![acara AUSTRALIAN CURRICULUM, ASSESSMENT AND REPORTING AUTHORITY]

ACARA STEM CONNECTIONS PROJECT REPORT

June 2016

Australian **CURRICULUM**

ACARA STEM CONNECTIONS PROJECT REPORT

June 2016

Contents

INTRODUCTION

Science, Technologies, Engineering and Mathematics (STEM) and STEM education have become the focus of considerable political, industry and media commentary. Widespread concern about Australia's performance in STEM disciplines and take-up of STEM careers has resulted in the development of the National School STEM Education Strategy (Education Council, 2015) that is to be implemented from 2016 – 2026.

In 2014–15, the Australian Curriculum, Assessment and Reporting Authority (ACARA) conducted a small action research project, the STEM Connections Project. This project was run in conjunction with the Australian Association of Mathematics Teachers (AAMT) and investigated the effectiveness of using an integrated approach to the teaching and learning of STEM disciplines. ACARA and AAMT worked with and supported 13 schools from around the country to develop an integrated STEM project that had its basis in the real world and incorporated the Australian Curriculum learning areas of Mathematics, Science and Technologies. Schools were also encouraged to identify aspects of the Work Studies curriculum and involve one or more industry partners in their project.

Purpose of report

The purpose of this report is to synthesise the information arising from the project and the observations and reflections made by the teachers and students and provide insight into a range of integrated teaching approaches.

This report is qualitative, drawing on the information provided by schools in their final reports. The school report template asked teachers to reflect on the first five aims. In addition, they were asked to comment more generally on student attitudes and to describe the type of assessment used.

Additional information was informally gathered through interviews conducted during school visits, and through five illustrations of practice videos to be published in 2016 on the Australian Curriculum website.
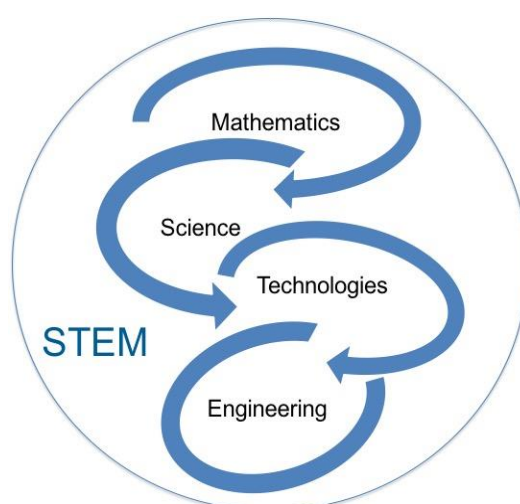

Figure 1. Learning areas involved in the STEM Connections project

BACKGROUND[1]

Australia's Chief Scientist has highlighted the need for STEM qualified Australians. STEM skills in the workplace are widely recognised as being crucial to our long-term future.

> *It is the knowledge that STEM will offer and the sensible application of that knowledge that are the means to the end: building a stronger Australia with a competitive economy. (Science, Technology, Engineering and Mathematics: Australia' Future paper*; Office of the Chief Scientist, 2014, page 5)

STEM education:

- is a national priority
- is closely linked to Australia's productivity and economic well-being
- is central to a well-rounded education
- will contribute to a diverse and capable STEM workforce pipeline.

The *National STEM School Education Strategy* (Education Council 2015) has addressed earlier concerns about the lack of a consistent definition of STEM or of a coordinated and coherent national approach to STEM education in schools. The strategy describes STEM education as:

- a term used to refer collectively to the teaching of the disciplines within its umbrella (science, technology, engineering and mathematics)
- a cross-disciplinary approach to teaching that increases student interest in STEM-related fields and improves students' problem-solving and critical analysis skills.

The strategy outlines five areas for action in STEM education around Australia:

1. increasing student STEM ability, engagement, participation and aspiration
2. increasing teacher capacity and STEM teaching quality
3. supporting STEM education opportunities within school systems
4. facilitating effective partnerships with tertiary education providers, business and industry
5. building a strong evidence base.

---

[1] Refer to reference section for a list of references related to research behind the project background.

PROJECT AIMS

While the STEM Connections project preceded the publication of the *National STEM School Education Strategy (2015)*, it did address all the areas for action identified in the strategy, either directly or indirectly. The major purpose of this project was to explore potential connections between STEM disciplines in the Australian Curriculum by implementing an integrated, project-based approach to the teaching of STEM. The aims of this project were to:

1. help students recognise the importance of knowledge, understanding and skills across STEM subjects

2. improve the confidence of students in STEM and their capacity to transfer knowledge, understanding and skill across STEM subjects and contexts

3. identify explicit connections for students between classroom learning in STEM and future work and learning opportunities

4. develop strategies that encourage girls to remain engaged in STEM subjects

5. establish guidelines for developing school–industry STEM initiatives

6. enable dialogue about the collaborative development of an integrated STEM program of study or subject.
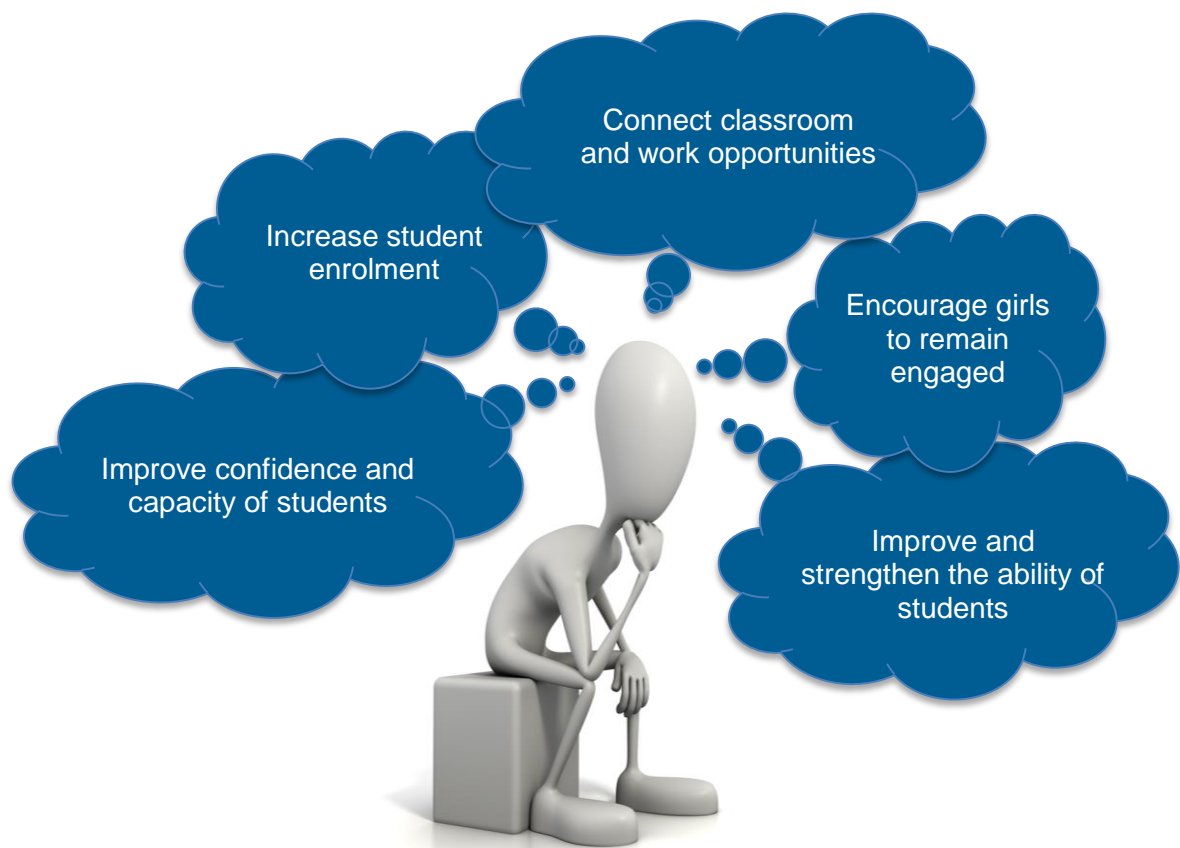

