The Effects of a Portable Computer Algebra System (CAS) on Pre-university Students' Attitudes towards CAS

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Abstract: *The main objective of this study was to investigate the effects of a portable computer algebra system (CAS) on students' attitudes towards CAS. An intact class of second year pre-university (Year 12) students in Singapore participated in this study. The participating students were each given access to a CAS calculator for approximately six months and underwent a CAS Intervention Programme (CASIP). The CAS Attitude Scale (CASAS) was administered on three separate occasions to the participating class to measure students' attitudes towards CAS. The CASAS comprises four subscales of 10 items to measure students' sense of Anxiety, Confidence, Liking and Usefulness in regard to the CAS. Based on paired-sample t-tests, even though the second and third surveys indicated improvement in all four subscales and the overall scale, with the exception of the liking subscale in the first comparison, the results were not statistically significant.*

1. Background

A computer algebra system (CAS) is a software program whose core functionality is to manipulate mathematical objects, such as algebraic expressions, equations, functions, derivatives, integrals, and matrices, in symbolic form. The extent of the symbolic manipulation depends on the type and version of the CAS available. Examples of CASs that operate on a computer platform are Maple, Mathematica (see [1]) and DERIVE (see [9]). In 1996, the CAS was made available for use on handheld devices known as CAS calculators (see [15]) or algebraic calculators. The fundamental difference between CAS and other technologies, such as the graphic calculator, commonly used in mathematics education is that the former can provide symbolic solutions to difficult mathematical problems, such as finding the indefinite integral of a given function or the general solution of a differential equation.

In Singapore, a Junior College (JC) is an educational institution where students undergo two years of education before taking the Singapore-Cambridge General Certificate of Education Advanced Level, or 'A-Level', Examinations. These two years are equivalent to the eleventh and twelfth grades of schooling in nations such as Australia, the U.K. and the U.S., which are a prerequisite for university admission. Generally, a JC student is required to take either three or four principal subjects, known as advanced or A-Level subjects, with the fourth principal subject being optional. At the end of the first year of JC, students take an internal examination known as the JC1 (junior college year 1) Promotional Examination to determine their promotion to JC2 (junior college year 2). Towards the end of JC2, the students take an internal examination known as the JC2 Preliminary Examinations, prior to taking their G.C.E. A-Level Examinations.

Even though CAS has been in existence since the 1990s, it has not been used as a tool for teaching and learning mathematics in Singaporean schools, with the exception of two studies on the use of CAS among local secondary students (see [10]) and JC students (see [11]). This study aims to find innovative ways of teaching mathematics using the CAS calculator and investigate whether the effects of the use of CAS in the teaching and learning of pre-university mathematics on JC students’ attitudes towards CAS.

This study focused on the use of the Voyage 200 (V200) CAS calculator by Texas Instruments. As a handheld technology, the V200 is more accessible and affordable than desktop computer based technologies and, therefore, has a greater impact on the teaching and learning of mathematics (see [15]).

2. Methodology

2.1 Research Setting

The participating class consisted of 22 students, comprising 10 female and 12 male students. Statistically, it is more desirable to have bigger samples. However, in JCs in Singapore, the average size of each first year class is approximately 25 students. Ordinarily, a number of students will drop out of class during the first year for various reasons, while a few others will be retained in the first year course. As a result, the average class size in the second year is reduced to approximately 20 students or less.

The participating students were from the Science faculty of an average JC in Singapore and had a subject combination of Mathematics, Physics, Chemistry and Economics. They are taught by the second author, who was a male teacher with 20 years of formal teaching experience.

