An investigation into the use of ICT to teach Calculus to Australian Primary Schools

Irene Penesis
Australian Maritime College, University of Tasmania, Launceston, Australia
i.penesis@amc.edu.au

Christopher Chin
Australian Maritime College, University of Tasmania, Launceston, Australia
c.chin@amc.edu.au

Dev Ranmuthugala
Australian Maritime College, University of Tasmania, Launceston, Australia
D.Ranmuthugala@amc.edu.au

Andrew Fluck
University of Tasmania, Launceston, Australia
A.Fluck@utas.edu.au

Abstract: Integral calculus is often taught in high schools to students aged fifteen or older, and is essential for students planning a career in engineering. However, the uptake of mathematics in schools is falling, partially due to inappropriate learning techniques. This project investigates the possibility of introducing these concepts and capabilities to students aged 10 to 12 years using computer based algebra system software. After eleven lessons the students completed a test constructed from questions equivalent to a first year engineering calculus examination. 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.

Introduction

Australia is currently facing a critical shortage of engineering, science, and mathematics graduates (Goldsworthy, 2008). The shortage has been most acute in engineering with declining enrolments. In 2008, the percentage of engineering graduates in Australia was only 10% in comparison to the OECD average of 14% and China with 40%. The University of Tasmania has undertaken a research project to identify the effect of school pupils' perceptions of engineering and technology careers on university enrolment. The project outlined in this paper supplements the above, and thus addresses a major issue still faced by many Australian universities. A major factor that deters school pupils from selecting engineering is a dislike for mathematics in schools. Is it possible to reverse this trend by changing the way mathematics is taught in schools, especially by introducing new tools and techniques early in the learning cycle?

Computers have become an integral part of our lives in the past decade. Children as young as four years of age are able to use the computer and in primary schools, most students would have access to a computer provided either by the school or their parents. The Australian government was concerned about lethargic Information and Communication Technology (ICT) based transformation in education: "while ICT has fundamentally reshaped whole industries, revolutionised production processes and generated massive improvements in productivity in our workplaces, our education systems have been slower in adapting" (Gillard, 2008). It is therefore imperative that learning processes adapt to meet the demands of a transforming society. To shape this change, it is important the school community

understands how the new tools and techniques can be used within the learning processes of pupils. Australian institutions aspire to systemic transformative uses of educational computers (Fluck, 2003). Professor Barry McGaw was appointed Chair of the new Australian Curriculum, Assessment and Reporting Authority (ACARA) to develop a world-class curriculum for all K-12 Australian pupils. In this endeavour ACARA needs to draw upon practical ways to transform education using ICT. This is not ICT literacy, nor is ICT solely a support for other learning outcomes already identified in school curricula. ACARA needs to examine learning outcomes which can only be achieved through pupil use of ICT (ACCE, 2011, p. 1). Australia desperately needs clear directions on what teachers can achieve in this area.

Digital and visual literacies are the next wave of communication specialisation. Digital reading skills refer to a person's ability to perform tasks effectively in a digital environment. This includes the ability to read and interpret media, to reproduce data and images through digital manipulation, and to evaluate and apply new knowledge gained from digital environments (Jones-Kavalier et al., 2006). In a recent OECD PISA survey (OECD, 2011) Australian 15-year-old students were ranked second in digital reading skills. The report also showed that girls continued to outperform boys in reading by a smaller margin. More importantly, the OECD said that computer use should be integrated into curricula and more resources invested in training teachers to use them for teaching and to help student learning. It was a refreshing point of view that encouraged us to investigate ICT use at the higher levels of numeracy learning. Classical educational theory revolves around Piaget's concrete and formal operational cognitive stages (Piaget, 1937) and suggests children start to develop concepts like area and volume, in sequence, at quite specific points or ages. This has been challenged by social constructivist theories of learning (Vygotsky, 1931) which infer zones of proximal development and connecting new ideas with previously mastered concepts. The project therefore accepted pupils would need to learn advanced mathematics in a logical sequence, but rejected conformity with traditional age brackets.

