

Changes in Year 11 Students' Self-Reported Experiences of Emotions Related to CAS and Pen-and-paper

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This paper reports three emotions (i.e., anxiety, confidence, & enjoyment) related to pen-and-paper (P&P) and a Computer Algebra System (CAS), that were experienced (or not) by twelve Year 11 Mathematical Methods students in a classroom where CAS was allowed. Some students had experienced the same emotions at the start and end of the study, hence experience with CAS did not always appear to impact students' emotions. Comparison of emotions related to CAS and P&P show students more frequently experienced anxiety related to CAS than P&P, and more frequently experienced confidence and enjoyment with P&P than CAS.

Students' attitudes towards CAS can impact their willingness to use CAS, and persistence in overcoming technical difficulties (Pierce & Stacey, 2004). Attitude can be defined as including beliefs and emotions (Di Martino & Zan, 2010), and both beliefs and emotions can impact student CAS use. Focussing on emotions, W. L. Ng et al. (2003) suggested students must be confident with, and enjoy using, CAS before they can effectively use it, and that anxiety may negatively impact CAS use. The potential impact of emotions (i.e., anxiety, confidence, & enjoyment) results from individuals favouring (or avoiding) stimuli that result in a positive (or negative) emotion (Shuman & Scherer, 2014). Meagher (2012) noted a lack of research exploring students' affective engagement with CAS. The literature review below identified few articles which investigated emotions (an aspect of affect) related to CAS. This study builds on literature which has reported students' emotions related to CAS at a single timepoint (e.g., Kissane et al, 2015; W. L. Ng, 2003) or changes resulting from an intervention designed to support attitudes towards CAS (e.g., W. L. Ng et al., 2005), and further contributes by contrasting emotions related to CAS with emotions related to P&P. The research question for this paper is:

- Which emotions (i.e., anxiety, confidence, & enjoyment) related to P&P and CAS were experienced (or not) by twelve Year 11 novice CAS users in a classroom where CAS was allowed, and were there changes over 8 months?

Literature Review

There are several definitions for emotions, but Hannula (2020) notes agreement in the literature that emotions involve three processes. Hannula (2006) summarised these as (i) changes in “physiological processes that regulate the body” (p. 219) (e.g., heart rate, body posture), (ii) a “subjective experience” (p. 219) which impacts decisions (e.g., frustration when encountering a CAS syntax error) and (iii) an “expressive process” (p. 219) which results in an observable behaviour (e.g., changing from CAS to P&P). Negative emotions are experienced when progress towards a goal is interrupted (Hannula, 2020); this may result in selecting a different approach, such as moving from CAS to P&P. Positive emotions are experienced when progress towards a goal is uninterrupted.

Three emotions were identified in CAS literature, namely (i) Anxiety (e.g., W. L. Ng et al., 2005), (ii) Confidence (e.g., W. L. Ng et al., 2005), and (iii) Enjoyment (e.g., Kissane et al., 2015).

These emotions are discussed below, including literature relating to P&P, to enable a contrast with CAS.

Emotion 1: Anxiety

Anxiety is an “unpleasant emotion of fear, which is usually directed towards an unexpected outcome in the future” (Hannula, 2020, p. 32). Such situations may include use of CAS in unfamiliar contexts or consideration of the role of CAS and P&P calculations in mathematics (Meagher, 2012). Both Alkhateeb (2002) and W. L. Ng et al. (2005) compared the mean anxiety reported by students with different levels of experience and reported that overall levels of anxiety decrease as students gain experience. More generally, mathematics anxiety involves feeling anxiety in response to problem solving situations (Ashcroft, 2002). Such anxiety has been found to impact a “considerable group” (p. 573) of the 294 secondary students reported in L. K. Ng’s (2012) study. Inability to solve problems and the application of symbols and formulae in algebra topics were identified as prompting mathematics anxiety.