2.2 Procedures and Instrumentation

The CAS Attitude Scale (CASAS) designed by Ng in [9] was used to measure the students’ attitudes towards using the CAS and was administered to the participating class at three different stages during the CAS Intervention Programme (CASIP), the details of which will be provided in Section 2.5. The initial administration of the CASAS was carried out during the first term of the school year after the students completed an introductory session on the V200 CAS calculator and its features. The second administration was conducted about a month later. During this period, students were encouraged to explore on their own the functionality of the V200 calculator. A training session on the use of the V200 calculator was also conducted to introduce more advanced functions of the calculator to the participating students. The second administration was conducted to measure any change in attitude after the participants had learned to operate the V200 calculator. The third and final administration was conducted at the end of the CASIP to measure any further changes in the participants’ attitude towards the CAS after having had a prolonged period of access to the V200 calculator.

2.3 Attitudes towards the CAS

The CASAS is a 40-item questionnaire comprised of 4 subscales of 10 questions to measure students' attitudes towards using the CAS in terms of Anxiety, Confidence, Liking and Usefulness. The CASAS uses a four-point Likert scale, with a higher score indicating a more positive attitude. In particular, a higher score in the Anxiety subscale indicates a lower level of anxiety. Within each subscale, 5 questions are worded positively and the other 5 questions are worded negatively. For the data analysis, the scores for the negatively worded questions are reversed, using the formula $5-x$, where x is the original score. The CASAS instrument was originally field tested in [9] using a sample of 50 pre-service teachers. In the field test, the internal reliability indices and alpha coefficients were adequate for all four subscales and the entire scale. The Pearson correlation coefficients between each of the four subscales and the whole scale were also significant at the 1% level. Thus, the CASAS was validated as a reliable instrument in [9].

2.4 Statistical Analyses

The reliability of the four subscales and the overall scale of the CASAS was measured by Cronbach's alpha. The Pearson correlation test was used to measure the correlations among all four subscales and the overall scale to investigate the interdependence among the different attitudes towards using CAS. Finally, paired sample t-tests were conducted on the four subscales and the overall scale of the three surveys administered to the participating class. These tests were conducted to examine the changes in attitude towards the CAS between the initial introduction to the V200 calculator and just after being taught how to use it, between just after learning how to use the V200 calculator and using it personally, and between the initial introduction to the V200 calculator and using it personally.

2.5 The CAS Intervention Programme (CASIP)

The CASIP, which was designed to investigate the effect of the CAS on students' achievement in mathematics, lasted for six months. One of the key guiding principles of the programme was to demonstrate the usefulness of the CAS calculator. The exercises were designed to guide the students in the participating class towards realizing how they could use the CAS calculator to help solve problems within their syllabus while, at the same time, strengthening their conception and understanding of the topics they were studying.

The design of the CASIP was shaped by several theories. For instance, the CAS calculator was used as a 'black-box' (see [2], [3] and [8]) to generate examples of similar problems in integration techniques, after the students had completed the 'white-box' phase of learning particular concepts and techniques. The calculator was also used as an automation tool (see [5]) to speed up working, for example, in topics like Applications of Integration. With the topic of Differential Equations, the CAS calculator served as a form of scaffolding (see [4], [5] and [8]) for sketching graphs that were beyond the students' level of proficiency. From time to time, the students were baffled by the results produced by the CAS calculator, such as imperfect graphs due to the constraints of screen size and resolution, and surprising results for trigonometric functions that differed from the students' solutions. In this study, the students had to work with and around these constraints as they attempted to complete the exercises. This process is known as instrumentalization (see [6], [12] and [14]). The students were expected to understand how the results produced by the CAS calculator were just as valid as the results they achieved by manually working out the problems. Within this context, the students were guided on how to verify their results using other features of the CAS calculator.

The participating class was given an introductory demonstration of the workings of the V200 CAS calculator, including its graphing features and ability to manipulate algebraic operations. The main focus of the demonstration was the algebra and calculus functions of the V200, such as its ability to differentiate and integrate algebraically, solve differential equations giving general and particular solutions, factorizing polynomials, expanding algebraic expressions, finding partial fractions, and solving equations involving polynomial as well as non-polynomial functions. The students were very impressed with the powerful functions of the instrument, making remarks such as "there is no longer any need to study mathematics."