This paper describes a project where ICT was used as an integral component of broader curricular reforms by using computer software to teach integral calculus. Integral calculus is key to a career route into the engineering profession, and hence an ideal choice to demonstrate the transformation in curriculum. Our research question was therefore "can young pupils using appropriate software tools master integral calculus of an advanced level?" The highly visual teaching multi-media format used visual cues to a high degree, thus creating a delivery tool that possibly suited the learning style of females whom tend to be more field dependent than males; i.e., females who do not do as well in lessons that are not highly structured (Witkin et al., 1977). Although the analysis conducted throughout the project focused on the ability to impart mathematical concepts and practices through ICT, it also enabled a comparison and thus an understanding of the differences between the genders in learning in the primary years, especially in mathematics. It provides an insight into the ability of boys and girls to grasp information pertaining to mathematics based problems when information is provided in various forms, for example the ability of the genders to interpret information presented in graphical form.

Approach

The project focused on teaching integral calculus to school pupils aged 10 to 12 years through the use of appropriate computer software and delivery techniques relevant to their experiences. The software selected was MAPLE®, as it is currently used in the first year mathematics units in the Bachelor of Engineering (Maritime) programmes at the University of Tasmania. The intention was for pupils to use the following functionality within MAPLE:

- accept input of mathematical functions;
- manipulate such functions and solve equations algebraically;
- perform calculus operations such as differentiation or integration;
- calculate the value of an integral between given limits; and
- graph and visualise functions and solutions.

In short, the software removes 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 basic methodology was an intervention study involving one class (about 25 students) in four state schools. The latter educate around 66 percent of pupils in Australia. These schools were drawn using purposeful sampling from four separate states, Tasmania, Victoria, New South Wales and Queensland, where the targeted pupils had already been assigned individual laptop computers. Each school provided a designated facilitator to deliver the programme and manage the assessment component at its culmination.

The programme consisted of 11 one hour periods of intervention instruction by the local facilitator working in tandem with the regular mathematics or class teacher. The delivery was based on a series of simple PowerPoint presentations (as seen in Figure 1) by the facilitator to explain the concepts, followed by an interactive MAPLE worksheet that guided the students progressively through a series of examples and exercises, gradually introducing them to new mathematical concepts and MAPLE functions.

Exercises were first introduced entirely through MAPLE, followed by a number of relevant problems on printed paper (albeit with sketches as required), with an associated MAPLE template to assist with their solution process. The students were allowed to progress through the problem series at their own pace, and encouraged to experiment with the various functions and capabilities of MAPLE.

Recognising that students of this age have short memory spans the programme had in-built revision exercises that endeavoured to maintain the competencies acquired during previous sessions. A final one hour assessment of achievement and understanding culminated the intervention and provided data for analysis. In addition to the data gathered from these tests, students and facilitators were interviewed to ascertain their views on the programme and their perceptions on the outcomes.

The first stage was a proof of concept demonstration. There is a general perception among teachers and pupils that integral calculus is one of the more challenging concepts to teach and understand within the school curriculum. Many carry this perception into university, with a number of undergraduates finding it difficult to master integral calculus in their first year (Galbraith & Haines, 2000) possibly due to difficulties experienced in school. The reason for the latter possibly stems from their inability to relate the concepts to everyday life, compounded by the difficulty in grasping the associated mathematical manipulations. It was therefore important to identify issues that were relevant to these pupils, thus linking the integration to events and actions that were understood, and importantly seen as 'useful' in their lives. In addition, it ensured that the questions were within their sphere of understanding and skill level.
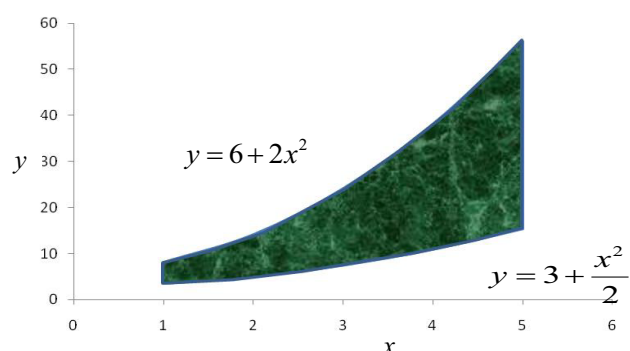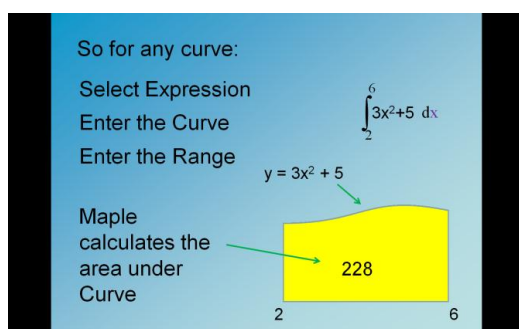

Figure 1: A snapshot of a PowerPoint presentation on how to perform integration

Figure 2: Planting grass seeds in a garden path

The next stage consisted of refining the programme and material based on the feedback to meet the skill and interest level of the target student population. This included reorganising the teaching sequence and incorporating real world problems to introduce concepts and activities linked to integral calculus.