Emotion 2: Confidence

Confidence relates to expectations of future success (Graham & Taylor, 2014), and students must have confidence that they will be able to use CAS successfully to integrate it into their mathematical routines (W. L. Ng, 2003). Ball (2015) reported a teacher who believed that an outcome of students lacking confidence in mathematics could be that they privilege P&P over CAS to demonstrate understanding. Kissane et al.’s (2015) survey of 522 Year 11 and 12 mathematics students found that approximately two-thirds of students were confident with CAS, consistent with W. L. Ng et al.’s (2005) study of 32 students, who also reported confidence increases with experience. Orellana (2016) surveyed 367 Year 11 students about attitudes to technology in mathematics, with technology encompassing a range of technologies. A positive relationship was found between students’ self-reported technology confidence and CAS use, with more experienced students reporting higher levels of technology confidence. Orellana’s use of the Mathematics Technology Attitude Scale (Pierce et al., 2007) enabled the comparison of technology confidence and mathematics confidence. Orellana’s results suggest students had higher levels of technology confidence than mathematics confidence, the latter defined as “students’ perceptions of their ability to obtain good results and handle difficulties in mathematics” (p. 18).

Emotion 3: Enjoyment

Kissane et al. (2015) reported that almost three-quarters of students enjoyed working with CAS, while W. L. Ng (2003) reported that more than half the students enjoyed using CAS and learning mathematics with CAS. CAS enjoyment increases with experience (W. L. Ng et al., 2005). Although we were unable to identify literature explicitly discussing enjoyment with P&P, Hine’s (2023) analysis of 1633 senior secondary students reported a lack of enjoyment as a key factor in students not enrolling in senior mathematics subjects. Students cited senior mathematics subjects as being “...too complex, impractical, unnecessary...” (p. 8) but did not attribute enjoyment to either P&P or technology.

Few studies about emotions related to CAS used a longitudinal research design across a school year and in situations that did not involve a deliberate intervention to support CAS use; hence there is little discussion of how emotions change as students gain experience with CAS under normal classroom conditions, or how emotions related to P&P compared to those related to CAS. This study addresses this gap.

Research Design

The twelve students reported here were from one Year 11 Mathematical Methods class in a co-educational government school in Victoria, Australia. Technology was expected for teaching,

learning and assessment (VCAA, 2015). Although a specific technology was not specified in the curriculum, the functionalities of technology expected to be used by students were contained within a CAS; in addition, CAS is expected in Year 12 mathematics examinations and hence was an integral part of learning mathematics. Students were novice CAS users, so gained experience with CAS across the study. Eight students had not used CAS before Year 11, while four reported limited experience with CAS.

The data used in this study was a subset of data used in the PhD study of the first named author. The data was from a questionnaire which focussed on students' beliefs and emotions; emotions being reported in this paper. A questionnaire was chosen as the research instrument to allow for the identification of emotions experienced by an individual through their agreement or disagreement with individual statements (Ajzen, 2005). A literature review was conducted to identify potential questionnaires (e.g., W. L. Ng et al., 2005; Pierce et al., 2007) for the larger study. However, we were unable to identify an existing questionnaire that met criteria of addressing all beliefs and emotions that had been identified in the literature review. Consequently, a new questionnaire was developed with four sections. The questionnaire was administered twice in one school year: once in April (after studying Linear, Quadratic & Cubic functions) and again in November (after studying Calculus). In completing the questionnaire, students were instructed to consider their use of symbolic functionalities of CAS for completing the algebra required in these topics, as algebra was a focus of the larger study and used across all four topics.

