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# Making Something Out of Mathematics: Using Advanced Technology to Interest Secondary School Girls in Mathematics

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# MAKING SOMETHING OUT OF MATHEMATICS: USING ADVANCED TECHNOLOGY TO INTEREST SECONDARY SCHOOL GIRLS IN MATHEMATICS

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**Abstract**

Australia is in the bottom third of all OECD nations in the proportion of girls studying mathematics and technology at undergraduate level. The representation of girls entering technology-related study at tertiary level over the past decade has averaged 11%. There is an urgent need for cultural change in attitudes and processes for encouraging girls into these disciplines. One of the key issues in female students undertaking tertiary study in technology disciplines is the importance of maintaining mathematics as a subject beyond the compulsory secondary school years. Within Australia, the study of mathematics at senior school levels has been in decline for over two decades. This project used the advanced technology available on a university campus to introduce secondary school girls (years 9 and 10) to creative workshop opportunities. A key aim of the project was to stimulate interest in technology and mathematics amongst young female secondary students. The girls had opportunities to engage with technology such as 3D printers, Computer aided design (CAD), and advanced manufacturing robotics to design solutions to real-world problems. Existing research indicates the importance of group work, peer mentoring, and role modelling in girls' learning styles and these techniques were used in the university settings. Students were engaged with the capability to conceive, design, implement, and operate technical systems and equipment.

Project results indicated significant student satisfaction with the use of the advanced technology and its capabilities; greater interest in technology-related careers; and a deeper understanding of the importance of studying mathematics in senior secondary years. The success of the project has also fuelled interest for on-going partnerships and student workshops. Such interest and understanding benefits not only the individual student, but future Australian society.

# Introduction

The importance of STEM (science, technology, engineering, and mathematics) disciplines for the future economic and social well-being of all nations cannot be under-estimated: 75% of the fastest growing global occupations require STEM skills and knowledge (Becker & Park, 2011; OCS, 2012). STEM research will, more than at any other time in history, contribute knowledge to a world that will rely upon a continuous flow of new ideas, technologies and applications. The STEM skills required to adapt to jobs and technologies that do not yet exist will continue to become increasingly important, as will the ability to access, filter and interpret knowledge across new non-disciplinary boundaries (Office of the Chief Scientist [OCS], 2014; Organisation for Economic Co-operation and Development [OECD], 2014). The Organisation for Economic Co-operation and Development (2014) has highlighted the supply of skilled professionals in STEM as an urgent global problem. This increasing global demand for “new” multi-disciplinary STEM graduates is a result of a number of factors:

- the growing use and impact of information and communications technologies **inter-woven** across all STEM disciplines;
- the high rate of innovation fuelling rapid application of scientific advances in multi-disciplinary products and processes;
- the growth in more complex global **interacting** problems (climate change, global security, etc.); and
- the shift to more knowledge-intensive industries and services, not reliant upon single discipline responses.

As society grapples with future challenges, STEM disciplines will be needed to underpin a differentiated, adaptable, globally competitive economy. The opportunities that will flow from competitiveness in these global economies will benefit all.

Yet there is widespread concern that, as a nation, Australia will not be able to participate in these global opportunities. Participation in future global economies is linked to STEM-related tertiary education, yet the number and capacity of STEM graduates Australia produces from tertiary institutions is inadequate (OCS, 2014; OECD, 2011; West, 2012).

The Chief Scientist of Australia has highlighted the declining number of STEM graduates as a national priority. Intrinsically linked to the supply of adequate STEM graduates into the future is the gender disparity in participation across STEM disciplines. The need to address the persistently low female engagement across STEM disciplines in Australia has become urgent. Australia is one of the bottom three countries for proportions of women enrolled and then employed in mathematics, engineering and science disciplines (OECD, 2011).

This gender disparity is highlighted starkly in the national statistics. Only 28% of the employed STEM-qualified Australians aged 15 years and over were female in 2011, with this figure as low as 14% in the field of engineering (Roberts, 2014, p.2). In the same year, only 33% of tertiary qualifications were awarded to Australian women in STEM fields (Roberts, 2014, p.2). Gender disparity in STEM fields is not isolated to the labour market, but can be traced back through each level of education. The under representation of women has been termed a “leaky pipeline”, in reference to the increasing loss of women from STEM fields through the various stages of education and employment (Roberts, 2014, p.4).

