STUDENTS' WAYS OF USING HANDHELD CALCULATORS IN SINGAPORE AND AUSTRALIA: TECHNOLOGY AS MASTER, SERVANT, PARTNER AND EXTENSION OF SELF

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Students' ways of using handheld calculators were investigated and compared on a sample of 964 Singaporean and 176 Victorian (Australia) senior secondary students. A survey instrument was developed based on four metaphors of technology use proposed by Geiger (2005): Master, Servant, Partner, and Extension of Self. Factor analysis found three factors: Master, Servant, and combined Partner and Extension of Self. Victorian students were found to have significantly lower scores on calculator as Master and as Servant, compared to Singaporean students. Males in both regions exhibited higher fluency of calculator use, compared to females.

Background

Handheld calculators such as the graphics calculator (GC) and calculators with computer algebra system (CAS) play an important role in secondary mathematics education (Wong, 2003). The GC and CAS calculators have been used in high stakes examinations at senior secondary levels in different parts of the world. In Victoria, Australia, the GC has been allowed in mathematics subjects in the Victorian Certificate of Examinations (VCE) since 1997 (Routitsky & Tobin, 1998), and currently CAS calculators are allowed in some examinations for year 12 VCE mathematics subjects (Victorian Curriculum and Assessment Authority [VCAA], 2010). In Singapore, GC use has been implemented in all the mathematics subjects at General Certificate of Examinations Advanced-level curriculum since 2006 (Wong & Lee, 2009). With the large number of senior secondary students taking mathematics examinations each year, research on handheld calculators is crucial in benchmarking and investigating the impact of the technology on mathematics teaching and learning.

The theoretical framework, instrument developed, and a report of the analysis and findings are described in the following sections.

Theoretical framework

While there have been a number of instruments developed to find out about students' attitudes towards the use of technology in mathematics education (e.g., Pierce, Stacey, & Barkatsas, 2007), there are few that measure students' ways of using technology. In order to enable investigations into students' use of technology in a broad and systematic

manner, without tying the technology use to specific topics or specific instructional strategies, an instrument was developed which drew upon the four metaphors framework originally developed by Goos, Galbraith, Renshaw and Geiger (2000). Grounded in socio-cultural models of learning, Goos et al. (2000) theorised that technologies are cultural tools and their use is "actively re-shaping human interactions and interactions between humans and the technology itself" (p. 318), thereby transforming the learning process. They posited four roles for technology in the teaching and learning context: technology as Master, Servant, Partner, and Extension of Self (MSPE). Geiger (2005) further refined the metaphors into subcategories with representative student descriptions. These descriptions were then modified into the survey items (see Tan, 2009) used in this study. An outline of the metaphors is shown in Table 1. Geiger (2005) noted that while the MSPE metaphors represent increased levels of complexity of technology use, they correspond to an expansion in the "technological repertoire where an individual has a wider range of modes of operation available to engage with a specific task" (p. 370), and not to a hierarchy of stages of use where an individual abandons one level to progress to another. Hence a student who is proficient in using technology as a Partner might use technology as a Servant for certain mathematical tasks such as menial computation, when required.

Table 1. MSPE framework of technology use by students.

Metaphor	*Description*
Technology as Master	The student is subservient to the technology – a relationship induced by technological (limited operations used) or mathematical dependence (blind consumption of whatever output generated, irrespective of accuracy and worth).
Technology as Servant	Technology is used as a reliable timesaving replacement for mental, or pen and paper computations. Student "instructs" the technology as an obedient but "dumb" assistant.
Technology as Partner	Students often appear to interact directly with the technology, 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.
Technology as Extension of Self	Students incorporate technological expertise as an integral part of their mathematical repertoire. Technology is used to support mathematical argumentation as naturally as intellectual resources.

Adapted from Geiger (2005, p. 371)

Research questions

1. How are Singaporean and Victorian students using handheld programmable calculators, with respect to the MSPE framework?
2. Are there differences among students from the two regions?
3. Are there any gender differences?

Methods

A survey instrument was developed based on the MSPE framework and piloted with 178 Singaporean senior secondary students (Tan, 2009). For the main study, a different group of Singaporean mathematics students (N=964) and 176 Victorian students taking the VCE mathematical methods subject participated.

