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An Innovative Approach using ICT to Teach Calculus in Primary Schools

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ABSTRACT

Purpose
The uptake of mathematics in schools is falling, partially due to the learning techniques employed by teachers. This project investigated the possibility of introducing the concept of calculus and its capabilities to students aged 10 to 12 years using computer based algebra system software.

Methodology
Teachers from five schools were brought to the university for a day of training in the use of computer algebra software MAPLE. They returned to their classes in four Australian states to deliver a sequence of 11 lessons where students had individual computer access. At the end of the program, the students attempted a test based on first year engineering degree calculus examinations.

Important findings
The findings of this study showed that properly structured learning programmes utilising appropriate technology can impart high level knowledge and skills to students and provide them with a good understanding of the applications, thus motivating them to engage in such studies. Females also demonstrated better skills at solving real world problems contrary to published data.

Conclusions
Curriculum designers and school communities should consider providing access to more advanced mathematics instruction than previously available, using the affordances of new technology.

Keywords: *Integral Calculus, ICT, Mathematics, Primary Schools*

INTRODUCTION

In 2013 Australia is on the verge of adopting a national curriculum for the first time. The curriculum design process aims to overcome a century of individual state-based control of schooling, and therefore upsets well established traditions. Technological progress is also rapid, so the conditions are ripe for significant changes to the way students learn, and to what they learn. For professionals rapidly adopting computers to make business efficient and accurate, this is a good time for schools to catch up with real world practice. Noted educator Seymour Papert espoused the role of computers in schools, saying "many topics that were unteachably abstract in the context of pencil and paper technologies will be considered appropriate for children in the context of a digital technology that makes the previously formal become concrete" (2000).

However, teachers stand between this generation and the next; between politicians and the society of the future. They have considerable compliance burdens to manage, and for many of them "any sufficiently advanced technology is indistinguishable from magic" (Clarke, 1962).

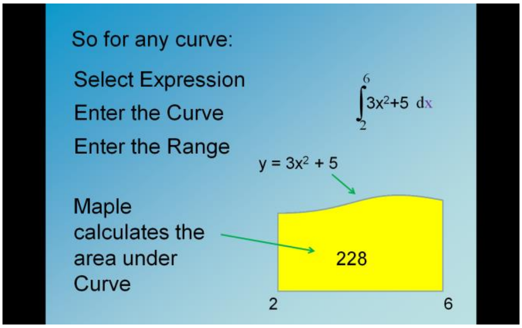
In this context therefore, we sought to explore the 'magic' of computer algebra systems in primary schools. By arranging meetings between professional engineering academics and classroom teachers, we sought to defuse the tension between technology adoption in the workplace and the lived reality of schools.

PROGRAMME STRUCTURE AND APPROACH

The project involved delivering integral calculus to primary school pupils aged 10 to 12 years using the computer software MAPLE®. This software is currently used in the first and second year mathematics units in the Bachelor of Engineering (Maritime) programmes at the University of Tasmania, and was selected due to its ease of use and the WYSIWYG interface. The project utilised the following functionality within MAPLE:

- how to input mathematical functions;
- manipulate functions and solve equations;
- graph and visualise functions and solutions;
- perform calculus operations such as integration; and
- calculate the value of any given integral between limits.

The software eliminates the need to memorise dozens of integration techniques and accurately calculates the value of a definite integral for a given range. The efficacy of similar software has been demonstrated at undergraduate level, reducing the time to learn calculus by half (Palmiter, 1991). The methodology was an intervention study of a class of about 25 students in five state schools from the Australian states of Tasmania, Victoria, New South Wales and Queensland. Around 66% of pupils are educated in state schools in Australia. The sampled pupils had either already been assigned individual laptops or had regular access to laboratory-based computers. Results from the initial trial where the first four schools utilised individual laptops only can be found in Penesis, Chin, Ranmuthugala and Fluck (2011) and Chin, Fluck, Ranmuthugala and Penesis (2011). Each school provided a designated facilitator (normally the mathematics teacher) to deliver the programme and manage the assessment component at the final stage. There were 11 one hour sessions that the facilitators were required to deliver. These sessions were presented using a series of simple PowerPoint presentations that were developed by the authors for the pupils (see Figure 1). This was followed by an interactive MAPLE worksheet which guided the students through a series of examples and exercises, gradually building up their confidence and introducing them to new mathematical concepts and MAPLE functions.