Poor participation of females in STEM tertiary study is due to a pipeline effect of poor participation in mathematics in secondary (high) school. As a gateway discipline to STEM careers, it is not only advantageous to have studied intermediate or advanced level mathematics at secondary school, but in many cases it is requisite to tertiary study in STEM disciplines, such as engineering and computing. Secondary school level mathematics is where students choose to be able to go on to further study in mathematics and its associated disciplines. These fields at tertiary level rely on, and indeed require, engagement in both intermediate and advanced level mathematics subjects during years 11 and 12. Across Australia, female participation in these subjects has been poor, with the proportion of girls taking these subjects even falling in recent years. In fact, only 47.3% of students studying intermediate or advanced mathematics programs at year 12 level were girls in 2000 (Roberts, 2014, p.9). By 2004, this proportion had already fallen to 45.6% (Roberts, 2014, p. 9). Another way to understand the problem is to look at the proportion of all female year 12 students who choose to take advanced level mathematics. Across Australia, around 76% of girls took a mathematics subject in year 12, compared with 85% of boys (Roberts, 2014, p.9). Approximately equal numbers were enrolled in an elementary mathematics subject. However, only 6.6% of all female year 12 students in 2013 studied an advanced level mathematics subject, down from 7.7% in 2006 (Roberts, 2014, p.9). This is in contrast to 12.6% of male year 12 students in 2013 and 13.9% of male students in 2006 (Roberts, 2014, p.9). Whilst the overall number of students studying advanced or intermediate level mathematics in their final years of high school in Australia continues to decline, the figures for females are always lower than for their male peers.

Disciplinary gender divergence is also apparent, with girls tending to choose biology or psychology in preference to physics or chemistry, and tending to choose either basic or intermediate level mathematics over advanced level subjects. At 15 years of age, the career ambitions of male and female students have already shaped their STEM engagement (Executive Office of the President [EOP], 2013). As a gateway discipline, the poor participation of girls in mathematics is particularly disturbing, and an opportunity for perhaps a substantial impact for change. In a sense, mathematics can be empowering, as skills in mathematics are “considered essential to success in STEM fields” (OCS, 2012, p.24).

The search for effective measures to address the under representation of women in mathematics and other STEM fields has, as Roberts (2014) noted, been haphazard and “unchartered.” What is clear is that the causes are not simple, are intertwined with cultural and societal norms, educational understandings and historical underpinnings. Add in a dash of national disinterest and the swings and roundabouts of government economic levers and the solutions appear more complex than the problem. As Roberts (2014) in her review of STEM female participation succinctly summarizes “there is no silver bullet”, (Roberts, 2014, p.11). No single measure will address all the issues.

To date much significant work has been undertaken in various attempts to “STEM the gender tide”, (Hill, Corbett, & St. Rose, 2011, p. 5). These various models, national activities and partnerships between government, employers and training providers have heralded small, promising results. There are many examples of implemented programs and measures that can be cited as effective across the range of levers available (Hill, Corbett, & St. Rose, 2011). However, the consistency and extent of national effort required to turn around women’s participation rates in mathematics and other STEM disciplines across a system is a challenge yet to be met. The Chief Scientist of Australia in his latest report on Mathematics, Engineering and Science in the National Interest, 2014 called for new approaches, and the need for cultural change in our attitudes and processes for encouraging girls into these disciplines. He called for high quality, contemporary, engaging and equitable programmes that address the gender gap and increase the overall numbers of students studying these STEM disciplines in tertiary institutions.

STEM disciplines are critical engines of innovation and growth. The future of the Australian economy will be underpinned by the number and calibre of STEM graduates and the academic staff leading them. We are at present falling short: something different has to be done, demanding a paradigm shift. (Office of the Chief Scientist, 2012, p. 7)

# Objectives and Purpose

In 2014, the Australian Government, in partnership with the Office of the Chief Scientist Australia, launched the National STEM Strategy. This strategy has objectives across four national areas:

- Australian Competitiveness
- Education and Training
- Research
- International Engagement.