An online survey was created using SurveyMonkey (http://www.surveymonkey.com) in two versions; the words "calculator" referring to "GC" for Singaporean students and to "CAS calculators" for Victorian students. Recruitment was carried out through schools via invitation emails in 2009–2010. There were three phases in the collection of Victorian data: (1) 110 schools from the Government, Catholic and Independent sectors were invited to participate; only two independent girls' schools and one Catholic boys' school participated; (2) 20 Independent schools (3 girls', 2 boys', 15 co-ed) were invited to forward invitation emails to their students; (3) an advertisement was created using Facebook (http://www.facebook.com) to invite more Victorian students to participate in the study (Tan, 2010).

The instrument consists of 12 positively worded items using 5-point Likert response formats, ranging from 1 (Strongly disagree) to 5 (Strongly agree). The items are shown in Table 2. Factor analysis was conducted using the software PASW Statistics 18.0 (SPSS) to investigate the underlying factors, based on the MSPE theory for both data sets.

Analysis and discussion

There were 964 Singaporean students (37.1% males, 62.9% females), and 176 Victorian students (31.3% males, 68.8% females). Higher percentages of females than males responded to the online survey in both regions. For the Victorian data, more independent girls' (n=6) than boys' (n=3) schools were invited to participate in the study in phases 1 and 2 as there were more Independent girls' (24) than boys' (14) secondary schools in Victoria (http://www.independentschools.vic.edu.au/); this partially explains the higher percentage of female participants. Similar numbers of female (29) and male (30) Victorian students responded through Facebook. In contrast, all four participating Singaporean schools were co-ed. In 2009, there were more female (55.5%) than male senior secondary students in Singaporean junior colleges (Ministry of Education, 2010), likely to be replicated among the participating schools. Research also indicates that girls are more likely than boys to respond to invitations issued via schools (e.g., Porter & Whitcomb, 2005).

It must be noted that the small sample size of Victorian data (< 300) and the high percentage of Independent school students (73.9%) limit the generalisability of the Victorian findings.

Factorability of the data was assumed since the Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy (KMO_{Vic}= 0.680 and $KMO_{S'pore}$= 0.763) were more than 0.6 (Tabachnick & Fidell, 2001), and Bartlett's tests of sphericity yielded significance (χ^2_{Vic} (66)= 404.5, $\chi^2_{S'pore}$ (66)= 3202.8; p<0.001). Initial factor analyses using the Kaiser criterion of eignenvalues > 1 (Pallant, 2001) resulted in a four-factor solution for Victorian data and a three-factor one for Singaporean data. Inspection of the scree plots justified the use of three-factor solutions to explore both data sets. Principal factors extraction (principal axis factoring) with Varimax rotation and Kaiser normalisation was performed on the items specifying three-factor solutions, accounting for 43.9% of total variance for the Victorian data and 46.8% for the Singaporean data. The rotated factor matrices with factor loadings less than .3 removed (Pallant, 2001) are shown in Table 2.

As seen in Table 2, the factors matched the MSPE metaphors, with items for Partner and Extension of Self combined as one factor (henceforth referred to as "Technology as

Collaborator"), consistent with the pilot study results (Tan, 2009). The factors are labelled Tech_Master, Tech_Servant and Tech_Collaborator. The cross-loadings in the Victorian data for items M1 and P2 are still consistent within the theoretical framework of increasing levels of sophistication of technology use.

Table 2. Rotated factor matrices for Victorian and Singaporean data.

	Victorian			Singaporean		
Factors	1	2	3	1	2	3
(M1)* I do not know why sometimes the calculator does not give me the answer that I want.		.40	.50			.60
(M2) I usually just follow the steps taught when using the calculator to solve problems, and do not really understand the maths involved.			.75			.68
(M3) I find calculators confusing because it uses different conventions and symbols than normal maths.			.72			.71
(S1) I use the calculator for basic calculations because it is more accurate than working by hand.		.59			.71	
(S2) I use the calculator for calculations because it is faster than working by hand.		.70			.89	
(S3) I use the calculator to look after large calculations and tedious repetitive methods.		.72			.55	
(S4) I copy the graphs on the calculator in my answers because they are more accurate than drawing by hand.		.42			.30	
(P2) I use the calculator to help me simplify steps in a complex problem.	.68	.33		.59		
(P3) I use the calculator 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).	.62			.75		
(P4) The calculator helps me understand concepts better.	.53			.68		
(E1) I often use the calculator to explore maths even before the teacher tells me to.	.43			.63		
(E2) The calculator allows me to expand my ideas and to do the work my own way.	.64			.76		

* Items developed according to MSPE framework (Tan, 2009).

