From concept to classroom

Translating STEM education research into practice

Christine Rosicka

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From concept to classroom

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About this review

So much has been written and spoken about STEM education, it has reached the point where the interest in it is 'an almost universal preoccupation' (English, 2016).

There have been many government and industry reports that address STEM education, from the Office of the Chief Scientist (2014) and the Education Council (2015), to the Council of Learned Academies (Marginson, Tytler, Freeman & Roberts, 2013) and Price Waterhouse Coopers (Caplan, Baxendale & Le Feuvre, 2016). Blackley and Howell (2015) also provide a useful historical overview of the STEM education narrative.

These reports discuss the importance of STEM education for Australia's future workforce. The Office of the Chief Scientist states that 75 per cent of the fastest growing occupations require STEM knowledge (2014, p. 7). However, the concerning reality in Australia is declining student results in mathematics and science and stagnating numbers of students studying science, technology and mathematics in senior secondary school and at university.

Such reports however do not focus on evidence-based practical applications, programs or interventions that can be implemented in the primary classroom to address STEM learning. To this end, we undertook a review that looked for STEM interventions based on research evidence. This was to inform consideration of how recent STEM education research could be translated into practical application for implementation by primary teachers.

This paper outlines the scope and methodology of the review. It then considers the findings in terms of four key themes and translates them into short messages for teachers. A small set of programs and frameworks are presented in Parts B and C.

The recent literature on STEM education was found to centre around four major themes:

- teacher capacity
- integration of STEM disciplines
- active learning
- student engagement and participation

Definition of STEM

What is STEM? Is it any one of the four domains of science, technology, engineering and mathematics or is it more than the sum of its parts? Definitions in the literature cover the full spectrum from a mix–and-match or continuum approach, inter- and multi-disciplinary, through to a fully integrated view of STEM education.

Australia's Education Council (2015, p. 5) appreciates the value of a cross-disciplinary approach, while recognising discrete learning areas.

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

Others define STEM as an entity in itself.

Integrated STEM education is not just the grafting of 'technology' and 'engineering' layers onto standard science and mathematics curricula. Instead, integrated STEM education is an approach to teaching that is larger than its academic parts. (Engineering in K-12 education, 2009, p. 21).

For the purpose of this review it was decided to adapt Sanders' (2009, p. 21) notion of STEM: 'Teaching and learning between/among any two or more of the STEM subject areas and/or between a STEM subject and a non-STEM subject such as the Arts.'

STEM education in the primary years

The primary years were chosen as the focus of this review. STEM education can begin from the earliest years and fundamental STEM skills should be established in primary school. The primary years are a time where students are developing a self-belief in their ability as a STEM learner.

Students' experiences in the primary and early secondary years of schooling establish a 'sense of competence that students have in the foundations of mathematics and science and can kindle their interest in science related fields' (Ainley, Kos & Nicholas, 2008, p. 3).

An early interest in STEM topics can be a predictor for later learning and eventual career intentions (DeBacker & Nelson, 2000). Broadening future options for students is a strong rationale for developing and nurturing a student's interest in STEM in the primary years.

Primary school is an optimum time when gaps in STEM knowledge and understandings can be addressed. Science achievement gaps that emerge when children are young and are unaddressed can continue into high school (Morgan, Farkas, Hillemeier & Maczuga, 2016).

Methodology: Looking for evidence of what works

This review sought the evidence behind the STEM education priority and reviewed recent documents and research studies to find successful interventions that could be applied by Australian primary school classroom teachers.

Literature review

A literature search for STEM education interventions in primary years was undertaken in order to identify integrated STEM programs that have had a proven impact on student outcomes. Searches were undertaken using the following research databases for the period 2005–2016:

- A+ Education
- ACER's library catalogue
- Education Research Complete
- ERIC
- MESHGuides
- What Works Clearinghouse

A combination of the following search terms was used: STEM, STEM education, intervention, achievement, primary and elementary. Thesaurus-based searches were used where information services provided these.

A total of 54 research and policy documents were reviewed and coded as part of the review. The researcher looked specifically for reports of randomised controlled trials (RCTs) related to integrated primary school STEM interventions.