These four areas were aligned to clearly articulate national goals, focused upon priority areas where there is critical advantage or need and scaled appropriately to achieve far-reaching and enduring change (OCS, 2014). Within the area of Education and Training, a number of competitive grants were introduced under the Mathematics Science

Partnerships Programme, which targeted education sectors working together to achieve improved outcomes for students. This paper outlines the *Making Something out of Maths* Project, which was trialed in Melbourne at RMIT University.

This project had a number of objectives which were to

- Introduce secondary school girls to the practical uses of mathematics in university engineering labs using Desktop Laboratories, Web Share and Rapid Prototyping

- Build interest, excitement, enjoyment and understanding of the relevance of mathematics and engineering in everyday life.

- Find novel ways of enhancing the classroom experience of secondary students whilst supporting teachers and bringing practitioners into the classroom (in this proposal, *students to the practitioners!*).

- Emphasize the teaching of maths as it is actually practiced: hypothesis, experimentation, observation, interpretation and debate.

- Focus secondary school girls on the relationship between mathematics, engineering, and real world problems.

- Build aspiration for future tertiary study in mathematics and engineering.

- Identify the applications of mathematics in tertiary degrees and professions such as mathematics, medicine, social science, engineering, health science, exercise science, psychological science, etc.

A key element of the project was the context in which the workshops were conducted. Secondary school girls attended the university once a week and engaged in the workshop activities, using technology and mathematics skills to solve problems. Through exposure to engineering environments and the role-modelling of tertiary students and staff, it was hoped the application of mathematics in real world settings would become explicit to the girls. This would lead to more informed subject choices at senior secondary years and thus place the girls in a greater position to select future STEM tertiary studies and eventually STEM careers.

# Theoretical Framework

One of the key frameworks upon which this project was premised was the identification of different learning styles amongst genders. Existing research has highlighted the importance of group work and creative solutions to real-world problems as an important aspect of girls learning styles (Honigsfeld & Dunn, 2003). The “social” aspect of learning is widely reported in the literature as of importance to girls, along with the critical importance of engagement with the learning and the environment of learning (Kaspura, 2012). In addition, the role of peer mentoring and role modelling has been shown to produce greater learning engagement for girls, particularly in STEM disciplines (McAnalley, 1991). This project allowed the girls to work in groups alongside tertiary staff to solve design problems that matched their real-world experiences and interests. Within the university labs and workshops, the girls were exposed to undergraduate female student role models in STEM disciplines.

Secondly, the importance of staff role-modelling, teaching behavior, and student engagement were also critical theoretical frameworks for the project. The role of teachers in motivating and encouraging STEM learning cannot be underestimated and this project was premised upon this understanding of the value of effective teaching. RMIT University is a leader in engineering education in Australia, with world-class facilities. The RMIT University staff involved in this project actively undertake teaching workshops with undergraduate students in STEM areas with outstanding results and increased student satisfaction. University students are motivated, and conceive, design, implement, and operate technical systems and equipment. This project expanded this excellence in teaching to potential future students and created pathways and partnerships for future engagement.

The importance of maintaining strong and sustainable partnerships as students move through the educational “pipeline” is also critical to the success of females in STEM (McAnalley, 1991). As Kaspura (2012) noted, the value of partnerships between schools and tertiary institutions can lead to effective use of resources and creative opportunities that underpins the importance of STEM work and highlights opportunities to students as they develop new skills (Kaspura, 2012). Excursions beyond the school setting, as well as expert visitors to the school, have also been found to make STEM studies more attractive and interesting to girls. The Gender Issues, Science Education and Learning (GISEL) project in Finland reported in 2005 that female students preferred engaging in visits to industry and museums, as well as engaging with experts in their science classes, more than the normal science classes they had experienced (Roberts, 2014).