Cronbach–α values were calculated to assess the internal reliability of the items for each of the three subscales: Tech_Master (α_{Vic}= 0.686; $\alpha_{S'pore}$= 0.714), Tech_Servant (α_{Vic}= 0.703; $\alpha_{S'pore}$= 0.699), and Tech_Collaborator (α_{Vic}= 0.735; $\alpha_{S'pore}$= 0.819). Although for the Victorian data the Cronbach–α value was less than the ideal of 0.7, it was still reasonable (Pallant, 2001). For the two data sets, performing the same factor analysis procedures produced the same factor solution consistent with the theoretical framework. This confirms the stability of the factors, and the validity and reliability of the instrument, allowing for comparisons between the two groups of students to be undertaken.

Subscale scores were calculated using the average score of all items within each factor, reduced to the range 1 to 5 for ease of interpretation. Table 3 shows the results of

comparisons of the mean subscale scores by region and gender, using t-tests (except where otherwise indicated).

Table 3. Regional and gender comparisons: N, mean scores, standard deviations, test statistics, and p-values.

Factor	*Region*	*Mean (SD)*	*test statistic, p value*	*Gender*	*Valid N*	*Mean*	*SD*	*test statistic, p value**
Tech_Master	Singapore	3.189 (0.801)	t (1051) = 5.341, p<0.001	Female	586	3.235	0.775	t (930)=2.308, p<0.05
				Male	346	3.110	0.840	
	Victoria	2.771 (0.860)		Female	98	2.871	0.840	U=751.5, p<0.05
				Male	23	2.348	0.832	
Tech_Servant	Singapore	3.777 (0.659)	t (140.2) = 2.793, p<0.01	Female	585	3.750	0.657	NS
				Male	349	3.821	0.661	
	Victoria	3.563 (0.807)		Female	98	3.625	0.836	U=745.5, p<0.05
				Male	22	3.284	0.599	
Tech_ Collaborator	Singapore	3.034 (0.733)	NS	Female	579	2.964	0.691	t (641.9)= -3.781, p<0.001
				Male	341	3.152	0.786	
	Victoria	3.058 (0.766)		Female	99	3.022	0.724	NS
				Male	23	3.218	0.934	

* Mann-Whitney U test was used for Victorian gender comparisons.

Comparisons between Victoria and Singapore

As seen in Table 3, Singaporean students generally scored significantly higher for Tech_Master ($\bar{x}_{S'pore}$=3.189, $\bar{x}_{Vic}$=2.771) and Tech_Servant ($\bar{x}_{S'pore}$=3.777, $\bar{x}_{Vic}$=3.563) than Victorian students. This suggests that the Victorian students had higher levels of fluency with handheld programmable calculators than Singaporean students.

There are various possible explanations for these differences, for example a socio-economic factor suggested by the high percentage of Independent school students in the Victorian sample. School-sector differences in student performances have been reported in Australia (e.g., Marks, 2009).

Another explanation may be the differences in the school systems in the two regions:

- With the use of GC allowed in the VCE since 1997, Victorian mathematics teachers may have more experience with teaching the use of programmable calculators and might be better able to mediate students' learning with calculators than Singaporean teachers.
- Most Victorian senior secondary students learn in a classroom structure, using published textbooks, whereas most Singaporean senior secondary students learn in a lecture-tutorial structure, using lecture notes provided by their teachers.
- Victorian secondary schools usually encompass grades 7-12, whereas most Singaporean senior secondary schools consist of grades 11-12 only.

These differences may have advantaged Victorian students with better quality or more consistent teaching and increased exposure to the use of programmable calculators. Since CAS calculators and GCs share a number of similar functionalities and syntax, Victorians may be less likely to use their CAS calculators at the Master level than Singaporean students use their GCs.

For both regions, the mean scores for Tech_Collaborator were not significantly different from the neutral value 3 (S'pore: $t(919)=1.394$, Vic: $t(120)=0.831$; $p>0.1$). This suggests that students use the calculators at this highest level only some of the time, consistent with Geiger's (2005) findings.

Gender differences in how students use calculators

Figure 1 shows the box plots for the three subscales by region and gender. The skewness in the distribution for Tech_Servant for male Victorian students, possibly due to the small sample size, is evident. Hence the non-parametric Mann-Whitney U test was used for the Victorian data (Pallant, 2001) – see Table 3. As shown in Table 3, males had significantly lower mean scores than females for Tech_Master in both regions (S'pore: $\bar{x}_M=3.110$, $\bar{x}_F=3.235$; Vic: $\bar{x}_M=2.348$, $\bar{x}_F=2.871$). Singaporean males also had significantly higher mean scores for Tech_Collaborator than females ($\bar{x}_M=3.152$, $\bar{x}_F=2.964$), with no significant difference for the Victorians.