Each student in the participating class was issued with a V200 calculator. For the training session, the students were each given a copy of an appendix, titled Functions and Instructions, of the V200 Guide Book, which is available online in PDF format (see [13]). The appendix lists the Algebra and Calculus functions of the V200 and the respective pages of the guide book that elaborate the syntax of each function. This served as a convenient reference for the students to look up the guidebook online, which could be downloaded if they needed to clarify the use of a function in the future. In addition, a worksheet was prepared for each student for the training session. In the training session, emphasis was placed on learning how to use the graphing features of the V200 and the functions listed in the Algebra and Calculus menus. The students were given the syntax of each operation and the keystrokes required to obtain the functions. The subtleties of different commands were also covered, such as using or not using parameters, and the differences between real and complex inputs and outputs.

The CASIP was conducted by giving the participating class extra exercises involving the use of the V200 calculator during an additional supplementary weekly lesson. The exercises focused on four areas of the curriculum, namely, Techniques of Integration, Application of Integration, Differential Equations and Complex Numbers. As the students would not be allowed to use the CAS during assessment, it was vital that they mastered the necessary skills required for assessment, such as integrating a given expression, solving differential equations and sketching curves, without becoming overly dependent on using the CAS calculator. Mastering such skills, which is the focal point of the curriculum, requires much practice over an extended period of time. Thus, traditional teaching without the aid of CAS was still essential during the four tutorial periods so that the students in the participating class would not be disadvantaged in the course of the research. However, the students were encouraged to use the V200 calculator during their personal learning and other tutorial periods throughout this period. The V200 calculators remained in the students' possession until the end of the JC2 Preliminary Examinations.

2.6 Exercises on Techniques of Integration

The exercises for use on the V200 calculator were designed to be enrichment activities that went beyond the objectives of the students' routine tutorial exercises. The intention was to encourage the students to explore beyond what they would normally encounter and examine their conceptual understandings a little deeper than they normally would as they engaged in the exercises. This form of exercise is in line with what is termed experimentation in [4]. The aim was for the participating students to discover particular facts through their numerous experiments using the V200 calculator.

In the exercise for Techniques of Integration, a tutorial question on integrating the expression $\frac{1}{\sqrt{10+4x-x^2}}$ was used to explore the use of the V200 calculator. In this exercise, the V200 calculator gave $\tan^{-1}\frac{x-2}{\sqrt{10+4x-x^2}}$ instead of $\sin^{-1}\frac{x-2}{\sqrt{14}}$ as the answer for $\int\frac{1}{\sqrt{10+4x-x^2}}dx$. Observation of the result given by the V200 calculator would give the impression that $\int\frac{1}{\sqrt{ax^2+bx+c}}dx = \tan^{-1}\left(\frac{2ax+b}{2\sqrt{ax^2+bx+c}}\right)+k$. Students were asked to explore this conjecture using the V200 calculator and to eventually narrow down the values of *a*, *b* and *c* for which this statement is true. This verification exercise can be done by hand but is extremely tedious and time-consuming. Moreover, carrying out this exercise by hand without the aid of the V200 calculator was way beyond the students' level of proficiency in integration and differentiation. In addition, the students were asked to differentiate $\tan^{-1}\left(\frac{2ax+b}{2\sqrt{ax^2+bx+c}}\right)$ using specific values of *a*, *b* and *c* to obtain the answer $\frac{1}{\sqrt{ax^2+bx+c}}$. They were asked to specifically try the case where $a=-1$ for which the statement is true and one other value for the constant a in the expression for which it is not true. This exercise follows the Black-Box/White-Box principle (see [2] or [3]) where the students first generate many examples using the V200 calculator as a 'black-box' to determine a conjecture they eventually have to prove.