This project provided such visits and use of resources through a partnership between a large local, socio-economically diverse all-girls school and RMIT University. Unique in its status as a state-wide provider for girls from year 9 to 12, MacRobertson Girls’ High School, sought to remain at the forefront of education for girls in Australia. It is a public secondary school situated in the central city and is attended by students from a wide area of metropolitan Melbourne and beyond. The selective nature of entry results in a broad socio-economic and cultural mix and a strong commitment to academic excellence. MacRobertson Girls Secondary College, includes amongst its students cohort:

- students from non-English speaking backgrounds
- students from low socio-economic backgrounds

- students who will represent first in family to attend university
- students from regional areas.

The capacity to offer cutting-edge engineering workshops (electives) using technology unavailable in high school settings, adds value to the school's programmes and provides potential career pathways into STEM disciplines for girls.

## Techniques

The National STEM Strategy (OCS, 2014) prioritized a number of areas under Education and Training. These were the encouragement of more students to study science, mathematics, technology, and engineering at university; the improvement of student outcomes in maths and science, and the encouragement of non-traditional cohorts (girls) to pursue engineering and mathematics studies at university. This project addressed these Australian Government priorities and employed the following techniques:

- The development and partnership arrangement with a local girls' schools to release middle school girls in a weekly workshop (elective) for one term per year
- The staff and undergraduate mentoring of the girls in the engineering labs
- The arrangement of the workshops into group work and non-threatening problem-solving activities
- The use of high-tech engineering machinery and computer resources
- The opportunity to engage in mathematical activities to solve real-world problems
- The role-modelling of academic staff in these disciplines
- The aspirational changes that come from familiarity with tertiary study in these disciplines
- The improved knowledge of engineering and technology usage
- The incidental improvements in career expectations
- The engagement with tertiary staff who were passionate about their discipline areas
- The improvements in complex problem-solving

RMIT University aligned all its engineering programmes with Engineers Australia. This project also aligned with the Engineers Australia, Women in Engineering strategic plan by adopting two of the basic initiatives- to attract and support women.

## Methods

Over a 10-week period (one term) of visits, the girls were placed in groups and given a real world problem to solve (e.g., design a heart valve, design an artificial limb, design a mobile phone, design a pop-up shop, etc.). Students worked in the computer aided design (CAD) labs at RMIT University, with staff assistance and examined several design for manufacture case studies based on prior work /knowledge. They learned CAD and Desktop lab design to plan their models under the guidance of university staff and students.

Students were given a bill of allowable materials, including consumables, rapid prototyping polymers, laser cut sheet and low-cost ball bearings, etc. to use in their design and eventual model. Students presented their initial concepts and, based on feedback (primarily from peers/staff/university student mentors), the groups then refined their design and developed detailed CAD models. They were then able to engage with technical equipment within the machine design domain to 3D print their design into a working model. They used digital design and rapid prototyping tools which allowed hands-on activity and built interest in the application of mathematics to solve design problems.

Students had opportunities to make a series of physical models through fabrication to allow demonstration of their solutions that would not be otherwise possible. Students were thus contributing to the design, manufacture and testing of these models as working solutions to their real world problems. By engaging with physical models of technical systems, the girls were able to enhance their capacity to engage with emerging engineering technologies, as well as increasing their capacity to solve new and complex problems using problem-solving skills and mathematical knowledge.

The workshops took place over a 10-week period, with tertiary staff and university students role-modelling and mentoring the girls. The emphasis was placed upon enjoyment, problem-solving, introduction to advanced manufacturing technology, and shared solutions to produce the models.

At the conclusion of the term, students made presentations to their peers back in the school setting of the problem, solution, learning, and design models they had produced. The theme was *“making something out of maths.”* Staff involved in the project were able to obtain feedback and compile an evaluation report on the outcomes of the project.

# Results/Outcomes

The workshops and equipment within the Advanced Manufacturing Precinct at RMIT University is used by industry, undergraduate, and post-graduate students. The overwhelmingly positive feedback from university students indicated that problem-based hands-on learning design using high tech equipment successfully engaged tertiary students and led to improved knowledge and skill. This project extended these resources to female secondary school students at a stage where it was most likely to have a positive impact on their perceptions of engineering and mathematics middle school.