Each problem contained a scenario from which a function equation could be derived and an area or rotational volume deduced. It was important pupils saw the relevance of each scenario to their lives,

thus catching their interest and providing engagement with the learning of the relevant mathematical concepts. An example problem addresses buying enough grass seeds for a garden path shown in Figure 2. The student is asked to calculate the area in order to obtain sufficient seeds 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 seeds required. The problem series were refined in line with the non-template problem solving method of Allen (2001) and a realistic mathematics education approach (Gravemeijer & Doorman, 1999) with the aid of a teacher advisor to ensure it fits pupils in the targeted age range. Pupils utilised MAPLE for algebraic manipulation and calculation of definite integrals, however the problem series ensured they also mastered relevant concepts.

The third stage consisted of recruiting and training the facilitators for each of the four schools to carry out the intervention delivery. Each school was encouraged to recommend a local facilitator, thus ensuring accessibility and acceptance to the students and the school, including meeting all statutory requirements stipulated to those dealing with children. In most cases, the facilitator was the mathematics or class teacher of the students designated for the project.

The research team trained these facilitators through a dedicated one-day training workshop conducted at the University of Tasmania aimed at introducing the project goals, mathematical concepts, software (including MAPLE), suggested delivery techniques, and the delivery and assessment tools. This included instructional sessions on how to use the developed problem series and Allen's (2001) non-template problem solving method to teach the underlying concepts and their application. For example, the explanations covering the equation of a curve and its integration must be in terms that the pupils can understand and relate to.

The fourth stage was the intervention conducted at the four schools. The facilitators had access to the target classes for two hours per week over six consecutive weeks. During this period, the facilitators gradually introduced each problem, the mathematical concepts, the software tool, and ways to solve the problem. For the integral problem dealing with the area of a surface bounded by curves (for example the planting of grass seeds in Figure 2) the process was presented as follows. In the first phase the facilitator used the problem to introduce the concepts and solution techniques related to curves and equations. The next phase introduced integration and its solution, including the use of MAPLE to solve the problem. Thus, the facilitators guided the pupils through the solution process, but were also able to ensure they imparted the underlying concepts to the pupils.

During this intervention stage, members of the research team visited each school to ensure that the programme was on track, required outcomes were being met, assist with any difficulties faced by the facilitator, and obtain relevant feedback. An intervention lesson was observed and focus group interviews conducted with pupils where possible. The research team also monitored the progress at each school via telephone conferences and email communication with the respective facilitators.

In the final stage, the pupils undertook a test based on questions drawn from first year engineering calculus examination papers to assess the knowledge and skills gained through the programme. The questions were provided on a printed sheet of paper, with a MAPLE template for students to carry out the solutions. The latter did not have any of the mathematical material in it, thus the pupils were required to demonstrate their capability to input mathematical functions through the MAPLE user interface. The completed MAPLE files were collected and analysed by members of the research team. Each participating school was provided with a community report on the project for publication in the local newsletter, and local facilitators given feedback on corrected test papers.

Results and Discussions

The overall 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 performance and variables such as gender, school location, and question types. The relevant data for this study were obtained from a total of 89 Years 6 and 7 students from the four selected schools.

The instrument used for data collection was a test with a total of 13 questions of which five were classed as application questions. 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 four schools. Unsurprisingly, the mean score of the more advantaged school was higher, but this is an expected result. More importantly, the mean scores are all above the 50% required to pass the engineering examination, and only 11 of the 89 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.

The means and standard deviations from the total raw score for each group were compared between the subject factors using the statistical package SPSS. 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 & Mertz (2009) that females are now accomplishing as well as males in mathematics and that the gender gap is closing, possibly due to the methods employed in presenting the material and concepts.

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	993	16	74	9	11	73	17	27	75	18
QLD	Urban	1099	13	87	9	10	89	8	23	88	9
TAS	Rural	982	12	70	12	11	67	23	23	63	26
VIC	Rural	988	8	73	17	8	56	13	16	58	27

*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.