An area in which students find integration challenging is integrating an expression involving fractions. These expressions are usually in the form of $\frac{f'(x)}{a^2+[f(x)]^2}$, which upon integration gives us $\tan^{-1}\frac{f(x)}{a}+k$. Traditionally, teachers will issue various exercises to familiarize students with the use of the formula $\int\frac{f'(x)}{a^2+[f(x)]^2}dx=\tan^{-1}\frac{f(x)}{a}+k$, by substituting various expressions for $f(x)$. In the CASIP exercises, the participating students were asked to substitute a set of expressions into $f(x)$. They were then asked to substitute any other expressions by themselves. This exercise utilized the power of the V200 calculator as a 'black-box' to generate many examples following the Black-Box/White-Box principle. Without the V200 calculator, this would be too time-consuming to achieve manually. The use of the V200 increased the students' exposure to examples and exercises that would normally not be possible without such an aid.

2.7 Exercises on Applications of Integration

The Applications of Integration exercise focused on one of the students' weakest topics, which was finding the volume of a solid generated through rotating a region about an axis. Normally, students are taught the Disc Method, which uses the formulae "Volume = $\pi\int_a^b y^2dx$" and "Volume = $\pi\int_a^b x^2dy$," but not the Shell Method, which uses the formulae "Volume = $2\pi\int_a^b xydx$" and "Volume = $2\pi\int_a^b xydy$." From time to time, to make the internal and external examinations more challenging, the questions are designed so that they are more difficult to solve using the Disc Method. In fact, however, these questions could have been more easily solved using the Shell Method. For the exercise on this topic, the participating class was taught the Shell Method and two particular questions were set that were extremely difficult to solve using the Disc Method. Solving these two questions required the students using both the Disc Method and the Shell Method. This exercise aimed to help the students realize the difference between the two approaches and to understand which approach was more appropriate under which circumstances. Having access to the V200 calculator, it was less time-consuming for the participating class to explore the questions using both methods. In addition, three questions from the past year's national examinations were also chosen for the participating students to explore using both methods. At this point, the participants were expected to have familiarized themselves with the techniques of integration and the V200 calculator was used as a 'black-box' to handle the integration process that the students have already learned. The V200 was also used in conjunction with the idea of "concentration," (see [5]) where the calculator removed the burden of integration from the exercise and allowed the participants to concentrate on the aspect of applying integration to find the volume of a generated solid. Our experiences have found that students are traditionally weak in this area because it encompasses two of their main areas of weakness in mathematics, sketching graphs and integration. This also fits the concept of scaffolding (see [4] or [5]), in that the participants were able to build their problem-solving skills using the scaffolding provided by the V200 calculator before having mastered their skills in sketching graphs and integration.

2.8 Exercises on Differential Equations

For the topic of Differential Equations, the students were asked to explore and sketch the family of curves of the differential equations they were set in their tutorial exercises using the graphing features of the V200 calculator. Most of the general solutions to these questions were too difficult for the students to sketch manually. However, with access to the V200 calculator, this task was no longer impossible for the students. The objective of the exercise was to give the students exposure to a greater variety of families of curves, besides the more elementary curves, such as quadratic functions. Using the V200 calculator to sketch the solution curves was a way of using the V200 calculator as a 'black-box,' except no conjecture needed to be formed or proven. The exercise merely sought to provide the participants an experience of the many actual curves that exist though are too difficult to handle at their level of proficiency.

In this exercise, the students were also introduced to the Existence and Uniqueness Theorem for First Order Differential Equations. Here, the objective was to make the students aware of the fact that members of a family of curves do not intersect with each other. Using the V200 calculator, the students were led to realize that the family of curves for a particular question in their tutorial apparently contradicted this theorem, as they seemed to intersect at one common point. With the use of the V200 calculator to help with graphing and algebraic manipulation, the students in the participating class were challenged to examine this phenomenon. Here, the V200 calculator served as scaffolding where the sketching of a family of solution curves was unmanageable by pen and paper. Using this scaffolding, the students could grasp the idea that members of a family of curves do not intersect each other and, in cases where they seem to intersect at a certain point, the point of intersection is actually excluded from each curve. Accordingly, the graphing feature of the CAS enables the teaching and learning of this topic to go beyond what would be possible to convey using conventional instruction techniques.