All students involved in the project were surveyed (written/paper) with a range of questions pertaining to their interest, involvement and future study intentions as part of the project. To date 50 middle school girls have been involved in the project, one class per semester. The project will continue into the next semester and a further 50 girls will be involved, providing stronger data. A number of girls were also involved in follow-up semi-structured interviews.

The survey questions were administered in line with RMIT University ethics guidelines and took place away from the university classrooms and labs. Participation in the survey, like the classes, was voluntary and appropriate permissions were sought from parents/guardians. A 90% response rate was received on the survey and the project leaders had additional access to semi-structured interviews with volunteer girls. The following discussion was drawn from the survey data and interviews.

A key objective of this project was to expose middle school girls to using mathematics in design and additive manufacturing. The students were asked questions about the CAD (computer assisted design) software they had used, and were asked if they had enjoyed the CAD sessions and making their final product. Of all students participating in the survey, 90% felt the sessions were enjoyable and that they had a positive experience using CAD. Only 10% did not like the CAD sessions, citing reasons such as it being "Too hard" and the need for greater patience and some assistance with homework tasks. The positive responses, detailed in Table 1, were further endorsed by the student interviews, with students outlining how their learning experiences had been enjoyable, and trials of new things:

"This was really good fun. I have really enjoyed the CAD work. I did not know how to use such software and in the first workshop I was drawing my own name!"

The experience of learning engagement was fuelled by the use of interesting technology and its practical applications. Students echoed the excitement of using technology to get results from the very first session:

"Right from the start, the teacher got us to design the key ring. I really didn't think I could do it, but the CAD just took my ideas and stretched them into designs that I could alter."

“I didn’t think I could do it…when we looked at the final phone cover, I said I would never make it…but I did…I even started helping others who hadn’t finished…”

“Using CAD at uni….was wow!”

When asked if there was any maths involved in their manufactured project, 85% of the students recognized the role of maths in their design projects. Seeing maths in action using the university workshops was both explicit and implicit and the students’ positive responses highlighted this:

“Well, you had to measure it ….my key ring would have been too big to fit through the front door, so my calculations were wrong….you had to be spot on, otherwise the printing would be all tied up and the thing wouldn’t look like a key ring.”

“At first I thought we just had to draw it and then it could be manufactured, but the measurements and ratios had to be perfect for the 3 D printing.”

The students used technology that was unavailable at their secondary school and their responses to this technology were also positive. Of all students participating, 95% enjoyed using the 3D printers and printing equipment, whilst overall 90% of the students enjoyed visiting the Advanced Manufacturing precinct and using the equipment. The only negative responses (10%) referred to the distance to the university and the size of the campus.

When participants were asked as to whether their experiences in the workshops had changed their minds or strengthened their intentions about maths study at senior levels, 85% felt they would go on to study maths at senior levels, with a similar number intending to consider engineering as a university option. The technology introduced to the students in this project impacted upon their thinking about senior secondary maths study and the study of maths beyond high school.

The majority of the students saw a link between the advanced manufacturing technology and the study of mathematics, along with a link between real-life solutions, maths, and technology. The excitement and engagement created by the technology aroused interest in the need to study maths beyond the compulsory years and to reconsider career options in STEM disciplines.

Participants in the semi-structured interviews were asked what they felt could be improved in the workshop sessions. Their responses indicated their desire for more opportunities to use the technology:

“I would just say more time and using the equipment again….we only had two sessions on the 3 D printing and I would have liked more”

“Just do it again, it was fun.”

“I told all my friends to sign up for this elective…you get to use real stuff and really cool equipment”

This project has resulted in direct impact upon:

- 50 secondary school students-all girls (a further 50 in next semester 2015)
- Maths and science high school teachers at MacRobertson Girls Secondary School (approximately four staff)

In addition, this project also indirectly impacted upon:

- All teachers at MacRobertson Girls Secondary School (approximately 109 staff)
- All students at MacRobertson Girls Secondary School (approximately 900 students)
- Tertiary staff involved in engineering education.( approximately 63 RMIT University)