RCTs are studies in which participants are assigned randomly to form two or more groups that are differentiated by whether or not they receive the intervention under study … This design allows any subsequent (i.e. post-intervention) differences in outcomes between the intervention and comparison groups to be attributed solely to the intervention (What Works Clearinghouse Procedures and Standards Handbook v. 3.0, 2014, p. 9)

The first finding was that few published RCTs address the impact of integrated STEM interventions on student outcomes, particularly in primary schools. The limited availability of research on impact on student outcomes is reinforced by English (2016) and Honey, Pearson and Schweingruber (2014).

A meta-analysis of integrated STEM projects by Becker and Park in 2011 found 28 studies with empirical data. Of these studies, only three were focused on primary STEM education. There is a stronger research base for traditional primary school disciplines of mathematics and science, compared to technology and engineering. While research in these disciplines can inform practice in the other disciplines, the key focus for this review was integrated STEM programs.

RCTs are large-scale research commitments, and limited budgets and time greatly impact the capacity for this type of research. A more practical form of research is a program evaluation, which is a 'systematic review of the feasibility, impact and value of a program in relation to stated objectives, standards, or criteria' (Australian Thesaurus of Education Descriptors).

In the literature reviewed, evaluations of STEM education programs tended to focus on learner engagement and teacher capacity, rather than student achievement.

Another way to inform teaching practice is through action research, which is 'the integration of action (implementing a plan) with research (developing an understanding of the effectiveness of this implementation) (NSW Department of Education and Training, 2010, p. 1). If action research does take place in primary schools, it is rarely published or shared.

Recommendations

The review of these reports reveals several gaps. To improve the usefulness of research in this area there is a need:

- to form and use a coherent, shared definition of STEM education
- to conduct more research into the impact on student outcomes of integrated STEM education programs
- to have agreed methodologies and metrics to assist the assessment of impact and participation in STEM education
- to establish a repository of STEM education research to help teachers identify STEM programs that could be implemented in their classrooms

Part A: Translating research into practical ideas for the primary classroom teacher

The literature review showed that the most common trends in terms of reports and articles reviewed related to teacher capacity, integration of STEM disciplines, active learning and student engagement and participation.

Teacher capacity

Seventeen reports cited teacher confidence and knowledge as a feature of STEM programs in primary schools. Reports that referenced the importance of pre-service teacher training and professional development were included in this set.

An RCT undertaken by Cotabish, Dailey, Robinson and Hughes (2013) looked at the impact of teacher professional development and inquiry-based science instruction on student outcomes in science skills and knowledge. The professional development in this study was a 30-hour summer intensive supported by an additional 30 hours of expert peer coaching in the classroom. The study concluded that the teacher professional development had a statistically significant impact on student skills and knowledge. The ongoing support was effective in allowing teachers to reflect on their teaching practice.

Skamp's 2012 review of the impact of the Primary Connections program found that it had a positive effect on teachers' self-confidence in teaching science. For teachers, this was in part related to a change in the way they approached the teaching of science. This confidence was also fed by their students' interest in science and the impact of the units on student learning (p. 223). The Primary Connections professional learning was also found to support pre-service teachers and help them overcome some of the barriers to teaching primary science (Cooper, Kenny & Fraser, 2012).

An Australian intervention that aims to develop science and mathematics skills in pre-service teachers is the Reconceptualising Maths and Science Teacher Education Programs (ReMSTEP) however evaluation of this program is yet to be published.

Messages for primary STEM teaching

Focus on sustained professional learning

Teachers and schools looking for the best way to build their capacity in STEM education should prioritise professional development. Strategies include employing STEM-specialist teachers and coaches, mentoring by industry STEM professionals, fostering school-based professional learning communities or offering extended study opportunities such as summer schools.

A key message from the research is that teachers require ongoing support and the ability to reflect on their practice.

Integration of STEM disciplines

The importance of integration of the STEM disciplines was raised in 29 reports. While it is necessary to teach skills from individual STEM learning areas, reports showed the benefits of integration, which include improved problem-solving skills, increased motivation and improved maths and science outcomes (Blackley & Howell, 2015; Becker & Park, 2011; English & King, 2015). An integrated approach helps students understand not only what they are learning but also why and how their learning can be applied (Everett, Imbrie & Morgan, 2000; Hanover Research, 2012).

Intelligent integration is important. An evaluation of the Technology Enhanced Elementary and Middle School Science II project (TEEMSS), which integrates technology such as probes and sensors as part of the science curriculum, found four out of eight units had a significant impact on student outcomes. A possible reason for this result was that the technology used was less relevant to some topics (Zucker, Tinker, Staudt, Mansfield & Metcalf, 2008).