Questionnaire Development

Cohen et al.'s (2018) method guided the development of questionnaire items. Statements (i.e., questionnaire items or student comments) where an emotion was stated or could be inferred, were identified from the literature review. For instance, Ball and Stacey (2005) reported interviews with five Year 12 students, three of whom enjoyed working with CAS. Based on this finding, the first-named researcher rephrased each emotion statement as a questionnaire item. For example, two items about enjoyment related to CAS were "I enjoy using CAS to solve algebra problems" (Item 39) and "I like solving algebra problems with CAS" (Item 41). Emotions refer to algebra as this was the context of the larger study. Some refer to P&P (e.g., "I like solving algebra problems with P&P"; Item 35) due to an expectation that emotions about P&P could influence CAS use (e.g., choosing P&P over CAS due to enjoyment). Co-authors reviewed all items, focusing on rewording items for clarity and removing unnecessary items. The questionnaire was then piloted using Cohen et al.'s (2018) process whereby subject matter experts are asked to provide feedback on content and format. Overall, 15 emotion items were generated relating to anxiety (4 items), confidence (6 items) and enjoyment (5 items). Tables 1–3 provide questionnaire items.

Data were collected using a five-point Likert scale (Strongly Disagree, Disagree, Unsure, Agree, Strongly Agree) despite seven-point scales being more sensitive and reliable (Cohen et al., 2018). As we grouped responses of Agree and Strongly Agree to describe an emotion being experienced and the opposite for responses of Unsure, Disagree or Strongly Disagree, the additional sensitivity of a seven-point scale was not required. The collapsing of the five-point scale to a two-point scale was done due to the small sample size and the inability to statistically validate the questionnaire. Without statistical validation of the reliability and validity of the instrument, the reliability of an analysis which focussed on changes of Agree to Strongly Agree or similar was not deemed appropriate for this sample at this point of our research.

Questionnaire Analysis

Each student reported that they either experienced (E) or did not experience (E') an emotion in April (i.e., start of the study) and November (i.e., end of the study). A response pattern of EE indicated the student reported experiencing the emotion at both the start and the end, hence their

experience of the emotion was the same. A response pattern of E'E' suggested the emotion was not experienced across the year. Response patterns of EE' and E'E indicated students whose emotional experiences had changed.

The conclusions reported here are limited by the small number of students in the study. The questionnaire was not statistically validated, and future validation and refinement of the questionnaire would strengthen the reliability and validity of this instrument.

Results and Discussion

The study aimed to investigate changes in students' emotions (i.e., anxiety, confidence, & enjoyment) related to CAS and P&P as they gained experience with CAS. Results for each emotion are provided below.

Anxiety

Table 1 provides the results for the four anxiety items, grouped into anxiety related to P&P and then with CAS. A total of eight students experienced anxiety when working with CAS (i.e., Item 36) at the start of the study (i.e., EE or EE'), and five of these students also reported experiencing anxiety related to CAS at the end of the study (i.e., EE). This contrasts with anxiety related to P&P, where no students experienced anxiety and both the start and end. Alkhateeb (2002) found that the average level of anxiety related to CAS reported by 100 students reduced as they gained experience with CAS. Similarly, in a study of 32 students, W. L. Ng et al. (2005) reported that average level of anxiety related to CAS increased as students learnt to use CAS but decreased after six months.

Table 1

Students' Experiences of Anxiety

Emotion (Item)	Same			Change		
	EE	E'E'	Total	EE'	E'E	Total
Anxiety related to pen-and-paper						
I feel anxious when I'm solving algebra problems with pen-and-paper (29)	0	8	8	3	1	4
I am more comfortable working with CAS than with pen-and-paper (37)	0	10	10	1	1	2
Anxiety related to CAS						
I feel anxious when I am using CAS to solve algebra problems (36)	5	3	8	3	1	4
I am more comfortable working with pen-and-paper than with CAS (30)	3	5	8	2	2	4

Note. A student could experience (E) or not experience (E') an emotion. EE, E'E', etc., indicate a response at the start and the end of the study. **Bold** indicates the modal response pattern.