Figure 2. Why should teachers use integrated STEM approach?

STEM IN THE AUSTRALIAN CURRICULUM

STEM is addressed in the Australian Curriculum through the learning areas of Science, Technologies and Mathematics, and through general capabilities, particularly Numeracy, Information and Communication Technology (ICT) capability, and Critical and Creative Thinking.

Engineering is addressed in Design and Technologies through a dedicated content description at each band that focuses on engineering principles and systems. It is presented across the curriculum through Science, Digital Technologies and Mathematics. Engineering often provides a context for STEM learning.

Evidence from the project suggests that STEM knowledge, understanding and skills seem to be:

- strengthened when the connections between learning areas are emphasised

- enriched when learning areas combine to find authentic learning opportunities for students in answer to an identified problem or in the creation of a solution.
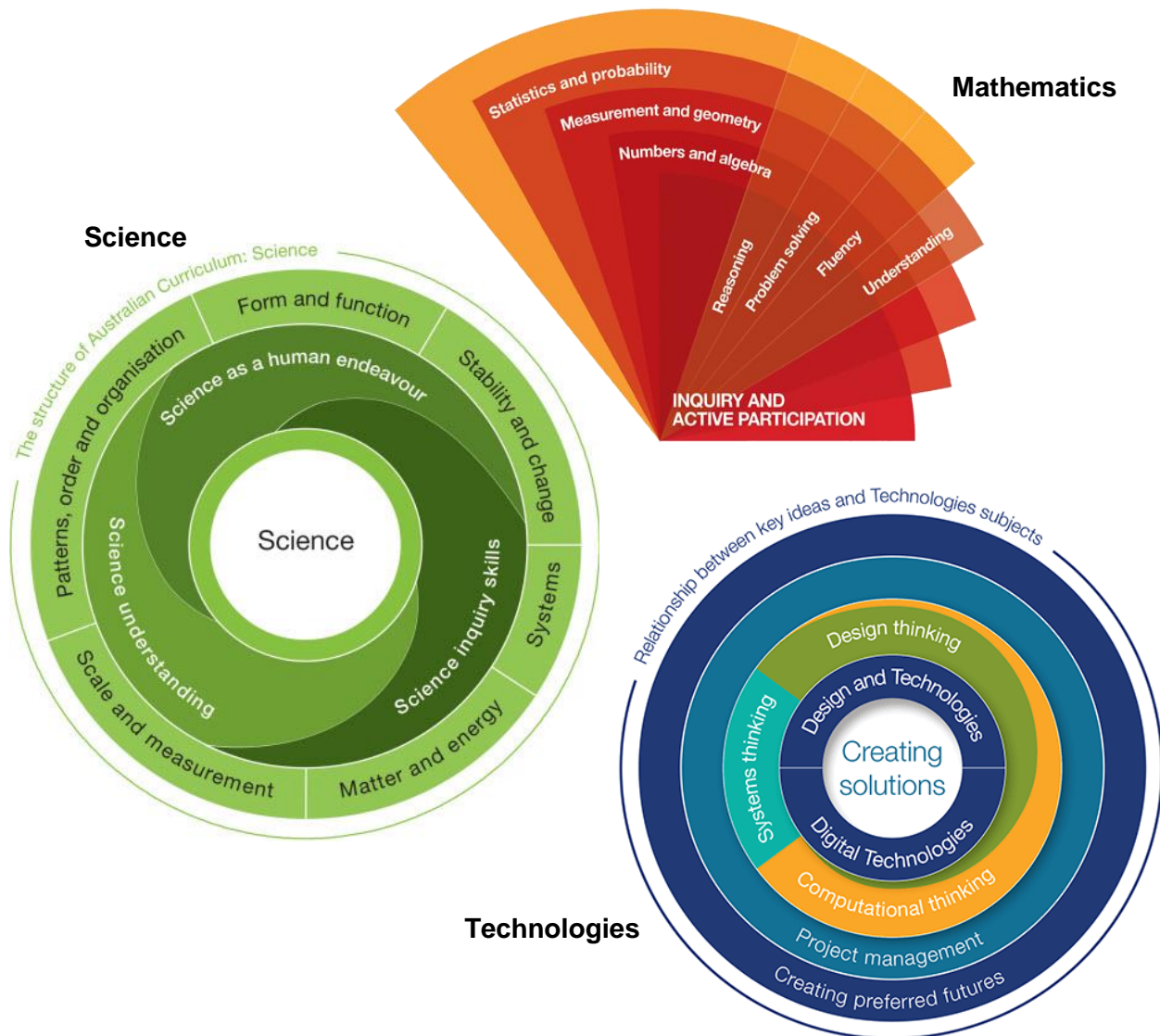

Figure 3. STEM in the Australian Curriculum

SCHOOL PROJECTS: ANOVERVIEW

Project types

School projects fell into one of two categories:

- pre-existing, well-tried projects with a defined outcome

- original projects, designed to appeal to the interests of students or to respond to a particular school or local context.