The difficulty with integration is intensified by the fact that through the learning area-based development of the Australian Curriculum in recent years, 'there has been no attempt to either replace or offer as an alternative, an integrated STEM curriculum to support teachers' (Blackley & Howell, 2015, p. 106).

Messages for primary STEM teaching

Adopt an integrated interdisciplinary approach

There is an argument for recommending that teachers use the STEM word only when it relates to genuinely integrated approaches. STEM programs that break down the disciplinary silos and provide opportunities to apply skills learnt from individual STEM domains are highly practical in a primary setting. If teachers are not confident in teaching maths and/or science as standalone subjects then the integration of STEM subjects may be even more difficult.

Address general capabilities within STEM

An integrated approach to STEM can teach more than the skills, competencies and knowledge of the four domains. Masters (2016, p. 6) is concerned that 'school subjects tend to be taught in isolation from each other, at a time when solutions to societal challenges and the nature of work are becoming increasingly cross-disciplinary.' Developing and implementing integrated units of STEM can provide chances for students to develop capabilities that include critical thinking, creativity, communication and self-direction.

Active learning

Sixteen of the reports on primary STEM initiatives highlighted the value of active learning or inquiry-based learning in integrated STEM teaching. Active learning involves students using multiple senses and interacting with other people and materials to solve a problem. Students are also required to take responsibly for their own learning (Sirinterlikci, Zane & Sirinterlikci, 2009, p. 14). Inquiry-based learning builds from a natural process of inquiry in which students experience a 'need to know' that motivates and deepens learning. Inquiry-based learning requires guidance from the teacher in the role of facilitator: providing structure and support for students as appropriate to their developmental stage (Victoria University, 2015).

Nugent, Barker, Grandgenett and Adamchuk (2010) and Barker and Ansorge (2007) emphasise the importance of hands-on, real-world problem-based learning that develops more than domain-specific skills and knowledge. Through these pedagogies, students collaborate with others, follow areas of interest, are creative and solve problems.

Evaluation of the US Engineering is Elementary program (Johnson, 2016; Lottero-Perdue, 2016) revealed the importance of allowing students to fail, and their ability to learn from failure in the engineering process. A case study from the 2015 Australian STEM Video Game Challenge noted failure as a way of developing students' resilience (Australian Council for Educational Research, 2015).

Messages for primary STEM teaching

Provide real-world challenges

Allowing students to integrate their knowledge of STEM subjects using real-world problems can help them understand why they are learning STEM subjects and how their knowledge can be applied outside the classroom. There are a number of challenges, competitions and other opportunities available to schools. Some are listed in the Office of the Chief Scientist's 2016 STEM Programme Index.

Allow students to learn from failure

The iterative and evaluative nature of real-world inquiry-based learning allows for reflection and helps to show students that failure is an important part of the learning process. The analysis of failure and continuous improvement process is important for developing a growth mindset.

Student engagement and participation

There were 11 reports that highlighted improved student engagement through participation in STEM education. These included students' learning from 'real life' STEM professionals (Tomas, Jackson & Carlisle, 2014), as well as explicit STEM programs, incursions and excursions that improved students' attitudes towards STEM and sparked their interest in both learning more and in career exploration (Dickerson, Eckhoff, Stewart, Chappell & Hathcock, 2013; Nugent et al., 2010; Gozali-Lee et al., 2015).

One of the key findings in the Marginson et al. (2013) report was that engagement in STEM in primary education influenced later participation in STEM, particularly at senior secondary years. Inquiry and creativity were a vital part of STEM curricula design in the countries surveyed.

Messages for primary STEM teaching

Nurture curiosity and questioning

Young children are naturally curious; they are inclined to test out ideas, have a go and are less averse to failure. These are all important attitudes for STEM learning. Curiosity can be nurtured through inquiry-based integrated STEM activities. Frameworks for STEM education disciplines have aspects of questioning, evaluating and reviewing, which allow this curiosity to be developed and encouraged. Students' ability to evaluate their work and look for improved solutions also develops their critical thinking and the ability to reflect on their actions and learning.

Promote explicit conversations about careers

Awareness of future study and career options is assisted by exposure to a broad range of people and experiences from STEM-related fields.