So for any curve:

Select Expression

Enter the Curve

Enter the Range

$\int_{2}^{6} 3x^2+5 \, dx$

$y = 3x^2 + 5$

Maple calculates the area under Curve

228

2

6

Figure 1: A snapshot of a PowerPoint presentation for the sessions

The pupils were first introduced to examples and exercises through MAPLE. This was followed by providing them with a series of problems representing practical day-to-day applications, with associated MAPLE templates to help them develop the model, input the information into MAPLE and solve the problem. The pupils were also encouraged to explore the various functions and capabilities of MAPLE. As pupils of this age have shorter memory spans, in-built revision exercises were embedded in each session so that the pupils were able to maintain the competence attained from the previous sessions. The programme culminated in a final one hour test in the twelfth week, which formed part of the data collected for analysis. Students and facilitators were also interviewed to gather their views and opinions on the programme and outcomes.

The first phase was a proof of concept demonstration. There is a general awareness that integral calculus is one of the more challenging concepts to teach, learn and understand within the school curriculum. Many carry this perception into higher education, with a number of undergraduates finding it difficult to master integral calculus in their first year (Galbraith & Haines, 2000), possibly due to the lack of understanding experienced in school. This could have arisen from the fact that the pupils find it difficult to relate calculus to everyday life and the difficulty in understanding the associated mathematical manipulations. It is therefore important to link the problems to applications that the students understand and relate to; clearly demonstrating how the integration process assists them to solve issues relevant and important to them. Thus, the questions must reflect the understanding and the skill level of the student.

The second phase was to incorporate feedback to improve on the programme and material in order to meet the skill and interest level of the sampled student population. For example, the material was reorganised such that there is a sequential flow of information and incorporating real world application problems to present concepts and activities related to integral calculus.

Each application problem consisted of a scenario where a function equation is derived. This then leads to the calculation of the required area or volume using the appropriate MAPLE functions. It was crucial that pupils saw the purpose of each scenario and relate them back to their everyday lives in order see relevance and ensure engagement. An example is a problem to calculate the amount of gravel needed for a driveway shown in Figure 2. The student is asked to calculate the area in order to purchase sufficient gravel for it. Pupils chose the curves as the boundary and then calculated the integral to find the area to be covered and thus the amount of gravel required. This follows the non-template problem solving method of Allen (2001) and the realistic mathematics education approach of Gravemeijer & Doorman (1999). Although MAPLE was used for manipulation and calculation, the students were required to develop the model from the problem, thus requiring them to master the relevant concepts.

The next stage was the recruitment and training of the facilitators for each of the five sampled schools to implement the intervention delivery. Each school recommended a local facilitator, in most cases the mathematics teacher. The facilitators were trained by the research team at the University of Tasmania in a one-day training workshop. The project goals were first explained to the facilitators and the mathematical concepts and the use of the MAPLE software were then introduced. Suggested delivery and assessment strategies were also discussed. This instructional workshop included the use of the application based problems and Allen's (2001) non-template problem solving method to develop understanding of the underlying concepts. For example, curves used to develop equations must represent a physical entity that the students can relate to, while the integration must provide an answer that makes sense to them.

The fourth phase was the execution of the project at the five schools. The facilitators conducted two one hour sessions per week for six consecutive weeks. During these sessions, the facilitators introduced the problems, the relevant mathematical concepts, the MAPLE functions, and the methods to solve the problems. For the integral problem dealing with the area of a surface bounded by curves (for example the purchasing of gravel in Figure 2), the process was presented as follows. The facilitator used the problem to introduce the concepts and solution techniques related to curves and equations. Integration and its solution was next introduced which included the use of MAPLE to solve the problem. The facilitators not only guided the pupils through the solution process, they also ensured that the underlying concepts were clearly communicated to the pupils.

During the programme, members of the research team visited each of the schools to provide assistance, advice, and obtain feedback. This included observing intervention sessions and conducting focus group interviews. Additional communication was maintained through appropriate electronic means.