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. 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. Table 1 also shows the relationship to the ICSEA value and as expected the mean score of the more advantaged school was higher.

A 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 et al., 1977 and Bosacki et al., 1997). A further analysis found that when solving non-application problems there was no significant difference between genders.

In addition to the quantitative results the team also reviewed the responses from pupil interviews and the assessment question "What is calculus good for?" The responses clearly 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 within the engineering field. 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".

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.

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 these 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. This is further supported by the interview and qualitative responses received from the pupils. It is noted that since the pupils used a computer for the final test, their capacity to 'do calculus' is unconventional, and this perhaps provokes one to consider what is meant by the term. It could be argued that they demonstrated a capacity to understand and use integral calculus in the way professional engineers would use it – as a tool to accomplish a goal.

Overall 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 school performed better.

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. Currently the project is being carried out in a 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.

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. 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.

References

Allen, D. (2001). "Learning integral calculus through non-template problem solving", *Primus: Problems, Resources, and Issues in Mathematics Undergraduate Studies* 11(2), pp. 147–160.

Australian Council for Computers in Education [ACCE](2011) *Position paper on ICT in the Australian Curriculum*. Online at http://acce.edu.au/sites/acce.edu.au/files/ACCE_Position_final.pdf.

Jones-Kavalier, B.R., and Flannigan, S.L. (2006). "Connecting the Digital Dots: Literacy of the 21st Century", *EDUCAUSE Quarterly Magazine,* Vol. 29, No. 2, pp.8-10. http://connect.educause.edu/Library/EDUCAUSE+Quarterly/ConnectingtheDigitalDotsL/39969

Bosacki, S., Innerd, W. and Towson, S. (1997). Field Independence-Dependence and Self-Esteem in Preadolescents: Does Gender Make a Difference?, *Journal of Youth and Adolescence*, Plenum Publishing Corporation, Vol. 26, No. 6, pp. 691-703.

Fluck, A. (2003). *Integration or Transformation? A cross-national study of ICT in school education*. University of Tasmania: PhD Thesis. Online at http://eprints.utas.edu.au/232/02/02whole.pdf on 9 February 2007.

Galbraith, P. and Haines, C. (2000). "Conceptual mis(understandings) of beginning undergraduates", *International Journal of Mathematical Education in Science and Technology*, 31, pp. 651–678.

Gillard, J. (2008). Address to the *Australian Computers In Education Conference*, Canberra, 1 October 2008. Available http://www.deewr.gov.au/Schooling/DigitalEducationRevolution/Documents/ACECMinistersSpeech_011008.pdf on 17 March 2008.

Goldsworthy, A. (2008). *Submission to the review of the national innovation system*. Fitzroy, Victoria: Business/Higher Education Round Table Ltd. Available online http://www.bhert.com/publications/submissions/2008-04-InnovationReview.pdf

Gravemeijer, K. and Doorman, M. (1999). "Context problems in realistic mathematics education: a calculus course as an example", *Educational Studies in Mathematics* 39, pp.111-129.

Hyde, J.S. and Mertz, J.E. (2009). "Gender, culture, and mathematics performance", *Proceedings of the National Academy of Sciences of the United States of America*, USA, Vol. 106, No. 22, pp. 8801-8807.

OECD (2011). *Education: Korea tops new OECD PISA survey of digital literacy*. Accessed at http://www.oecd.org/document/42/0,3746,en_21571361_44315115_48267882_1_1_1_1,00.html on 27 July 2011

Palmiter, J. R. (1991) "Effects of Computer Algebra Systems on Concept and Skill Acquisition in Calculus", Journal for Research in Mathematics Education 22 (2), pp. 151-156.

Piaget, J. (1937/1954). *La construction du réel chez l'enfant / The construction of reality in the child*. New York: Basic Books.

Vygotsky, L. (1931) *Pedologija podrostka* [*Paedology of the Adolescent*]. Moscow-Leningrad: Uchebrio-Pedagogicheskoe lzdatel'stvo. Online at http://www.marxists.org/archive/vygotsky/works/1931/adolescent/ch10.htm

Witkin, H.A., Moore, C.A., Goodenough, D.R., and Cox, P.W. (1977). Field dependent and field independent cognitive styles and their educational implications, Review of Educational Research, 47(1), 1-64.