Summary

It seems that good practice in primary STEM programs looks very similar to good practice in primary education generally. Primary teachers will be familiar with the four themes discussed, from sustained professional learning, integration of learning areas, active learning strategies and a focus on student engagement and participation. Put simply, the STEM education challenge is to apply these same principles within the context of STEM-specific content, knowledge and skills.

Part B: STEM education programs

A lack of ready-made, proven integrated STEM programs and resources should not deter primary teachers from getting started with STEM in their classrooms. The following programs, while not necessarily fully integrated STEM initiatives, have been selected as useful to teachers as they either:

- allow for integration of STEM
- provide sustained professional development, or
- focus on aspects of STEM that are newly included in the primary years of the Australian Curriculum (Australian Curriculum Assessment and Reporting Authority, [ACARA], 2016)

Primary Connections

Primary Connections (www.primaryconnections.org.au) is an existing and well-known integrated primary science program. The program integrates science and literacy and is supported by the Australian Academy of Science. Primary Connections uses an inquiry and investigative approach, and with its supporting professional development and curriculum resources, it provides a sound starting point for teachers developing STEM capacity. The program is based on Bybee's 5E learning cycle: Engage – Explore – Explain – Elaborate – Evaluate (Bybee, Taylor, Gardner, Van Scotter, Carlson Powell, Westbrook & Landes, 2006).

EngQuest

Engineering is an element of STEM which lends itself to integration (English & King, 2015, Lachapelle, Oh, Shams, Hertel & Cunningham, 2015). While engineering has not been commonly taught in primary schools, the Australian Curriculum has an engineering focus as part of the Design and Technologies domain which begins at Foundation (ACARA, 2016). EngQuest (www.engquest.org.au) is a program developed by Engineers Australia and has resources for lower primary, primary and middle years' students. It is a collaborative problem-solving based program which, like Primary Connections, uses the 5E model. EngQuest is not another thing teachers need to teach, rather it has links to maths and science outcomes and can easily be linked back to the Design and Technologies curriculum. EngQuest allows students to apply science and maths skills in real-world situations. There is a strong emphasis on students working collaboratively and undertaking different roles as is the case in the engineering and scientific workplace.

CS Unplugged

The Computer Science Education Research Group's CS Unplugged (www.csunplugged.org) is a collection of learning activities to introduce computational thinking to students without the use of a computer. Resources include activities, videos and teacher resources. A downloadable book provides background information for activities and helps teachers build computing knowledge. Part of the program integrates maths and technology and provides explanations for the relevance of activities. There is also a draft of how CS Unplugged links to the Australian Digital Technologies Curriculum. As with Primary Connections and EngQuest, CS Unplugged incorporates skills including 'communication, problem solving, creativity, and thinking skills in a meaningful context' (Bell, Witten & Fellows, 2015).

Robotics in primary schools

There have been a number of studies that focus on the teaching of robotics in primary schools (Barker & Ansorge, 2007; Nugent et al., 2010;

Sullivan, 2008; Kim, Kim, Yuan, Hill, Doshi & Thai, 2015). Learning with robots can integrate all of the STEM elements, as well as teaching problem solving and teamwork.

A successful robotics intervention was identified by Barker and Ansorge (2007). The robotics program used Lego Mindstorm kits and the ROBOLAB programming language. They describe the program as beginning with simple building and programming challenges and culminating in advanced robotic programming and engineering topics.

The program was based on an experiential learning theory: Experience – Share – Process – Generalise – Apply. The study showed that the robotics program using this framework had a significant positive effect on student outcomes in areas such as computer programming, robotics, mathematics and engineering. Sullivan (2008) also highlighted that robotics allows student to apply science process skills and teachers to develop open-ended and extended inquiry.

Aerospace Engineering Challenge framework

As part of an Aerospace Engineering Challenge, English and King (2015) developed a framework of five comprehensive core engineering design processes: Problem scoping – Idea Generation – Design and construction – Design evaluation – Redesign. This framework was used in the study of Grade 4 students' engineering investigations in aerospace. Students were required to use the framework when working in small groups (three or four students) to design and build a paper plane that could 'stay in the air for the longest time possible'. They found that the students applied maths and science concepts more in the design evaluation and redesign phase and stressed the importance of allowing young learners enough time for the final two phases of the framework. Based on their study, English and King recommend that in the primary years, teachers should spend more time with the class 'unpacking the outcomes' of the initial design (in this case the first test flight) and engage and scaffold students in discussions regarding areas for improvement before students move onto redesign.