Consequently, we might expect some students who experienced anxiety related to CAS at the start would not at the end (i.e., EE'). Such a change was evident for three students (item 29), less than half of those who experienced anxiety when first working with CAS. In contrast, one student experienced anxiety at the end, but not the start (i.e., E'E). However, the data reported here only indicates whether students experienced anxiety and does not provide insight into how frequently students experienced anxiety or how strong the emotion was. Hence, we can conclude that five students experienced anxiety at the start and end of the study, not whether their level of anxiety had decreased. Meagher (2012) reported that students experienced anxiety when using CAS in

unfamiliar contexts; it is possible that students encountered a range of unfamiliar contexts throughout the year as they learnt how to use CAS in a range of different topics, so using CAS in a new topic may be a stimuli that prompts anxiety. This study was conducted under normal classroom conditions without intervention (cf. W. L. Ng et al., 2005), so teachers may need to consider anxiety when working with CAS and have strategies to support students to overcome this emotion.

Items 30 and 37 provided a comparison between CAS and P&P, so a reversed pair was used to determine differences. Responses of E'E' to Item 37 show that 10 students did not feel less anxious when working with CAS compared to P&P. We expected these 10 would respond EE to Item 30, but only three did, so there were inconsistencies in students' responses to these items. This could occur if a student did not feel comfortable working with either P&P or CAS.

Confidence

Table 2 provides the results for the six confidence items, grouped into confidence in ability to solve problems with P&P and then with CAS. Confidence related to P&P essentially stayed the same across the year (i.e., 29 same cf. 7 different); for students who have been working in P&P classrooms for more than ten years their confidence may have been established over many years. Responses to Items 38 and 41 suggest that very few students were confident in using CAS to solve algebraic problems, however the responses to Item 40 suggest that this lack of confidence might not extend to other types of problems for some students. If students consider algebra to be largely algebraic manipulation which requires complex syntax compared to other procedures (e.g., differentiation), then they may feel less confident in solving algebra problems with CAS than other problems.

Table 2

Students' Experiences of Confidence

Emotion (Item)	Same			Change		
	EE	E'E'	Total	EE'	E'E	Total
Confidence in ability to solve problems with P&P						
I am good at using pen-and-paper to solve algebra problems (31)	5	5	10	1	1	2
I can use pen-and-paper to solve many different problems (33)	7	4	11	1	0	1
I feel confident using pen-and-paper to solve algebra problems (34)	3	5	8	3	1	4
Confidence in ability to solve problems with CAS						
I am good at using CAS to solve algebra problems (38)	2	6	8	0	4	4
I can use CAS to solve many different problems (40)	6	2	8	2	2	4
I feel confident using CAS to solve algebra problems (41)	1	5	6	2	4	6

Note. A student could experience (E) or not experience (E') an emotion. EE, E'E', etc., indicate a response at the start and the end of the study. **Bold** indicates the modal response pattern.

Confidence related to CAS did change (i.e., E'E or EE') for some students, particularly for items related to confidence in solving algebra problems (i.e., 38 & 41). These changes suggest that confidence with CAS was less entrenched than that for P&P. Orellana (2016) found that the average technology confidence for a group of 367 students increased with experience, so we might expect that some students in a cohort would experience confidence and even greater confidence over time, while others would move from lack of confidence to experiencing some confidence with CAS. In

Mathematical Methods algebra is expected to be embedded in all topic areas and revisited across the year (VCAA, 2015), hence the structure of the subject may have supported students' development of CAS facility for solving algebra problems, and hence resulted in a greater number of students experiencing confidence with CAS.

Although comparison of EE response patterns to P&P and CAS items suggests that more students experienced confidence with P&P (15 P&P items cf. 9 for CAS), incorporating students with changed experiences of confidence shows that the occurrence of P&P confidence was similar to CAS confidence (37 instances of E across all response patterns for Items 31, 33 & 34 cf. 34 for Items 38, 40, & 41). Changes in confidence occurred more frequently with relation to CAS than P&P, so it may be that over time, most students would experience confidence in solving problems with both P&P and CAS. Victorian Year 12 mathematics students need to complete both technology-free and technology-active examinations, so it may be important for teachers to consider how to continually develop both CAS confidence and P&P confidence as students progress through Year 11 and 12.