Pre-existing projects have two advantages: their high levels of structure and support can make them a good choice for schools wanting to try STEM-based learning for the first time; and they can be repeated. Their principal disadvantages are that teachers and students do not 'own' projects in the same way as original projects, and they do not make their own connections between STEM disciplines.

The majority of the projects were based on original ideas, in that they were new to the school, the teachers and the students. Many schools selected projects that either addressed a particular school-based problem or tapped into students' interests.

The benefits of such projects are the high levels of student engagement resulting from a personal or local focus of their work and the high degree of personal satisfaction when a sound proposal is completed or a product made. In this STEM Connections project, these are particularly evident where students can see the impact of their local school context.

> *Wow, I actually made this. It looks good and you can show people that this is what we learnt and we did a good job with it and we enjoyed it. I enjoyed it. (Simonds Catholic College student talking about the vertical garden)*

School projects

The projects undertaken by schools address a broad range of problems, needs or opportunities. These were as follows

- sustainable biofuels (Henley High School, SA)

- solar photovoltaic power with robotic movement (Merici College, ACT)

- safe water quality in rainwater tanks (Redlynch State College, Qld)

- design of a school sustainability centre (Northcote High School, Vic.)

- redesign of the school playground (Cherrybrook Technology High School, NSW)

- design of an app for new students (St Michael's Collegiate, Tas)

- redesign and adaption of mousetrap dragsters (The Canobolas Rural Technology High School, NSW)

- design, development and marketing of an F1 racer (Balga Senior High School, WA)

- effect of exercise on health (Duncraig Senior High School, WA).

- design and construction of a vertical garden in the school grounds (Simonds Catholic College, Vic)

- innovation, design and marketing of a personal grooming product (Heathfield High School, SA)
- promotional campaign to raise awareness of impact of introduced species in the Northern Territory (O'Loughlin Catholic College, NT).

Models of delivery

There were three main models for delivery: a single elective class, multiple classes with subject overlap, and separate class(es) for each learning area, but each model focused on the common project and its outcomes.

Single elective classes were structured in one of three ways:

- one teacher leading the major learning area, with support from teachers of the two other learning areas
- two teachers covering two of the learning areas together, with support from one teacher of the third learning area
- full team teaching covering all three learning areas.

Multiple classes that taught one or more subjects to the same class group worked in three ways. This model involved:

- two teachers covering two of the learning areas together as a team, with additional classes for the third learning area
- one teacher covering two of the learning areas, with additional classes for the third learning area
- one teacher covering one of the learning areas, with support from two teachers of the other learning areas.

Classes were taught separately for each learning area with*:*

- extensive joint teacher planning and coordination
- a single learning area as the basis of the project and teaching in other areas occurring as needed.
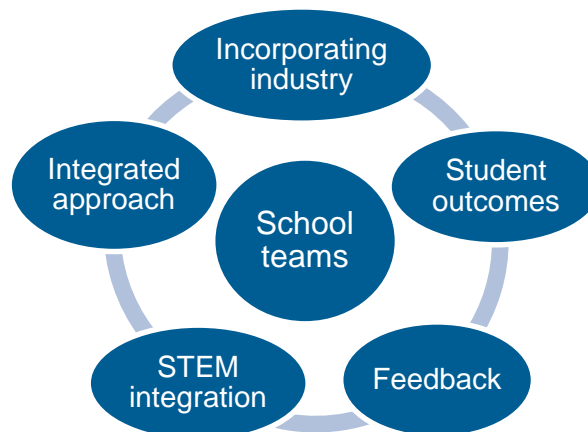

Figure 4. STEM Connections project overview

REPORT ON PROJECT AIMS – QUALITATIVE DATA

Participating schools were asked to report against the project aims as part of their evaluation. This section provides a summary of their responses and outlines additional benefits of the project.

Aim 1: Support students to recognise the importance of knowledge, understanding and skills across STEM subjects

This aim was largely addressed through the range of content descriptions covered. All schools reported that original intentions for content coverage were ambitious, often because of time constraints. Teachers made modifications as the projects progressed in response to student need.

Teachers also commented that the depth of coverage of the three learning areas varied. This had been anticipated because of the nature of the project itself.

As most schools were not teaching Work Studies as a discrete subject, they tended to cover its content holistically.

Learning area feedback
Science

Schools were generally satisfied with the coverage of the Science content descriptions. Most dealt thoroughly with the Science Inquiry Skills strand, as students formulated questions for scientific investigations, planned and conducted field work or experiments, and collected and recorded data. It was through processing data and drawing conclusions that students were able to work towards a solution, using their science knowledge in the process.

> *Evidence was shown in some of the science reports where students noticed or identified some abnormal changes to their readings. They then hypothesized and looked further into this abnormality in data. (Redlynch State College)*

Science content targeted in the projects was diverse:

- motion and aerodynamics
- energy transfer and renewable energy
- global systems and their interactions
- abiotic factors and biotic interactions with plants
- body systems and interconnectedness
- atoms, chemical reactions, acids and bases
- data trends
- ethics and human impacts on ecosystems.

Teachers reported strong evidence of learning in students' written and oral presentations (especially in laboratory reports) and how they evaluated findings, using scientific evidence to support their claims.

> *In particular, the average level of understanding and analysis demonstrated in their final experimental reports was better than the reports produced for experimental investigations by previous Year 9 cohorts. (Merici College)*

Technologies

Many schools found that Technologies was a key driver of the project as a whole, especially when the solution involved development of a product. As a result, the number of Technologies content descriptions tended to be high. Of key significance were:

- innovation, enterprise and production skills

- the design process, including

- investigating and defining (design briefs, design thinking)

- generating and designing (communicating possible solutions including drawings, models, prototypes)

- producing and implementing

- evaluating

- collaborating and managing (developing project plans and project management).

> *The code was continually being tested and students uploaded Beta versions onto iPhones to test, find faults and eventually redesign their section of the applet. (St Michael's Collegiate)*

As in Science, the nature of the projects dictated the specific technologies and associated skills to be used. Depending upon the project, the students used a range of technologies, including laser cutting, CAD design and 3D modelling, and a range of materials.

> *Students achieved a designed solution based on research through prototyping, experimentation … and internet research. (The Canobolas Rural Technology High School)*

Mathematics

School reports indicate that Mathematics was the most difficult learning area to plan for in the project. Some teachers commented that they found it hard to integrate Mathematics effectively into those projects that were focused on Science or Technologies.