In the final phase of the intervention program, the pupils took a test to assess their knowledge and skills gained throughout the program. The test was based on questions from first year engineering calculus examination papers and were provided to students on printed paper. A MAPLE template with no mathematical material was provided to the pupils to carry out their solutions. The pupils were required to demonstrate their capability to develop the model, input mathematical functions into MAPLE and manipulate the information using the appropriate functions to provide the answers. The completed MAPLE files were sent back to the research team for analysis. A community report on the project was provided to each of the participating schools for publication in their local newsletter. Local facilitators were also informed with regard to the outcome of the graded test papers and any feedback associated with them.

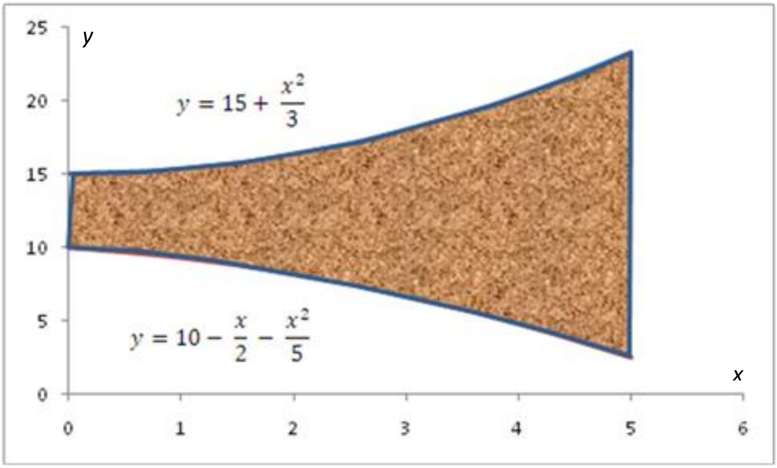


Figure 2: Calculating the area of a driveway to order gravel

RESULTS AND DISCUSSIONS

The aim of this study was to determine the ability to transfer higher level concepts and skills to students using appropriate technology and processes. However, it also provided information on the relationships existing between student's performance and variables such as gender, school location (and its socio-educational advantage) and the ability to solve real world problems. The relevant data for this study were obtained from a total of 100 students of years six and seven from five selected public schools in four states across Australia. Pupils from the four initial schools used 15" screen Acer and Dell laptops financed by the school, but the last Tasmanian school only had access to laboratory-based computers. Results from the initial trial with the first four schools can be found in Fluck, Ranmuthugala, Chin, and Penesis (2012).

The instrument used for data collection was a test with a total of 13 questions of which five were classed as application questions based on real world problems. These were supplemented by feedback interviews with pupils and facilitators. To provide consistency, facilitators e-mailed the MAPLE documents produced by pupils in the culminating assessment to the research team for marking.

Table 1 contains a summary of the student demographics, location, school advantage, mean test scores based on gender, and performance in application questions for each of the five schools. The findings of this study showed that students' performance on the test was high. More importantly, their performance was similar to that of students in a university engineering course but tested in the traditional way of pen and paper. As described in Fluck, Ranmuthugala, Chin, and Penesis, I (2011), the mean scores are above the 50% required to pass the engineering examination, and only 11 of the 100 pupils scored below this level. Students were also able to explain why calculus was useful in the real world. This result indicates that if students have a favourable attitude towards a particular subject, then this will be reflected in their performance in that subject.

Table 1: **Student demographics, location, school advantage, and overall performance by gender and in application questions**

State	**Location**	**ICSEA***	**Scores - Females**			**Scores - Males**			**Application Questions**		
			n	**Mean**	**Standard Deviation**	***n***	**Mean**	**Standard Deviation**	***n***	**Mean**	**Standard Deviation**
NSW	Urban	1004	16	74	9	11	73	17	27	75	18
QLD	Urban	1118	13	87	9	10	89	8	23	88	9
VIC	Rural	984	8	73	17	8	56	13	16	58	27
TAS	Rural	959	12	70	12	11	67	23	23	63	26
TAS	Rural	887	4	90	7	7	86	7	11	90	10

*Index of Community Socio-Educational Advantage (ICSEA): The mean ICSEA value is 1000 with a standard deviation of 100. Values below the mean indicate schools with fewer advantages.