2.9 Exercises on Complex Numbers

For the topic of Complex Numbers, the focus was mainly on algebraic manipulation involving the properties of the imaginary number *i*, the argument and modulus of complex numbers, and rationalizing the denominators of fractions involving complex numbers. The sketching of loci mainly involves manipulating an equation or inequality involving complex numbers into a Cartesian equation for a graph or interpreting that equation or inequality geometrically. The obstacle to students' mastery of this topic is their failure to master the basics, such as finding the argument of a complex number, gaining confidence in handling algebraic manipulations, and recognizing the equations for the three basic loci, namely, the straight line $|z - z_1| = |z - z_2|$, the circle $|z - z_1| = a$ where $a > 0$, and the part-line $\arg(z - z_1) = \alpha$. A common weakness among students is that they tend to find the arguments of complex numbers mechanically using the formula $\arg(x + iy) = \tan^{-1}(\frac{y}{x})$, which is valid only if $x > 0$.

Even though the V200 calculator can handle operations using complex numbers, it is not meant to replace the basic skills that students need to master. Students require hands-on practice to develop confidence in handling the algebraic manipulation associated with the properties of complex numbers. In this regard, the only use for the V200 calculator was to enable the students to personally check their answers. As the CAS had limited application in this area, it did not offer much advantage compared to conventional teaching. From a theoretical perspective, the use of the V200 calculator was merely for automation as described in [4].

3. Results and Discussion

3.1 Measuring Students' Attitudes towards CAS

Table 1 shows the Cronbach's alpha for the four subscales and the overall scale for the first CASAS survey administered after the participating class was introduced to the features of the V200 calculator.

Table 1 Reliability Indices of the 4 Subscales and the Overall CASAS for the Pre-V200 Training Session

Scales	Anxiety	Confidence	Liking	Usefulness	Overall
Alpha	0.75	0.81	0.78	0.84	0.93

The reliability index of the overall scale is 0.93, and the lowest index among all of the subscales is 0.75, for the anxiety subscale, once again confirming the reliability of the CASAS. The correlations between each subscale and the overall scale are very high, as shown in Table 2. All of the correlations are significant at the 1% level, which again confirms the reliability of the CASAS. The anxiety and confidence subscales are the most highly correlated of the intercorrelations between the four subscales, followed by the liking and usefulness subscales.

Table 2 Intercorrelations between Subscales and the Overall Scale of the CASAS for the Pre-V200 Training Session

Scale	1	2	3	4	5
1. Anxiety	-	0.84**	0.63**	0.70**	0.88**
2. Confidence		-	0.67**	0.74**	0.91**
3. Liking			-	.81**	0.87**
4. Usefulness				-	0.92**
5. Overall					-

Note. Numbers of participants = 22.
*Correlation is significant at the 5% level (2-tailed).
**Correlation is significant at the 1% level (2-tailed).

These results are not unexpected, as the more confident a student becomes in using the CAS, the less anxious he or she will be and vice versa. Nevertheless, the negative attitude of the students would have affected the correlation between the usefulness and liking subscales, which were highest in Ng's studies of pre-service teachers in [9] and junior college students in [11].

While the magnitudes of the inter-correlations among the subscales indicate that the total score based on the four subscales could reasonably be interpreted to represent a general attitude towards working with CAS that reflect freedom from anxiety, confidence, liking and perceived usefulness, they would also seem to suggest that the subscales were not measuring distinct attributes. A varimax rotated factor solution might be needed to further confirm the subscale structure.