Mathematics content typically planned for inclusion included:

- collecting, representing and interpreting data

- linear measurement, scale ratios and similarity

- measurement of area and volume

- Pythagoras' theorem and trigonometry

- the Cartesian plane

- financial mathematics.

A diverse range of topics were addressed incidentally as part of the problem-solving process for the project, with some falling outside the scope of Years 9–10 Mathematics. These included:

- Simpson's Rule
- radian measure
- exponential growth and log functions.

'Just in time' teaching of mathematical concepts was valued by teachers and students as they could see the direct applicability of mathematics. Transfer was increased and teachers commented that students could engage in the learning area better.

> *Students were doing real mathematics ... they had all these data in front of them, they had to draw conclusions and interpret them in ways that were deeply analytical … they were trying to present an argument, justify the case they were making and they were doing it all on mathematical grounds …*
> *(Cherrybrook Technology High School)*

The real benefits of this project for mathematics learning came through students being able to connect their learning directly to real world problems. Teachers reported that students were more independent and persistent than they would typically be, as mathematics was needed to draw a conclusion or formulate a solution.

> *Students had significant learning in how to grapple with large sets of real data, how to represent and interpret these for a purpose. (Heathfield High School)*

> *The understanding they have gained and their confidence and disposition to use those (maths) skills was far deeper and far more comprehensive than if I simply took the approach of saying here is an algorithm I need you to replicate and master these skills. (Cherrybrook Technology High School)*

The nature of project-based learning lends itself to the explicit development of problem-solving and reasoning and the incorporation of the Mathematics proficiencies.

> *The proficiencies were particularly evident. (Heathfield High School)*

Work Studies

Because of the recent introduction of Work Studies and its elective nature, only three participating schools commented directly on Work Studies. Nonetheless, teachers were able to comment on generalised behaviour and attitudes in relation to work. Most comments were about the importance of teamwork and collaboration, enhancing personal potential, establishing connections with others (including clients) and building positive relationships. Other schools mentioned entrepreneurial behaviours.

> *Throughout the design and creation process, students were observed in regard to their abilities to communicate and work effectively in a team, research and analyse information and present information to others verbally. (The Canobolas Rural Technology High School)*

> *In Work Studies, the students have worked on their oral presentation skills …*
> *Students have worked in teams during their extended investigation to develop*
> *an understanding of strengths within a team. (Balga Senior High School)*

Work Studies was seen as being addressed implicitly rather than explicitly. There were comments, however, that it played a greater role than initially thought.

> *We found that the general capabilities and Work Studies content descriptions*
> *that we identified were addressed more significantly than we originally thought*
> *would be the case. (Heathfield High School)*

Informally, teachers commented on the work-ready qualities being developed throughout the project, such as learning to work with others and appreciating individual learning preferences.

Aim 2: Improve the confidence of students in STEM and their capacity to transfer knowledge, understanding and skill across subjects and contexts

There was a general consensus that student confidence increased over the period of the project. This was most notable with students' presentation skills and their ability to respond to questions about the project and its processes. Some surmised that the novelty of working in a cross-curricular fashion in teams for a substantial period of time may have added to student engagement. Despite this, some teachers commented that the change in attitude was not significant.

> *Most of the students were more engaged in the integrated STEM approach.*
> *Students often commented that they liked that their learning applied to real*
> *life. The students felt more trusted and grown up when given a real life task.*
> *They also liked having a bigger goal to work towards, rather than feeling like*
> *they were just learning for the exam. (Northcote High School)*

> *While I did not collect any evidence of this, the best evidence of this would be*
> *video footage from the expo. Students confidently explained their biofuels and*
> *the details of their experiments and performed extremely well under scrutiny*
> *and questioning. (Henley High School)*

Some schools found that positive feedback came from families of the students.

> *Informal feedback from parents indicated that students had developed*
> *confidence and engaged more through this project. They indicated that*
> *students were more motivated and willingly spending time outside of school*
> *focusing on aspects of the project. (Merici College)*

However, the integrated approach was not universally well received. Although attitudes were reported to be predominantly positive, some schools reported that reactions were mixed.

> *There were one or two students who didn't like the approach, though. They*
> *preferred having subjects taught to them separately as they found it difficult*
> *always trying to link one area of learning to another and often found it more*
> *difficult than if theory had been taught in distinct blocks. (Northcote High*
> *School)*

Overall engagement was high, even though this engagement fluctuated, depending upon the status of the project.

One of the key objectives of the STEM connections project was to investigate whether integrated approaches to teaching STEM would improve students' abilities to transfer their skills. AAMT's research indicates the importance of introducing students explicitly to a range of contexts in which mathematical skills are needed.

> *Given that the transfer of mathematical skill to the workplace is not straightforward, there is a need to promote the teaching of mathematical skills and understandings in a way that encourages transfer. The more contexts in which students are explicitly required and supported to transfer their mathematics, the more highly developed these skills will become. (AAMT, Identifying and Supporting Quantitative Skills of 21st Century Workers Final Report. 2014: p 4).*

The integrated nature of the projects provided opportunities for making the transfer of knowledge, understanding and skills between learning areas explicit. However, student understanding of the connections between the learning areas and their ability to transfer skills were only partially developed. The connections between some subjects were clearer than between others. This seemed to be a consequence of the project selection.

> *In Mathematics (for one of the classes), transferability of skills has been evident with students readily drawing on and using knowledge and skills from the project. (Heathfield High School)*

> *… they saw STEM as a separate topic rather than making the lessons integrated and relevant to the real world. (O'Loughlin Catholic College)*

There was acknowledgement that the integrated nature of the projects naturally led to some degree of transfer, but that teachers played a key role in making this explicit to students.

> *Due to explicit connections being drawn, they could also easily see the connections with mathematics; however, the connections with the science they were learning in their Year 9 class was a little more of a stretch for them. (St Michael's Collegiate)*

> *The teachers involved in the project were very explicit in acknowledging the knowledge and skills attained across the STEM domains and this gave students the opportunity to reinforce and "remember", and **somewhat transfer** [this author's emphasis] the knowledge and skills across the learning areas. (Simonds Catholic College)*

> *Some students showed an improved confidence in STEM, but still struggled to effectively apply skills across subjects. … we still feel that they have a better appreciation of the interdisciplinary nature of STEM than if they had not participated in this project. (Merici College)*

Some evidence for identification of the links between learning areas emerged from the students' final reports and blog entries. Several teachers made specific comments about students now seeing directly the links between mathematics and science. For example, students were able to relate mathematics formulas to science experiments.