Wonder of Science Challenge

Case studies provide examples of programs in action within a specific context. This can help teachers consider application in their own school or classroom.

Tomas, Jackson and Carlisle (2014) reviewed and wrote a case study of the impact of the Australian Academy of Sciences and Engineering's 2012 Wonder of Science Challenge on a teacher and his primary students. This challenge was open-ended. The problem the students needed to investigate in small groups was 'to design a solar-powered vehicle to complete a revolution of a circle in 10 seconds'. This allowed for integration of the science, maths and design and technology curriculum.

The use of open inquiry improved the teacher's self-confidence for teaching science using the science inquiry skills in the Australian Science Curriculum (ACARA, 2016a). The teacher involved in the case study also believed that the open inquiry allowed every student to reach their full potential and use higher order thinking skills. This was supported by the views of the students who thought that, compared to the more prescriptive way that science had been taught previously, they were able to complete more experiments, take more ownership of their learning and were able to explain their ideas in their own words, which resulted in an improvement in their attitudes towards science.

The Challenge also used practising scientists to support the students and provided a professional development day for teachers. The scientists helped students develop their science knowledge and communicate their ideas as part of the final presentations.

This case study highlights the importance of open inquiry STEM projects, support for teachers though professional development and involvement with practising STEM professionals for primary students.

STEM education frameworks

The Office of the Chief Scientist (2014) recognises that STEM frameworks provide ways of tackling new problems. This review has identified several frameworks from research and the Australian curriculum. While they are all different, there are common themes in these frameworks that can help teachers structure an integrated approach to implementing STEM curriculum. The cyclical and iterative nature of the STEM frameworks allows students to scope, design, create, evaluate, review and improve their solutions.

A matrix comparing these frameworks is provided in Part C.

Evaluating STEM programs

The number of STEM-related programs and initiatives on offer to schools is exploding however most do not have published evaluations. If a program has not been evaluated, teachers and schools need to consider how the impact on student learning will be measured. Discussions with a program provider before committing funding, and equally importantly, time, should ask the following questions:

- Is there existing evidence of the impact of this program on students' learning?
- What evaluation will be incorporated in our use of this program?
- How will the results of the evaluation be published?

If we are to improve the evidence available on STEM education, teachers need to be encouraged to get involved in any available randomised controlled trials, programme evaluations or research activity, particularly when they relate to monitoring student outcomes from STEM initiatives.

Disseminating research

While research is important, so is the dissemination of research findings. It is important that there is an easily accessible repository for any such research into STEM as highlighted by the National STEM School Education Strategy (Education Council, 2015). This will help overcome the difficulty in finding relevant STEM research and studies.

In the United States, the *What Works Clearinghouse* (WWC) identifies studies that provide reliable evidence that educational interventions improve student outcomes based on RCTs or quasi-experimental design, http://ies.ed.gov/ncee/wwc/default.aspx.

MESH Guides is a global initiative that develops online guides and research summaries to help link teachers to relevant research, http://www.meshguides.org/meshguides-full-list.

Social Ventures Australia is adapting the UK Education Endowment Foundation's Teaching and Learning toolkit. Evidence for Learning provides an overview of interventions and their overall cost and impact on student achievement based on available research, http://evidenceforlearning.org.au/teaching-and-learning-toolkit.

Part C: STEM education process frameworks

This table compares STEM frameworks identified in the research to the Australian curriculum frameworks. While they are each different, there are common themes in these frameworks that can help teachers structure an integrated approach to implementing STEM in the curriculum. While displayed here as a table for ease of comparison, the cyclical and iterative nature of STEM frameworks is important. It is interesting to note that there are obvious variations in process between the individual disciplines that make up STEM education. The left hand column is an attempt to classify the various steps across the process frameworks. While the Australian Curriculum provides skills and process frameworks for science and technologies incorporating engineering, the mathematics proficiency strands are not expressed in an equivalent structure. The mathematical literacy framework presented here was developed specifically for this review by Dave Tout, and is based on the PISA mathematical literacy framework.