Table 3 Comparison of Students' Scores on the 4 Subscales of the CASAS and the Overall Attitude Scale Before and After the V200 Training Session

Scale	Mean of Difference	Standard Deviation	Standard Error Mean	t	*p* <
Anxiety	-0.53	3.64	0.78	-0.69	0.50
Confidence	-1.12	3.67	0.78	-1.43	0.17
Liking	0.15	4.91	1.05	0.14	0.89
Usefulness	-0.13	4.99	1.06	-1.26	0.22
Overall	-2.84	12.66	2.70	-1.05	0.31

Note. Numbers of participants = 22.

Two comparisons of the students' attitudes towards the use of the CAS were carried out using the paired-sample t-test. The first comparison was between the students' attitudes before and after the V200 training sessions and the second was between before the V200 training session and post-CASIP. Table 3 shows the results of paired-sample t-tests performed on the participants' responses to the CASAS before and after the V200 training session. A negative t-value indicates an improvement in attitude. Recall that a higher score on the Anxiety subscale indicates a lower level of anxiety. All of the subscales and the overall scale show an improvement in attitude, with the exception of the liking subscale between before and after the V200 training session. However, none of the results is significant. The drop in the liking subscale is very slight, with a t-value of 0.14, which can be perceived as no change in attitude. On the other hand, the confidence subscale has the largest t-value of -1.43. As the scores on the four subscales in all three administrations of the CASAS are above the value of 3.2 out of 4, the small differences found in the paired-sample t-tests could be because of ceiling effects.

Even though the results of the t-tests are not significant statistically, which means that a decrease in the score for the 'liking' subscale may have happened by chance alone, based on the observations of the authors, the decrease in the score for the 'liking' subscale could be an indication of resentment, as some students were reluctant to use the V200 calculator and felt that they were wasting their time learning how to use it.

Table 4 Comparisons of Students' Scores on the 4 Subscales of the CASAS and the Overall Attitude Scale Before the V200 Training Session and Post-CASIP

Scale	Mean of Difference	Standard Deviation	Standard Error Mean	t	*p* <
Anxiety	-0.82	3.05	0.65	-1.27	0.22
Confidence	-1.24	3.43	0.73	-1.69	0.11
Liking	-0.27	4.15	0.89	-0.31	0.76
Usefulness	-0.90	4.56	0.97	-0.93	0.37
Overall	-3.23	11.90	2.53	-1.27	0.22

Note. Numbers of participants = 22.

Table 4 shows the results of paired-sample t-tests performed on the participants' responses to the CASAS before the V200 training session and post-CASIP. A negative t-value indicates an improvement in attitude. From the comparisons, all of the subscales and the overall scale show improvements in the respective attitudes towards the CAS. However, none of the results is significant. Again, the small differences found in the paired-sample t-tests could be because of ceiling effects. The students' liking of the CAS improved after the CASIP, even though there was a slight drop in the score for this subscale after the V200 training session, as reported previously. The t-value dropped from 0.14 to -0.31, even though this subscale still shows the least improvement among the four subscales. This could be attributable to the reluctance of a few students to use the V200 calculator throughout the CASIP even though it may have happened by chance alone statistically. A survey conducted at the end of the CASIP revealed that 6 participants responded that they would not be interested in having a V200 calculator, even if it were given to them for free. Similar to the previous comparison between the pre-V200 and post-V200 training sessions, the confidence subscale has the largest t-value of -1.69. In addition, the anxiety subscale shows a marked improvement, with its t-value increasing from -0.69 (after the training session) to -1.27 (after the CASIP), indicating a further reduction in the level of anxiety. Based on observations of the authors, this could be explained by the fact that after using the V200 calculator for a period of time, the participants overcame their initial apprehension towards the new technology.