Aim 3: Identify explicit connections for students between classroom learning in STEM, and future work and learning opportunities

Overall, the connections between classroom learning and work opportunities were successful. Many of the teachers' comments attributed this success to the involvement of industry and community partners.

> *The industry involvement really helped in this area. Being able to talk to people who did this for a living highlighted career opportunities. (St Michael's Collegiate)*

In pre-surveys, students most often identified engineering and related science-based careers as STEM-related options. Post-surveys showed that students had a significantly wider understanding of STEM-related careers, such as landscape architecture, manufacturing, project management, finance and marketing.

> *If, for example, a student was interested in a career where they worked with animals, they discovered how important and integral mathematics and science were to the process, and how they are intertwined. (O'Loughlin Catholic College)*

> *From the post-project reflection tool, "Letter of Advice to Future Students", many students identified that they now had a better understanding of how mathematics, science and technologies go hand-in-hand in the workplace and the types of careers that require these skills. (Heathfield High School)*

> *By the final survey, the responses were more sophisticated and included a much better understanding of which careers involved STEM. Every student gave at least a reasonable and accurate response. (Merici College)*

Industry and community partnerships contributed to the project in two major ways: they provided expertise and guidance in a specific technical or business way; and they informed students of potential careers and the skills that employers were seeking. The partners were able to present a very broad range of careers to students; and students were able to see the nature of problem-solving involved in those careers.

> *The ability to problem-solve was a prevalent feature of this unit of work, with many students able to share multiple examples of careers where their ability to problem-solve would improve their ability to be an effective employee. (The Canobolas Rural Technology High School)*

Aim 4: Develop strategies that encourage girls to remain engaged in STEM subjects

This aim was regarded as being beyond the reach of the project schools. Instead, schools evaluated the engagement of girls in the STEM connections project itself.

The responses ranged from no evidence of difference to comments that the girls appeared to be more engaged.

> *As evidence was not formally gathered, it is difficult to comment. Informal discussions and interviews did not identify any obvious negativity to the concept of STEM projects. (Redlynch State College)*

School reports identified two aspects as playing a significant role in the engagement of girls: the appeal of the project itself, and the group work that predominated.

As the projects were developed to suit the context of the school and appeal to student interests, it is not surprising that there was no appreciable difference in level of engagement. While some schools deliberately targeted projects according to apparent gender interests, this was not typical.

> *… using iPhone and Apple devices was chosen specifically to appeal to design side that often appeals to female students. (St Michael's Collegiate)*

> *This project was conducted with mixed groups of students. The project was not exclusive and many of the male and female students were deeply engaged in the project. (Northcote High School)*

> *The girls in the STEM class were just as engaged as the boys. (Cherrybrook Technology High School)*

Schools with mixed gender classes found that the higher achieving teams were typically all female.

> *The winning team was all girls, and they loved it. (Henley High School)*

> *The three female groups produced the best performing designs. One group produced the most radical design; one, the fastest dragster; and one, the furthest travelling dragster. (The Canobolas Rural Technology High School)*

Overall, however, the project context did not appear to have had any influence on the engagement of either boys or girls.

Many comments reflected on the type of roles undertaken by girls. Within the groups, girls seemed to be much more willing to take on the role of team leader or manager.

> *They commonly assumed the role of project leader / manager. (Cherrybrook Technology High School)*

> *Girls were generally more dominant in leading and directing group discussions with superior communication and relational skills (particularly in the class where students were more challenged by this project). (Heathfield High School)*

> *In Graphics, there were more girls who were more eager to manage the website and to polish the work that was produced. (O'Loughlin Catholic College)*

> *The girls were often the leaders of their groups as we had two boys / two girls. Girls needed to organise the boys and give them clear tasks to achieve. (Henley High School)*

The group or team approach seemed to suit girls well.

Aim 5: Establish guidelines for developing school–industry STEM initiatives

Rather than establishing guidelines for developing school–industry partnerships, reports concentrated on describing the nature of their partnerships. The advice given was general in

nature and focused on the need for clear and regular communication, and careful planning for industry engagement.

> *One of the main things that you need is to keep the lines of communication open between you and them [industry partners] as we are not obviously their key priority. We do this by doing thank you presentations at their places of work and engaging the local newspapers with our stories where we can. (Balga State High School)*

Having a clear plan for industry engagement had implications for project management and timing, as interventions were not necessarily anticipated. The success of the partnerships relied very much on the goodwill of both sides.

There were three kinds of partnership: research/academic, private sector and community. Many schools used a combination of partnerships. The industry partners provided background information, expert advice and school support.

All three types of partnerships provided project management advice and planning assistance, technical advice, presentations to students about the nature of the work or potential careers and input into judging the final product.

Private sector and community-based partnerships also supported students with the design and marketing of their product. Some provided background briefings to staff and gave financial support to schools.

Some of the partnerships consisted of a single interaction, such as a guest speaker, hosting a single field trip or providing a staff training session. Other partnerships engaged more deeply by providing continuing technical advice, having direct involvement in classes and with students, assisting with design and planning, and conducting meetings with team leaders and the teaching team.

> *[Partners] … were very impressed with the engagement shown by students and this led to them wanting to give more of their time and resources to support the project and to continue a partnership with us in the future. (Heathfield High School)*

Schools generally found it difficult to maximise the industry partnerships because the newness of the venture meant they had only partially formed ideas of how a partner could contribute to the project and when assistance would be most opportune.

> *… the project benefited from the insight of multiple people at different points of the program as the project itself was exploratory and did not have a definitive right or wrong. Therefore, the team didn't know at the time of commencing the project what type of information the students would need. (Cherrybrook Technology High School)*

Despite this, many schools felt that they received more from their industry partners than they had expected. This took the form of additional student or teacher support.

> *A fringe benefit of the relationship was the professional development gained by those teaching engineering in our school from working with university*

engineering professor, which was not originally planned. (The Canobolas Rural Technology High School)

Schools and teachers found real benefit in including partners in the assessment of the final product/output, as this added authenticity to the project. It was also regarded as a good way of completing the project, informing the partner of the outcome(s), and using external expertise to provide feedback to students through sophisticated conversations about their products.

School reflections on their partnerships were uniformly positive, and there was a strong feeling that this was an illuminating and valuable aspect of the project.

Aim 6: Enable dialogue about the collaborative development of an integrated STEM program of study or subject.

Schools were provided with the opportunity to collaborate across schools via the project's SharePoint site. However, there was little evidence of this occurring.