		SCIENCE		TECHNOLOGY		ENGINEERING			MATHEMATICS
Skills and processes	Experiential learning model	ACARA Science	5Es instructional model	ACARA Digital Technologies	ACARA Design and Technologies	Process of engineering design	Engineering design process	Informed design matrix	PISA IMMC
	4-H Cooperative Curriculum System	*Science Inquiry Skills*	*Primary Connections & EngQuest*	*Process and production skills*	*Processes and production skills*	*English & King*	*Engineering is Elementary*	*Crismond & Adams*	*Mathematical Literacy Framework*
Investigating and scoping		**Questioning and predicting** With guidance, identify questions in familiar contexts that can be investigated scientifically and make predictions based on prior knowledge (ACSIS053) & (ACSIS064)	**Engage** Create interest and stimulate curiosity Set learning within a meaningful context Raise questions for inquiry Reveal students' ideas and beliefs, compare students' ideas	**Investigating and defining** Define problems in terms of data and functional requirements drawing on previously solved problems (ACTDIP017)	**Investigating and defining** Critique needs or opportunities for designing, and investigate materials, components, tools, equipment and processes to achieve intended designed solutions (ACTDEP024)	**Problem scoping** Understanding the boundaries of a problem Clarify and restate the goal Identify constraints Consider problem feasibility Add context Experiment with materials Establish collaboration	**Ask** Identify the problem Determine design constraints Consider relevant prior knowledge (e.g., science concepts)	**Understand the challenge** Define criteria and constraints of challenge. Delay decisions until critical elements of challenge are grasped Build Knowledge Enhance background knowledge, and build understanding of users, mechanisms and systems	**Exploring and identifying** Identify a (real world) problem based on a theme or context of interest to students - current popular topic, issue of concern or interest from community, work or study
Questioning and brainstorming						**Idea generation** Brainstorming and planning Share and formulate ideas Discuss strategies Develop a plan	**Imagine** Brainstorm design ideas Draw and label those ideas.	**Generate** Generate range of design ideas to avoid fixation Know guidelines/ reasons for various divergent thinking approaches	**Brainstorming and defining starting point** Brainstorm the possible areas and topics that exist and that could arise out of the context/issue and develop possible starting questions for the problem to be solved

		SCIENCE		TECHNOLOGY		ENGINEERING			MATHEMATICS
Skills and processes	Experiential learning model	ACARA Science	5Es instructional model	ACARA Digital Technologies	ACARA Design and Technologies	Process of engineering design	Engineering design process	Informed design matrix	PISA IMMC
Planning and designing		**Planning and conducting** With guidance, plan and conduct scientific investigations to find answers to questions, considering the safe use of appropriate materials and equipment (ACSIS054) (ACSIS065) Consider the elements of fair tests and use formal measurements and digital technologies as appropriate, to make and record observations accurately (ACSIS055) (ACSIS066)		**Generating and designing** Design a user interface for a digital system (ACTDIP018) Design, modify and follow simple algorithms involving sequences of steps, branching and iteration (repetition) (ACTDIP019)	**Generating and designing** Generate, develop and communicate design ideas and processes for audiences using appropriate technical terms and graphical representation techniques (ACTDEP025)	**Design and construct** Model development Sketch and design Interpret design Transform design to model	**Plan** Pick one idea. Draw and label the idea. Identify needed materials or conditions	**Represent ideas** Explore and investigate different ideas via sketching, modelling solutions and making simple prototypes Weigh options and make decisions Consider both the benefits and trade-offs of all ideas before making decisions	**Formulating and planning** Formulate a mathematical model to address the question (involves translating from the real-world setting to the domain of mathematics, making simplifying assumptions, choosing variables, estimating magnitudes of inputs etc)
Producing and creating	**Experience** Do the activity		**Explore** Provide experience of the phenomenon or concept. Explore and inquire into students' questions and test their ideas. Investigate and solve problems	**Producing and implementing** Implement digital solutions as simple visual programs involving branching, iteration (repetition), and user input (ACTDIP020)	**Producing and implementing** Select appropriate materials, components, tools, equipment and techniques and apply safe procedures to make designed solutions (ACTDEP026)		**Create** Carry out the plan; create the design. Designed solution testing (and opportunity for design failure)	**Conduct experiments** Run valid 'fair test' experiments to learn how prototypes behave and to optimise their performance	**Employing and applying maths** Employ mathematical concepts, facts, procedures and reasoning (reasoning, argumentation, manipulation and computation) to solve the problem in the maths world
Sharing	**Share** Share reactions and observations								