In both comparisons, even though the results obtained were not statistically significant, there was improvement in all four subscales and the overall scale, with the exception of the liking subscale in the first comparison. This may again be attributable to some of the participants' resentment towards being "forced into using the V200 calculator that could not be used in the examinations." In fact, two participants deliberately skipped the training session. This differs from the results of the study of junior college students in [11], where the liking subscale improved significantly at the 2% level after the students' training session. On the other hand, with the second comparison, the study in [11] found significant improvement in all four subscales and the overall scale after the students' completed the CASIP.

There were several possible reasons that led to these differences in the two studies. First, in the study in [11], the students completed two training sessions lasting two hours. The four hours of training greatly contrasts with the barely one hour of training given to the participants in the present study, which was met with many obstacles and hindrances. The participants' proficiency in using the V200 calculator would certainly differ in the two studies. This, in turn, could have affected the participants' attitude towards using the V200 calculator. Second, the participants in this study were only able to focus on using the V200 calculator once a week whereas the participants in the study in [11] used the V200 calculator in their daily lessons. Accordingly, when the participants in this study used the V200 calculator on other occasions, much of their use of the device was left to their own initiative and motivation. Third, the participants in the study in [11] were first year students who were probably much more enthusiastic about learning new tools. Moreover, as Further Mathematics students, they were already allowed to use graphic calculators in their examinations. A lateral transfer in learning between the graphic calculator and the CAS calculator would undoubtedly have occurred. Hence, it would not have been unpractical for them to learn, as well as use the CAS calculator. Unlike the second year students in this study, who faced the urgency of performing well in their examinations and regular tests, the first year students in the study in [11] would have had more liberty and been more at ease with their time.

A comparison of the t-values from the two comparison tests showed that the participants' attitudes in the four subscales and the overall scale improved between the training session and the end of the CASIP, with the exception of the usefulness subscale. The explanation may be that the participants did not find the CAS applications directly relevant to their curriculum assessment criteria, in which skillful algebraic manipulation plays a major role, even though they found the graphing and other features to be powerful and convenient. It is important to note that students in Singapore are very examination conscious and have a practical approach to learning in schools. This is especially the case for final year students who are apprehensive about their forthcoming examinations.

4. Conclusion and Implications

This study investigated the effects of the use of the CAS V200 calculator on junior college students' attitudes towards the CAS. The participants in this study were from a junior college in Singapore and had above-average abilities in general. Owing to the small sample size, the results of this study cannot be generalized to the overall population of junior college students in Singapore.

The following factors were identified as having affected the accuracy of the results of this study: (1) the students were reluctant to use, and resented using the CAS because they were not allowed to use it in their examinations and the CAS was clearly not a requirement specified in the curriculum; (2) the students' lack of proficiency in using the CAS hindered them from fully utilizing it to benefit their learning; and (3) quantitative analysis of the participants' examination results to measure achievement failed to identify the benefits the students gained from using the CAS for specific topics. Based on these findings, further research could introduce the CAS as an optional tool for teaching and learning mathematics, provide short training sessions for students on specific features of the CAS from time to time as opposed to intensive training on many features of the CAS, and qualitatively investigate the specific benefits derived from using the CAS for specific curriculum topics.

Integrating technology into mathematics education does not end with making technological gadgets accessible to students. Mathematics education is not just about enhancing students' speed and efficiency in carrying out mathematical routines. Like all forms of education, it is about learning and knowledge construction. Especially in an academic institution like a junior college, the students are not there to simply receive information. They are also groomed to appreciate the beauty behind the subjects they are studying. This requires teachers to give much effort to exploring ways to maximize the educational effects of technology in their lessons. At this point in time, some mathematics teachers in junior colleges in Singapore are still struggling to fully integrate the use of a graphic calculator in the classroom. This is a far cry from effectively introducing the CAS calculator and technology in general into mathematics education. Nevertheless, this study has attempted to investigate the effectiveness of using the CAS calculator in mathematics education in Singapore and will hopefully pave the way for future implementation.

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