ADDITIONAL BENEFITS AND CHALLENGES

Benefits

Many teachers commented on the unanticipated benefits for their students from their involvement in the STEM Connections project. The development of general capabilities, such as Critical and Creative Thinking, and Personal and Social Capability, was overwhelmingly identified as an outcome for some students. They became evident in teamwork and collaboration, the breadth of communication skills developed and used, and the creative approaches to the project as a whole and to problem-solving in particular.

The predominant benefit for students was the development of increasingly mature and effective ways of working together. Students could take on different roles and work to their strengths. Some adapted well to leadership roles; others were happy to act in more supportive roles.

> *… all teams identified that they had learnt how important it was to work collaboratively, listen to each other, to take responsibility for their own actions, and to manage their time effectively so that timelines are met. (Heathfield High School)*

Many students commented in interviews that one of the benefits of the project was working with students with whom they would not normally interact. This engendered respect for others and helped create a collegial atmosphere. Students recognised that social skills were very important for a cohesive team. One school suggested that group dynamics be explored in earlier years to prepare students to undertake complex problem-based learning.

Completed projects usually required multiple modes of presentation and this enhanced students' communication skills. Students had to be adept at communicating through group discussions and oral presentations, as well as through text, visual/symbolic representations and physical models. For the final assessment, many schools chose a presentation of the completed project to an audience or formal judging panel. Students had to select the most appropriate modes for conveying their information and understanding to the target audience, and be prepared to justify their choices, decisions and solutions. Overwhelmingly, teachers commented on how competently and confidently students managed this.

The authentic contexts in which challenges were set led to students experiencing a real sense of purpose, which, in turn, increased engagement. The requirement to solve real-world problems led to the development of personal qualities such as persistence, independence and learning from mistakes. In most projects, there were substantial stumbling blocks along the way, due to equipment failure, difficult searches for data and problems with new technology.

Students also learned to be independent in their research and resourceful in their problem-solving, especially when they realised that their teachers did not necessarily have immediate answers.

> *The best indication of the students' development was informal assessment on how well they could problem-solve solutions to bugs in their code. This was a reflection of how resourceful they were in tracking down answers*

independently other than just relying on teacher assistance. (St Michael's Collegiate)

Interviews indicate that students enjoyed the open-ended challenges that encouraged creativity. Many commented that it was invigorating to be able to 'think outside the square' and that there were few limits to the aspects they could consider. They felt genuinely challenged and relished taking ownership of their own learning.

Benefits for staff

Many staff members were stimulated by, and pleased with, the positive effects of teacher collaboration in the STEM Connections project. By working closely with members outside of their faculties, they became more aware of the knowledge and skills being taught in other domains, and gained a higher degree of respect for these colleagues. They also strengthened their own knowledge of the links between various learning areas and were able to make those explicit links in their classrooms. By working together, consulting with each other, and sometimes teaching in team, teachers modelled well-developed group work and problem-solving skills to their classes.

Challenges
Staff

The open-ended nature of the projects and group work focus caused challenges for some staff. These fell into the following broad categories:

- the need to surrender their role as leader of learning and subject expert to allow greater autonomy for students
- classroom management and planning
    - uncertainty about when and what content would be required
    - monitoring progress when groups were all at different stages
    - handling group dynamics
- time commitments required for team-planning, resource-sharing, personal learning and communication across the school
- school constraints such as timetabling and staffing impact on the way the project could be delivered.

Students

Teachers reported that less confident learners did not like the freedom of the open-ended task; they tended to 'get lost', became disengaged and ended up wasting a lot of time. Some tasks needed more scaffolding for some groups.

Some students found it difficult to work in groups in the sustained way required by project-based learning. Teachers suggested that students needed some training in how to allocate tasks, take responsibility for particular tasks and manage their time sensibly. These students also needed some preparation for the interpersonal demands of working in groups, such as managing conflict resolution, and understanding the complex nature of leadership roles. It was suggested that organising the project later in the school year would allow for this kind of preparation and for increased maturity of the cohort.

CONCLUSIONS

In general, this project highlighted the strong and natural links between the Australian Curriculum: Science, Mathematics and Technologies. ACARA's STEM Connections project was well-received by participating schools, with the majority of students and teachers expressing enthusiasm about the 'real world' nature of the project, the integrated approach to teaching and learning, the collaboration required by participants and the sense of independence and responsibility developed by the students.

While not all aims of the project were fully met, the project demonstrated that an integrated STEM approach:

- has the potential to be very engaging for both students and teachers

- offers explicit opportunities to identify and consolidate connections between learning areas

- can deliver content from STEM disciplines throughout the life of an authentic project

- has the potential to improve students' ability to transfer knowledge and skills from one learning area to another or to other contexts

- can directly link school learning to future study and work opportunities, especially with the involvement of an industry partner

- develops students' ability to collaborate with others

- improves students' ability to communicate ideas and information to a range of audiences and to use a range of modes

- provides a rich context for learning and developing the general capabilities for 21st century learning.

The project also identified potential obstacles to an integrated STEM approach. It showed that the approach:

- needs a high degree of commitment and expertise from the staff involved, both during the planning and implementation phases

- can have significant implementation issues, regardless of the implementation model, in traditional school settings, as timetabling structures do not necessarily have the flexibility to accommodate such projects

- can result in inconsistent content coverage of some learning areas within a single project if planning is not thorough.

While the scale of the project does not make it possible to draw any definitive conclusions, it does add to the growing body of knowledge about STEM education in schools. The findings are sufficiently strong to suggest that further investigation would be beneficial.

REFERENCES

Australian Curriculum and Assessment Reporting Authority (ACARA) F–10 Curriculum. www.australiancurriculum.edu.au/mathematics/curriculum/f-10 (viewed November 2014) www.australiancurriculum.edu.au/science/curriculum/f-10 (viewed November 2014) www.australiancurriculum.edu.au/technologies/design-and-technologies/curriculum/f-10 (viewed November 2014) www.australiancurriculum.edu.au/work-studies/curriculum/f-10 (viewed November 2014)

Australian Association of Mathematics Teachers and the Australian Industry Group through the Office of the Chief Scientist 2014, *Identifying and Supporting Quantitative Skills of 21st Century Workers Final Report*. www.aamt.edu.au/Activities-and-projects/Workplace-maths-skills (viewed March 2015)

Australian Industry Group 2013, *Lifting our Science, Technology, Engineering and Maths (STEM) Skills Report*. www.aigroup.com.au/policy/reports (viewed October 2014)

Australian Industry Group 2015 *Progressing STEM Skills in Australia.* www.aigroup.com.au/portal/binary/com.epicentric.contentmanagement.servlet.ContentDeliveryServlet/LIVE_CONTENT/Publications/Reports/2015/14571_STEM%20Skills%20Report%20Final%20-.pdf (viewed November 2015)