Enjoyment

Table 3 provides the results for the five enjoyment items, grouped into enjoyment when working with P&P and then with CAS. All students provided the same responses to Items 32 and 35, with eight indicating they enjoyed solving algebra problems with P&P at both the start and the end (i.e., EE). In contrast, only 1 (and 3) student(s) reported enjoying solving algebra problems with CAS for Items 39 (42) at both the start and end. Hence, students were more likely to enjoy solving algebra problems with P&P than CAS over the period of the study.

Table 3

Students' Experiences of Enjoyment

Emotion (Item)	Same			Change		
	EE	E'E'	Total	EE'	E'E	Total
Enjoyment when working with P&P						
I enjoy using pen-and-paper to solve algebra problems (32)	8	1	9	1	2	3
I like solving algebra problems with pen-and-paper (35)	8	1	9	1	2	3
I enjoy solving problems more when I am using pen-and-paper than when using CAS (43)	6	1	7	4	1	5
Enjoyment when working with CAS						
I enjoy using CAS to solve algebra problems (39)	1	6	7	1	4	5
I like solving algebra problems with CAS (42)	3	7	10	0	2	2

Note. A student could experience (E) or not experience (E') an emotion. EE, E'E', etc., indicate a response at the start and the end of the study. **Bold** indicates the modal response pattern.

Responses to Item 43 also support this finding, however it is important to note that a student may or may not enjoy solving algebra problems with CAS even though they indicate they enjoy solving problems more with P&P than CAS. Average enjoyment when working with CAS increases as students gain experience (W. L. Ng et al., 2005), so we expect some students who did not enjoy working with CAS at the start would at the end. One-third of students responded E'E to Item 39, which demonstrates this increase. In contrast, half the class did report enjoying CAS at the start or end (i.e., E'E'). Students have explained that they enjoy using CAS (Ball & Stacey, 2005), and enjoy

learning mathematics with CAS (W. L. Ng et al., 2005). Given the potential for enjoyment to influence CAS use, it is important for teachers to support students to enjoy working with CAS.

Conclusions

This study identified how students' emotions related to CAS and pen-and-paper (P&P) changed as they gained experience. We demonstrated that some students experience the same emotion at different points in time, even though Shuman and Scherer (2014) indicate that emotions are short lived. Emotions occur in response to a stimulus, so either the recurrence of the stimulus prompted the same emotion or students' emotions were persistent over time. These students used CAS regularly, so if the stimulus was a particular aspect of CAS use (i.e., solving algebra problems as indicated by confidence items), then students may need additional support to overcome negative emotions (e.g., anxiety) and experience positive emotions (e.g., confidence & enjoyment). It was outside the scope of this study to identify the stimuli that prompted these emotions, but understanding these stimuli may have implications for how teachers introduce CAS into the classroom. Further research could identify relevant stimuli which could then inform interventions supporting students to effectively incorporate CAS into their mathematical routines. For example, students experiencing anxiety related to CAS may avoid using it, so teachers would need to provide the students with the required skills to overcome difficulties that prompt anxiety (e.g., syntax difficulties or interpreting CAS outputs).

The inclusion of emotions related to both CAS and P&P in a single instrument was a new approach. Analysing the number of students who experience an emotion is a coarse measure compared to the approaches of Alkhateeb (2002), W. L. Ng et al. (2005), and Orellana (2016). However, the instrument provided useful insights into these students' emotions related to CAS and P&P. In this small sample, we found that more students experience (i) anxiety related to CAS than P&P (ii) confidence related to P&P than CAS, and (iii) enjoyment related to P&P than CAS. These differences could be expected as students were novice CAS users who had many years of experience of P&P mathematics. However, as emotions may impact choices about CAS or P&P, it is important for teachers to support students to experience confidence and enjoyment related to CAS, and to limit feelings of anxiety.

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