The means and standard deviations from the total raw score for each group were compared between the subject factors using the statistical package SPSS. The data comparing gender is summarised in Table 1. On whether performance is influenced by gender, the preliminary *t*-test assuming equal variances showed no significant difference when comparing the mean. A further analysis suggests that there is still a variation in scores at the lower end with females performing better than males. This result is in agreement with Hyde and Mertz (2009) that females are now accomplishing as well as males and that the gender gap is closing, possibly due to the methods employed in presenting the material and concepts.

Table 1 also shows the Index of Community Socio-Educational Advantage (ICSEA) where the mean ICSEA value is 1000 with a standard deviation of 100. Values below the mean indicate schools with fewer advantages. As expected, the mean score of the more advantaged schools were higher.

On whether location of a school influences performance, the preliminary *t*-test showed that students from urban schools performed better than those from rural schools (t cal = -2.74 < 1.66, see Table 2). This is possibly due to the schools being better staffed, having better facilities, and the students exposed to good study habits within a conducive learning environment. Surprisingly, the second rural school in Tasmania (see Table 1) outperformed even those from urban schools. The students in this school were selected by the principal as being better performers. It is also important to note, these students were only utilising laboratory-based computers available during school hours, rather than their own personal notebooks with extended access outside school.

Table 2: Result of *t*-test analysis of the influence of school location on performance of primary students

Location	*n*	Mean	Standard deviation	*t*-value	Degrees of freedom
Rural	50	71.41	17.82	-2.74*	98
Urban	50	80.00	13.21		

*Significant at 0.05 level (critical value t=1.66)

A further analysis on the performance of the individual states (see Figure 3) showed that Queensland students performed significantly higher than those from Victoria, Tasmania and New South Wales, with no significant difference between the latter three states. However, participation from a greater number of schools is required to provide a definite conclusion.

A paired *t*-test of two means with equal variances was used to assess whether students are better at solving real world problems. A plot of the cumulative frequency of results obtained in application questions (shown in Figure 4) showed no significant difference (at a 0.05 significance level). Queensland pupils overall performed better at the application questions with no clear difference between the other three states. A further *t*-test showed that females performed better at solving real world problems than males. This result is contrary to the findings that males tend to be more field independent than females (Witkin, Moore, and Goodenough, 1977; Bosacki, Innerd, and Towson, 1997). A further analysis found that when solving non-application problems there was no significant difference between genders.

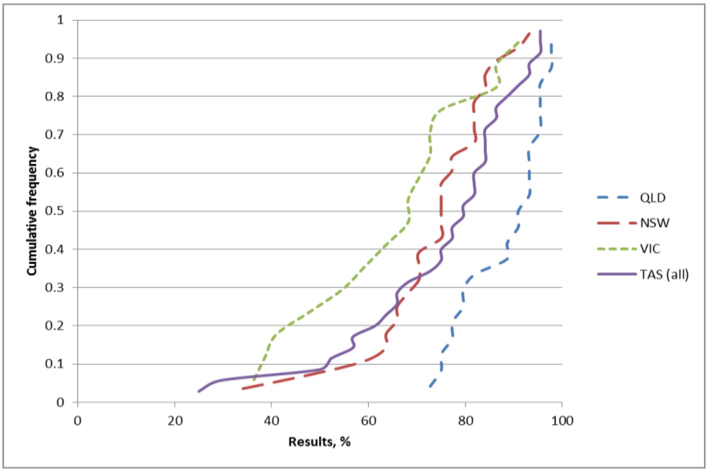


Figure 3: Cumulative Frequency Distribution based on final results

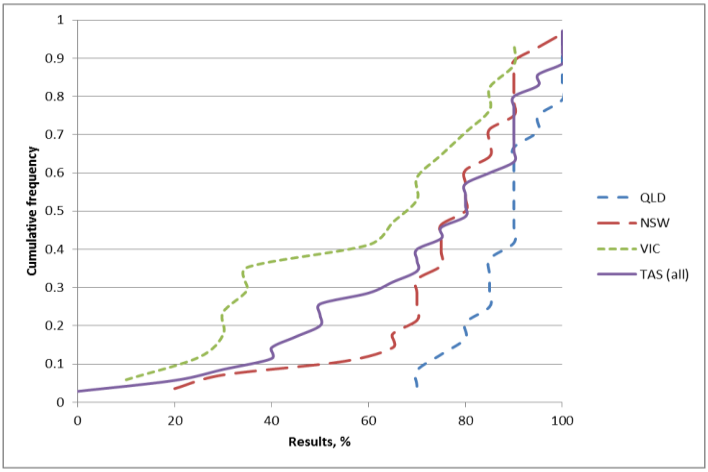


Figure 4: Cumulative Frequency Distribution of performance in application questions