Australian Workforce and Productivity Agency 2012, *Australia's Skills and Workforce Development Needs Discussion Paper*. www.awpa.gov.au/our work/Workforce%20development/national-workforce-development-strategy (viewed October 2014)

Australian Workforce and Productivity Agency 2013, *Future focus: 2013 National Workforce Development Strategy https://docs.education.gov.au/system/files/doc/other/futurefocus2013nwds-2013.pdf* (viewed April 2015)

Barrington F, Evans, M 2014*, Participation in Year 12 Mathematics 2004–2013:* Australian Mathematical Sciences Institute (AMSI) publication*,* http://amsi.org.au/publication-categories/publications/ (viewed August 2014*)*

Bjorklund, L 2013, *Why Do They not See What I See? The Difference between Knowing How and Knowing that*, in Middelton, HE, Baartman, LKJ (eds), Transfer, Transitions and Transformation of Learning*,* Sense Publishers, Rotterdam

Business Council of Australia & McKinsey & Company, 2014, *Building Australia's Comparative Advantages Discussion Paper* www.bca.com.au/publications/building-australias-comparative-advantages (viewed May 2015)

Cole, P 2012, (pdf) *Linking Effective Professional Learning with Effective Teaching Practice,* AITSL http://www.aitsl.edu.au/docs/default-source/default-document library/linking_effective_professional_learning_with_effective_teaching_practice_-_cole (viewed 16 June 2014)

De Vries, MJ, 2013 *Transfer in Technology through a concept-context approach*, Middelton, HE and Baartman, LKJ (eds) Transfer, Transitions and Transformation of Learning, Sense Publishers, Rotterdam

Education Council 2015, *National STEM School Education Strategy 2016–2026* www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf (viewed December 2015)

European Schoolnet, Engineering UK, InGenious & Intel, *Science, Technology, Engineering and Mathematics: Overcoming Challenges in Europe* 2011 www.ingenious-science.eu/c/document_library/get_file?uuid=3252e85a-125c-49c2-a090-eaeb3130737a&groupId=10136 (viewed October 2014)

Pilling R, MD BASF Australia and New Zealand. National President of the Australian Industry Group, '*Decline in science students a danger to the economy*', *Financial Review* Tuesday 1 July 2014

Goodrum, D, Druhan A, Abbs, J 2011, *The Status and Quality of Years 11 and 12 Science in Australian Schools,* Australian Academy of Science, Canberra

Marginson, S, Tytler, R, Freeman, B, Roberts, K 2013, *STEM: Country Comparisons. Report for the Australian Council of Learned Academies* www.acola.org.au/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf (viewed 20 June 2014)

Meyrick, K 2011, 'How STEM Education Improves Student Learning', *Meridian K–12 School Computer Technologies Journal*, vol. 14 No 1 http://ncsu.edu/meridian/summer2011/meyrick/print.html (viewed July 2014)

Nathan, M 2014, *Integration in K–12 STEM Education: Status, Prospects, and an Agenda for Research*, University of Wisconsin–Madison, 121st ASEE Annual Conference & Exposition

National Academy of Engineering and National Research Council 2014 *STEM Integration in K–12 Education: Status, Prospects and an Agenda for Research* www.nap.edu/catalog/18612/stem-integration-in-k12-education-status-prospects-and-an-agenda (viewed October 2014)

National STEM Centre *What is STEM?* www.nationalstemcentre.org.uk/stem-in-context/what-is-stem (viewed November 2015)

Office of the Chief Scientist 2012 *Mathematics, Engineering and Science in the National Interest.* Australian Government, Canberra www.chiefscientist.gov.au/wp-content/uploads/Office-of-the-Chief-Scientist-MES-Report-8-May-2012.pdf (viewed October 2014)

Office of the Chief Scientist 2014 *Science, Technology, Engineering and Mathematics: Australia's Future.* Australian Government, Canberra www.chiefscientist.gov.au/wpcontent/uploads/STEM_AustraliasFuture_Sept2014_Web.pdf (viewed November 2014)

Office of the Chief Scientist 2014 *Tackling the School – Industry Mathematics Divide*, www.chiefscientist.gov.au/wp-content/uploads/Office-of-the-Chief-Scientist-MES-Report-8-May-2012.pdf (viewed November 2015)

P21 2014 *Partnership for 21st Century Skills*. www.p21.org (viewed November 2014)

Sanders, M 2009 'STEM, STEM Education, STEMmania', *The Technology Teacher*, vol. 68 Number 4 December 2009 www.questia.com (viewed November 2014)

Scientix, the Community for Science Education in Europe 2014, *Building a STEM education community in Europe* www.youtube.com/watch?v=qmidAbl43wA (viewed October 2014)

Senate Committee on *Education, Employment and Workplace Relations Report* 2012, http://apo.org.au/research/shortage-engineering-and-related-employment-skills (viewed October 2014)

STEM Education Coalition 2013, *STEM Education Coalition 2013 Annual Report*, www.stemedcoalition.org/wp-content/uploads/2014/01/Note-2013-Annual-Report-for-the-STEM-Education-Coalition-Final1.pdf (viewed October 2014)

STEM Education Coalition 2012, *Statement of Core Principles:* www.stemedcoalition.org/wp-content/uploads/2012/04/Note-STEM-Education-Coalition-Core-Principles-2012.pdf (viewed October 2014)

STEMNET Science, Technology, Engineering and Mathematics Network, www.nationalstemcentre.org.uk (viewed October 2014)

Stohlmann, M, Moore, T, and Roehrig, G 2012, 'Considerations for Teaching Integrated STEM Education*' Journal of Pre-College Engineering Education Research* (J-PEER): vol. 2: iss. 1, article 4. http://dx.doi.org/10.5703/1288284314653 (viewed August 2015)

Strimel, G 2014*, 'Engineering by Design™: Preparing STEM teachers for the 21st century'*, PATT27 conference proceedings, Technology education for the future: a play on sustainability

Thompson, S, Hillman, K, Wernert, N, Schmidt, M, Buckley, S, and Munene, A 2012, *Highlights from TIMSS and PIRLS 2011 from Australia's perspective*, Australian Council for Educational Research www.acer.edu.au/files/TIMSS-PIRLS_Australian-Highlights.pdf (viewed 18 July 2014)