		SCIENCE		TECHNOLOGY		ENGINEERING			MATHEMATICS
Skills and processes	Experiential learning model	ACARA Science	5Es instructional model	ACARA Digital Technologies	ACARA Design and Technologies	Process of engineering design	Engineering design process	Informed design matrix	PISA IMMC
Analysing and explaining	**Process** Analyse and reflect upon what happened	**Processing and analysing data and information** Use a range of methods including tables and simple column graphs to represent data and to identify patterns and trends (ACSIS057) & (ACSIS068) Compare results with predictions, suggesting possible reasons for findings (ACSIS215) & (ACSIS216)	**Explain** Introduce conceptual tools that can be used to interpret the evidence and construct explanations of the phenomenon. Construct multi-modal explanations and justify claims in terms of the evidence gathered Compare explanations generated by different students/groups Consider current scientific explanations						**Interpreting and evaluating** Interpret and evaluate the mathematical outcomes (interpretation, justification, and explanation) and review the mathematical results in terms of their real world meanings
Generalising and applying	**Generalise** Discover what was learned and connect to life **Apply** Apply what was learned to similar or different situations		**Elaborate** Use and apply concepts and explanations in new contexts to test their general applicability Reconstruct and extend explanations and understanding using and integrating different modes, such as written language, diagrammatic and graphic modes, and mathematics						
Evaluating		**Evaluating** Reflect on investigations, including whether a test was fair or not (ACSIS058) & (ACSIS069)	**Evaluate** Provide an opportunity for students to review and reflect on their own learning and new understanding and skills Provide evidence for changes to students' understanding, beliefs and skills	**Evaluating** Explain how student solutions and existing information systems are sustainable and meet current and future local community needs (ACTDIP021)	**Evaluating** Negotiate criteria for success that include sustainability to evaluate design ideas, processes and solutions (ACTDEP027)	**Design evaluation** Meeting constraints Test model Check constraints Assess goal attainment		**Troubleshoot** Diagnose and troubleshoot ideas on prototypes based on simulations or tests	**Reflecting** Critique and identify the limits of the model used to solve a problem and make a judgment as to the adequacy of the solution to the original question(s)

		SCIENCE		TECHNOLOGY		ENGINEERING			MATHEMATICS
Skills and processes	Experiential learning model	ACARA Science	5Es instructional model	ACARA Digital Technologies	ACARA Design and Technologies	Process of engineering design	Engineering design process	Informed design matrix	PISA IMMC
Improving (continuous process)						**Model** redevelopment Review first design Sketch new design Transform design to revised model	**Improve** Reflect on testing results. Plan for, create, and test a new (improved) design. Designed solution testing (and opportunity for design failure)	**Revise/Iterate** Manage project resources well. Use iteration to improve ideas based on feedback. Employ design strategies repeatedly in any order as needed Reflect on process Periodically reflect while designing and keep tabs on strategies used. Review to check how well solutions met goals	**Improving** Report on success or make adjustments and try for a better solution
Communicating and managing (throughout the process)		**Communicating** Represent and communicate observations, ideas and findings using formal and informal representations (ACSIS060) & (ACSIS071)		**Collaborating and managing** Plan, create and communicate ideas and information, including collaboratively online, applying agreed ethical, social and technical protocols (ACTDIP022)	**Collaborating and managing** Develop project plans that include consideration of resources when making designed solutions individually and collaboratively (ACTDEP028)				**Communicating** Communicate the process and the solution, taking into consideration the context of the problem
Source	Barker & Ansorge (2007)	ACARA (2016a)	Bybee et al (1997)	ACARA (2016) Digital Technologies Processes and Production Skills. Years 5 and 6	ACARA (2016) Design and Technologies Processes and Production Skills. Years 5 and 6	English & King (2015)	Lottero-Perdue (2016)	Crismond & Adams (2012)	OECD (2012) International Mathematical Modeling Challenge (2016) Tout & Motteram (2006)

References

Ainley, J., Kos, J., & Nicholas, M. (2008). *Participation in science, mathematics and technology in Australian* education. Retrieved from http://research.acer.edu.au/acer_mono graphs/4

Australian Curriculum Assessment and Reporting Authority. (2016). Australian Curriculum: F-10 curriculum: Design and technologies (Version 8.2). Retrieved from http://www.australiancurriculum.edu.au/technologies/design-and-technologies/curriculum/f-10