In addition to the quantitative results the team also examined the responses from interviews with pupils and their responses to the question "What is calculus good for?" The responses showed that they understood the concept and its value in the wider world, with a number of pupils identifying areas in which integral calculus could be used, including those in the engineering field. Pupils at the last Tasmanian school showed a good understanding of calculus, stating it was useful:

- It helped me with my school work as well; just the other day I figured out the area of an irregular shape by splitting the shape up like I learned here.
- There are a lot of jobs that need different qualifications, just say engineering as one or building, are jobs you need to know calculus for.
- It is useful because it can help us with solving everyday problems like building a path to your house.

For those who had laptops, they also shared their learning and experience with friends and parents. They celebrated their learning because they were able “to outwit Mum & Dad” or more seriously, “measure my house - figure out how much building material went into it”. They enjoyed graphing functions. One girl stated “My dad's an architect, so I showed him MAPLE. He had a go with it. He said he wished he'd had it when he was studying! My mum doesn't like it because she doesn't understand it, and she's a teacher at this school!” These comments are particularly important, because they epitomise the gulf between school-based learning and functional professional use of these important mental tools. The general consensus was that they enjoyed using MAPLE and would like to continue to use and explore its features, concluding that “it made maths fun”.

CONCLUSIONS

The results described in this study have made it possible to analyse and thus understand some of the factors that influence the performance of students aged between 10 and 12 years in the learning of mathematics related material. The project has demonstrated successful curriculum transformation through the use of ICT by showing that 10 year old students in school can learn integral calculus through the use of appropriate technology and techniques. The results indicate that the students have acquired a good understanding of the concepts and the relevant applications. The interview and qualitative responses show the pupils had a good understanding of what they were doing. It must be clear that since they used a computer for the final test, their capacity to ‘do calculus’ is unconventional, and this perhaps provokes us to consider what is meant by the term. It is our feeling that they demonstrated a capacity to understand and use integral calculus in a way which professional engineers would do so – as a tool to accomplish a goal.

Across all four states tested, Queensland outperformed the other three states, while students from urban schools performed better than those from rural schools. Overall, across all states, females performed better than their male counterparts, with a distinct difference in their ability to solve real world problems. These results clearly indicate a favourable attitude and interest towards the subject, with the techniques employed able to stimulate the interest of the female students. The study also showed that students from the more advantaged schools performed better than the others.

The paper evaluates some influential factors such as school location and gender, but leaves others such as age and school type (private versus public schools) requiring the collection of further data. Hence, it is intended to expand the project to additional schools across Australia and possibly internationally, thus addressing these variables and increasing the sample population. The project was lastly carried out in a Tasmanian school within a low socio-economic area, using laboratory-based computers as opposed to individual laptops. The computer laboratory represents most Australian primary schools, since the Digital Education Revolution policy only provides individual computers to pupils in Years 9 to 12; hence this is seen as a natural extension to the project moving forward. As more schools adopt a 1:1 computing policy or a 'bring-your-own-technology' approach, it becomes more realistic to envision the rapid adoption of computer algebra systems. However, teachers will need to experience the effects before they will change practices, so future work is expected to demonstrate students can devise their own functions to model the real world. This is seen as mimicry of traditional teaching, and inherent in demonstrating students truly 'know calculus'. Perhaps this will sufficiently demonstrate it is technology – not 'magic'?

The project goal is not to introduce integral calculus to Year 6 students, rather to demonstrate the need to change or update the methods of learning to attract students towards technical studies such as engineering and the sciences. Furthermore, the example demonstrates the use of new and innovative tools and techniques, linked to relevant and 'real life' concepts to motivate students to engage in subjects such as mathematics that have gradually fallen out of favour with school pupils. By arresting this trend at an early age, it is considered possible to gradually increase the uptake of engineering in schools across Australia.

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