APPENDIX A: SCHOOL SUMMARIES

School	Location	Type			Enrolments
Balga Senior High School	West Perth, WA	Metropolitan	Government	Coeducational	800
The Canobolas Rural Technology High School	East Orange, NSW	Rural	Government	Coeducational	650
Cherrybrook Technology High School	North West Sydney, NSW	Metropolitan	Government	Coeducational	2000
Duncraig Senior High School	West Perth, WA	Metropolitan	Government	Coeducational	1000
Heathfield High School	Adelaide Hills, SA	Metropolitan	Government	Coeducational	870
Henley High School	Western suburbs, Adelaide, SA	Metropolitan	Government	Coeducational	1300
Merici College	Inner suburbs, Canberra, ACT	Metropolitan	Catholic	Girls	950
Northcote High School	Northern suburbs, Melbourne, Vic.	Metropolitan	Government	Coeducational	1600
O'Loughlin Catholic College	Karama, Darwin, NT	Provincial	Catholic	Coeducational	530
Redlynch State School	Cairns, Qld	Metropolitan	Government	Coeducational	1800
Simonds Catholic College	Inner suburbs, Melbourne, Vic.	Metropolitan	Catholic	Boys	500
St Michael's Collegiate	Hobart, Tas.	Metropolitan	Independent	Girls	400

APPENDIX B: TYPES OF MODELS

Single elective

St Michael's College

Elective class taught by the technologies teacher (who was also trained in mathematics and science).

One science teacher and one mathematics teacher supported the lead teacher. They did not teach the class as such; the students participating in the project were scattered through the normal science and mathematics classes.

Balga High School

Elective class team taught by three teachers who were present in all lessons, taking turns to be the lead depending on their area of expertise. One was mathematics/science trained, one librarian/technologies and the third had the role of language support.

The school had an ethos of enterprise, so there were a number of elective possibilities of which the F1 in Schools was one.

The Canobolas Rural Technology High School

Gifted and talented class taught in usual mathematics and science lessons by usual teachers.

The technology teacher joined the class as a guest lecturer when possible and was also available at some out-of-lesson times.

There were several half-day 'incursions' with all staff present.

Cherrybrook Technology High School

Elective technology class taken by one technology teacher.

Mathematics and science teachers were available occasionally as required as guest lecturers, but needed to have their usual classes covered in order to do this.

Northcote High School

One elective STEM class with one science/mathematics teacher but timetabled in science time.

Double lesson for design also taken by the single teacher but supported by the design staff when they could be released.

Multiple classes

Henley High School

Whole year level project taught in regular mathematics and science lessons.

There were eight classes, and each one was taught both mathematics and science by one teacher (the school has a middle school philosophy where one teacher will teach multiple subjects to their home class).

In addition, the Personal Learning Plan (PLP) time (sometimes staffed by the same teacher, sometimes not) was used.

Design and Technology was an elective, but at least one student from each group took this subject. Students were permitted to use their PLP time in the technology area if there was a suitable staff member available.

O'Loughlin Catholic College

Whole year level project taught in regular mathematics and science classes.

One teacher took all four science classes; the mathematics classes were delivered by four different teachers.

There was only one elective class for Design, Technology and Graphics.

An additional staff member was used for copyright research and editorial duties.

Duncraig High School

Two mixed ability classes delivered in normal science lessons.

Mathematics and technology teachers appeared as guest lecturers.

Heathfield High School

One STEM integrated class (Innovation and Future Studies), for which students had to apply.

This class (outside the STEM Connections project) has a focus on student-centred learning and a collaborative approach. It was taught by three teachers, one for each learning area.

There was one 'standard' mixed ability class (Advanced Technologies), where the subjects were studied separately and delivered by three different teachers.

Merici College

Two mixed ability classes timetabled so that students were in the same mathematics and science classes together.

Each class was team-taught by two teachers (one mathematics, one science).

The Information Technologies (IT) topic was Robotics and was taught by two different teachers. As IT was an elective, not all students selected it, so there were students who did the mathematics and science elements of the STEM Connections project but not the IT. However, all students participating in the project were involved in all three classes.

Separate classes

Redlynch High School

Three separate elective classes (Science Enrichment taught by a mathematics/science teacher, Graphics taught by a technology teacher, and Robotics taught by a technology teacher) taught by three different teachers with some interaction. Minimal common student enrolment.

A separate STEM coordinator (trained in design and technologies) oversaw the project.

Simonds Catholic College

Three separate subject classes, with mathematics and science for all.

The Technology subjects (Product Design Technologies and System Technologies) were electives, so only 25 percent of the STEM students did this in addition to mathematics and science. Therefore, not all students were involved in the actual manufacture or the several 'building' days.

APPENDIX C ADVICE FOR IMPLEMENTATION

Advice

School reports and surveys for students and staff members provided valuable insight into what contributes to a successful project.

Schools

Strong commitment from the school as a whole is vital for the success of such a project. Key to project success is a supportive school principal and school executive who recognise the importance of:

- resourcing, through provision of staff time, materials, time for incursions and excursions and presentation events

- developing a supportive whole-school ethos that encourages working with staff, students and parents to establish a shared understanding of STEM

- allowing for integrated approaches to assessment and reporting

- considering timetable flexibility to allow for team teaching, scheduling of regular meetings for the STEM team and overlap of STEM students between learning areas.

Staff

All staff involved in the STEM projects need to be fully committed to the underlying philosophy of integrated STEM teaching. They need to:

- be aware of the challenges, including time commitments, which lie ahead

- be willing to allow students a considerable degree of autonomy and responsibility for their own learning and to relinquish their role as the leader of learning

- work across learning areas and with digital technologies

- collaborate extensively with their colleagues in planning, preparation and teaching

- develop rich assessment task that cross learning areas

- be prepared to manage long-term student group work, including the provision of direct guidelines about working in groups.

Communication strategies

Communication is fundamental to the success of a project such as this. Project planning should incorporate regular communication:

- to the school community through updates about the progress of the project and the nature and value of the learning taking place

- within the teaching team through scheduled formal meetings (informal meetings to address concerns should be held as the need arises)

- between the school and their industry/business partners to ensure the development of strong relationships and commitment to the project.

Industry engagement

Industry engagement is of great value to the project, as it adds authenticity and gives opportunities for project teams to receive expert advice on their progress and product. Partnerships also help create positive community outreach, which is of mutual benefit.

When establishing partnerships it is important to:

- develop a clear idea of what the partner has and would like to offer in support of the project (ideally, the project plan would be developed with the industry partner)

- hold planning meetings well before the beginning of the project to develop an overview of, and schedule for, the interactions between industry and the project teams

- schedule regular meetings to share successes and challenges of the project and plan any joint interventions

- be generous in giving thanks to the industry/business partner.