# Scholarly Significance of the Work

This project involved only a small number of girls and staff from RMIT University- this is an obvious limitation. Further workshops are being conducted as the project progresses into the second semester. It is also important to be cautious about the overwhelmingly positive results: the girls volunteered to undertake these workshops as electives in their annual programme- they were self-selected and keen to trial new approaches and work. Such positive results may not be reflected in other student samples. However, it was evident from this small study that the use of advanced technology can fuel interest and enjoyment in STEM-related disciplines in Australian classrooms. It was also evident from the data collected that using such technology to “make something of value” can highlight the importance of mathematics and its value as a school subject. As a gateway subject, the study of maths is critical to STEM-related tertiary study and in this project the use of technology to support maths learning yielded a positive result. Roberts (2014) has highlighted the importance of mathematics as a gateway subject to STEM studies at tertiary levels in Australia. Her work identifies the decline of interest in young school girls in studying maths at high school and the importance of a range of initiatives to combat this decline. This project, through its results and outcomes, identifies one initiative that realizes this importance.

Forssen, Lauriski-Karriker, Harriger and Moskal, (2011) have all called for future research to examine the long-term stability of the witnessed change in female students’ attitudes as well as methods for maintaining and further encouraging female interests in STEM. This research adds to this need for future research into females’ learning needs in STEM.

Finally this project and the research paper add to the growing body of knowledge around STEM education and future learning initiatives (Tytler, 2007).

## Conclusions

If Australia is to be a productive and progressive economy in the future, a workforce of scientifically and technologically literate people is required. Australia is in the bottom third of all OECD nations in the proportion of girls studying mathematics and technology at undergraduate level. One of the key issues in female students undertaking tertiary study in technology disciplines is the importance of maintaining mathematics as a subject beyond the compulsory secondary school years. Within Australia, the study of mathematics at senior school levels has been in decline for over two decades. This project used the advanced technology available on a university campus to introduce secondary school girls (years 9 and 10) to creative workshop opportunities. A key aim of the project was met: to stimulate interest in technology and mathematics amongst young female secondary students. The girls had opportunities to engage with technology such as 3D printers, CAD, and advanced manufacturing robotics to design solutions to real-world problems. Teaching and learning techniques specifically targeted at the ways girls like to learn,-group work, role modelling and peer mentoring, were used in the university settings. Students were engaged with the capability to conceive, design, implement and operate technical systems and equipment.

The project results overwhelmingly indicated significant student satisfaction with the use of the advanced technology and its capabilities; greater interest in technology-related STEM careers; and a deeper understanding of the importance of studying mathematics in senior secondary years. The success of the project has also fuelled interest for on-going partnerships and student workshops in engineering and advanced manufacturing.

It is anticipated that the interest and satisfaction derived from this project will drive further interest for future electives within this and other secondary school settings and drive interest in studying mathematics and engineering at university. Such interest and STEM understanding benefits not only the individual student, but future Australian society. Only when we have achieved this greater interest and STEM understanding, will it be possible to say we have *Made Something out of Maths*.

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Table 1

*Student Responses to Survey*

| Survey Question | Yes/Positive % | No/Negative % | Unsure/Other |
|---|---|---|---|
| Did you enjoy using CAD? Why or why not? | 90% | 10% | • Too hard<br>• Needs patience<br>• Homework help |
| Is there any maths involved in your manufactured project? | 85% | 0% | 15%<br>• unsure |
| Did you enjoy using the 3D printers? Why or why not? | 95% | 5% | • Unclear directions<br>• Failed/poor prints |
| Have you enjoyed using the RMIT workshops? | 90% | 10% | • Too early<br>• Too far to walk<br>• Too big/lost |
| Would you encourage other girls to do this elective? Why or why not? | 100% | | • Exciting/new<br>• Fun, new equipment<br>• Research labs<br>• Friends |
| Have the sessions changed your mind or strengthened your intention to study maths at senior high school? | 85% | | 15%<br>• Always intended, regardless of workshops<br>• Depends on other factors, parents, teachers, results, etc. |
| Have these sessions encouraged you to think about studying maths or engineering when you leave school? | 85% | | 15%<br>• Undecided what to study beyond school |