For Tech_Servant, no significant gender difference was found for the Singaporeans, whereas Victorian males' mean scores were significantly lower than females' ($\bar{x}_M=3.284$, $\bar{x}_F=3.625$). This suggests that Victorian males may be less reliant than females on calculators to replace mental or pen-paper computations; this finding may partially explain the higher percentages of males than females scoring top grades in the calculator-free VCE mathematics examinations (Forgasz & Tan, 2010).

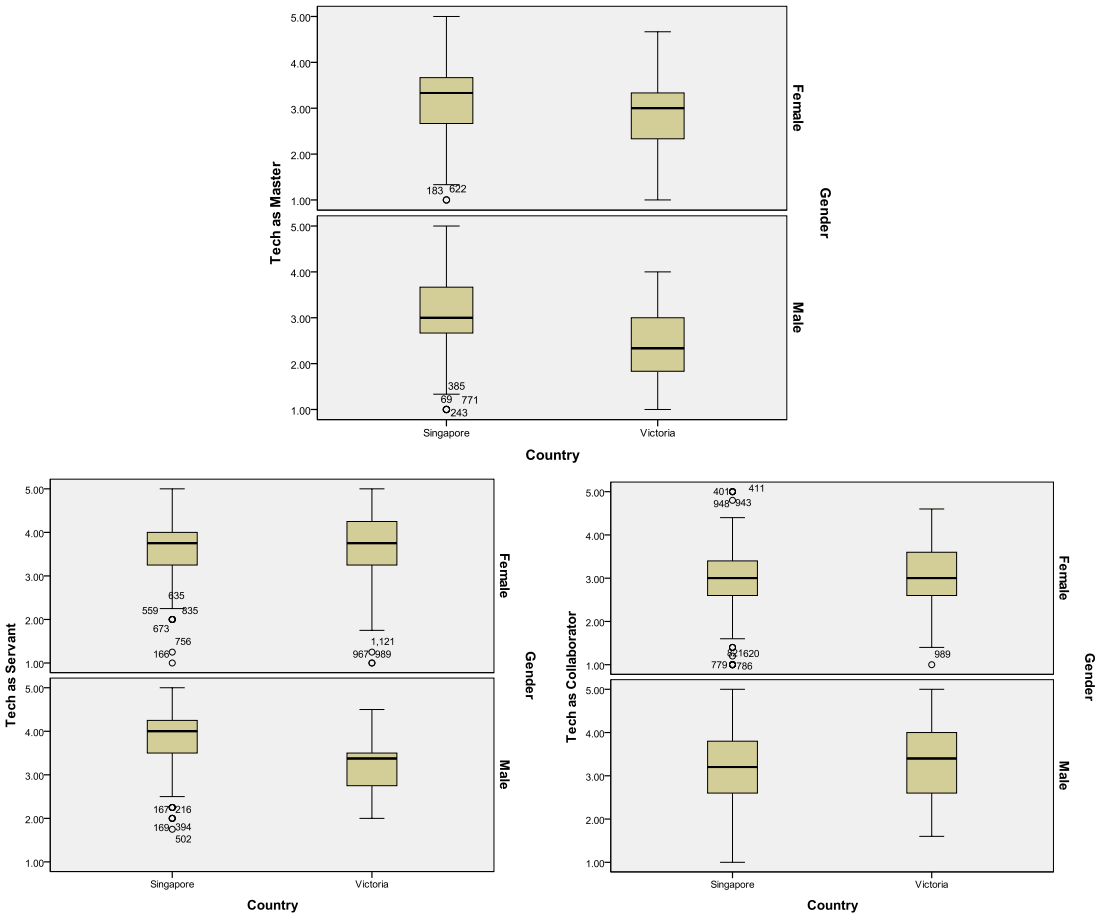

Figure 1. Box plots for Singaporean and Victorian data, grouped by gender.

Conclusion

In conclusion, Victorian students appeared to have greater fluency than Singaporean students with sophisticated calculators, despite the finding of no significant differences at the highest level of calculator use (Tech-Collaborator). For greater generalisability for Victoria in particular, more research is needed with larger samples and broader school sector representation. Gender differences were consistent with past research in that males showed greater mastery of the calculators than females, in both regions. Given that the calculators were used in high-stakes mathematics examinations where the results affect entrance into university courses, these findings call for further research into assessment and instruction to address these gender differences.

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