5

	Component (original)				Component (final)		
	1	2	3	4	1	2	3
(E2)[1]	0.852				0.786		
(P3)	0.688				0.780		
(P4)	0.661				0.742		
(E1)	0.777				0.714		
(P2)	0.567				0.565		
(P1)		0.734					
(S5)	0.347	0.567	-0.366				
(S2)				0.770		0.810	
(S1)				0.812		0.773	
(S3)		0.620		0.398		0.651	

(S4)	0.635		0.515	
(M2)		0.743		0.778
(M3)		0.730		0.747
(M1)		0.602		0.553

[1] For wording of items, see Table 3.

In this second factor analysis, only three components corresponding to the four metaphors emerged; items representing the metaphors GC as Partner and GC as Extension of Self loaded onto a single factor. This may be due to the relatively small sample size that may not have included students working at the most sophisticated level with the calculators. Another possible explanation might be the short timeframe of one year since Singaporean students began using graphics calculators, and that they may not yet have reached this most sophisticated level of use. In his study, Geiger (2005) noted only two responses at the level of Technology as Extension of Self.

Overall, the pilot testing of the instrument indicated that the instrument was valid and fairly reliable. Based on the new 3-component model, the Cronbach–α values for the subscales were 0.788 (GC as Partner and Extension of Self), 0.664 (GC as Servant), and 0.542 (GC as Master). Based on the 12 remaining items, mean scores for each category were calculated for males and females, and independent t-tests conducted to explore for gender differences. It was found that although males scored lower ($\bar{x} = 3.18$) on GC as Master than females ($\bar{x} = 3.30$), the difference was not statistically significant ($p < 0.05$). Males had higher mean scores for GC as Servant ($\bar{x} = 3.89$) than females ($\bar{x} = 3.75$); again the difference was not statistically significant. However, there was a statistically significant difference in the mean scores for GC as Partner and Extension of Self: ($\bar{x}_{MALE} = 3.22$, $\bar{x}_{FEMALE} = 2.94$, $p < 0.01$). This suggests that males tended to rate themselves higher with respect to the levels of sophistication of GC use, consistent with previous research on gender and technology use for mathematics (e.g., Vale & Bartholomew, 2008).

Further study is necessary to increase the validity and reliability of the instrument. Data from a larger sample will be collected when the survey is administered in the main study to students from more schools. A case study is also planned for the main study to examine in greater depth students' use of graphics calculators in the classroom context.

Acknowledgements

I would like to acknowledge the guidance, support and contributions of my supervisor, Associate Professor Helen Forgasz of Monash University, in the planning and development of the study, as well as in the preparation of this paper.

References

Brown, J. P. (2005). Identification of affordances of a technology-rich teaching and learning environment. In H. L. Chick & J. L. Vincent (Eds.), *Proceedings of the 29th annual conference of the International Group for the Psychology of Mathematics Education* (Vol. 2, pp. 185-192). Melbourne: PME.

Doerr, H. M., & Zangor, R. (2000). Creating meaning for and with the graphing calculator. *Educational Studies in Mathematics, 41*(2), 143-163.

Fogarty, G., Cretchley, P., Harman, C., Ellerton, N., & Konki, N. (2001). Validation of a questionnaire to measure mathematics confidence, computer confidence, and attitudes towards the use of technology for learning mathematics. *Mathematics Education Research Journal, 13*(2), 154-160.

Geiger, V. (2005). Master, servant, partner and extension of self: A finer grained view of this taxonomy. In J. P. Clarkson, A. Downton, D. Gronn, M. Horne, A. McDonough, R. Pierce, & A. Roche (Eds.), *Building connections: Research, theory and practice.* (Proceedings of the 28th annual conference of the Mathematics Education Research Group of Australasia, Melbourne, pp. 369-376. Melbourne: MERGA).

Goos, M., Galbraith, P., Renshaw, P., & Geiger, V. (2000). Reshaping teacher and student roles in technology-enriched classrooms. *Mathematics Education Research Journal, 12*(3), 303-320.

Kutzler, B. (2003). CAS as pedagogical tools for teaching and learning mathematics. In J. T. Fey, A. Cuoco, C. Kleran, L. McMullin, & R. M. Zblek (Eds.), *Computer algebra systems in secondary school mathematics education.* (pp. 53-71). Reston, VA: National Council of Teachers of Mathematics.

Lee, H. S., & Hollebrands, K. F. (2006). Students' use of technological features while solving a mathematics problem. *Journal of Mathematical Behavior, 25*, 252-266.

Lynch, J. (2006). Assessing effects of technology usage on mathematics learning. *Mathematics Education Research Journal, 18*(3), 29-43.

Pallant, J. (2001). *The SPSS survival manual: A step-by-step guide to data analysis using SPSS for Windows (version 10)*. St Leonards, NSW: Allen & Unwin.

Penglase, M., & Arnold, S. (1996). The graphics calculator in mathematics education: A critical review of recent research. *Mathematics Education Research Journal, 8*(1), 58-90.

Schmitt, M. (1996). Uses and abuses of coefficient alpha. *Psychological Assessment, 8*(4), 350-353.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics*. MA: Allyn & Bacon.

Vale, C., & Bartholomew, H. (2008). Gender and mathematics: Theoretical frameworks and findings. In H. Forgasz et al. (Eds.). *Research in mathematics education in Australasia 2004-2007,* (pp. 271-290). Rotterdam, The Netherlands: Sense Publishers.

Wong, N.-Y. (2003). The influence of technology on the mathematics curriculum. In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Second international handbook of mathematics education* (pp. 271-321). Dordrecht: Kluwer Academic Publishers.