Australian Curriculum Assessment and Reporting Authority. (2016a). Australian Curriculum: F-10 curriculum: Science (Version 8.2). Retrieved from http://www.australiancurriculum.edu.au/science/structure

Australian Council for Educational Research (ACER). (2015). Teacher perspective: Mill Park Secondary College. Retrieved from http://www.stemgames.org.au/interviews/mill-park-secondary-college

Barker, B., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education*, *39*(3), 229–243. Retrieved from http://files.eric.ed.gov/fulltext/EJ768878.pdf

Becker, K., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students learning: A meta-analysis. *Journal of STEM Education*, *12*(5), 23–37.

Bell, T., Witten, I., & Fellows, M. (2015). *CS Unplugged. An enrichment and extension programme for primary-aged students.* (2015). Retrieved from http://csunplugged.org/wp-content/uploads/2015/03/CSUnplugged_OS_2015_v3.1.pdf

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), 102–112. doi:10.14221/ajte.2015v40n7.8

Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Carlson Powell, J., Westbrook, A., & Landes, N. (2006). *The BSCS 5E Instructional Model: Origins, effectiveness and applications*. Retrieved from http://www.bscs.org/bscs-5e-instructional-model

Caplan, S., Baxendale, H., & Le Feuvre, P. (2016). *Making STEM a primary priority: Practical steps to improve the quality of science and mathematics teaching in Australian primary schools*. Retrieved from https://pwc.docalytics.com/v/making-stem-a-primary-priority

Cooper, G., Kenny, J., & Fraser, S. (2012). Influencing intended teaching practice: Exploring pre-service teachers' perceptions of science teaching resources. *International Journal of Science Education*, *34*(12), 1883–1908. doi:10.1080/09500693.2012.698762

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The effects of a STEM intervention on elementary students' science knowledge and skills. *School Science and Mathematics*, *113*(5), 215–226. doi:10.1111/ssm.12023

Crismond, D., & Adams, R. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, 101(4), 738–797.

DeBacker, T., & Nelson, R. (2000). Motivation to learn science: Differences related to gender, class type, and ability. *The Journal of Educational Research*, *93*(4), 245–254. doi:10.1080/00220670009598713

Dickerson, D. L., Eckhoff, A., Stewart, C., Chappell, S., & Hathcock, S. (2014). The examination of a pullout STEM program for urban upper elementary students. *Research in Science Education*, *44*(3), 483–506. doi:10.1007/s11165-013-9387-5

Education Council. (2015). *National STEM school education strategy, 2016–2026*. Retrieved from http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf

Engineering in K-12 education: Hearing before the Subcommittee on Research and Science Education, *Committee on Science and Technology*, *House of Representatives* (Serial No. 111-57), 111 Cong. (2009). Retrieved from US Government Print Office website: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=111_house_hearings&docid=f:52859.pdf

English, L. (2016). STEM education K–12: Perspectives on integration. *International Journal of STEM Education*, *3*(1). doi:10.1186/s40594-016-0036-1

English, L., & King, D. (2015). STEM learning through engineering design: Fourth-grade students' investigations in aerospace. *International Journal of STEM Education*, *2*(1). doi:10.1186/s40594-015-0027-7

Everett, L., Imbrie, P., & Morgan, J. (2000). Integrated curricula: Purpose and design. *Journal of Engineering Education*, *89*(2), 167–175. doi:10.1002/j.2168-9830.2000.tb00511.x

Gozali-Lee, E., Mueller, D., Streich, F., & Bartholomay, A. (2015). *2014–2015 STEM pathways evaluation: First-year results of an informal STEM education partnership in conjunction with Minneapolis Public Schools and Minnesota Department of Education*. Retrieved from https://www.wilder.org/Wilder-Research/Publications/Studies/STEM%20Pathways/2014-2015%20STEM%20Pathways%20Evaluation,%20Full%20Report.pdf

Hanover Research. (2012). *Best practices in elementary STEM programs*. Washington, DC: Hanover Research.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. doi:10.17226/18612

Johnson, M. (2016). *Failure is an option: Reactions to failure in elementary engineering design projects* (Unpublished doctoral dissertation). Pennsylvania State University, Pennsylvania, US.

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, *91*, 14–31. doi:10.1016/j.compedu.2015.08.005

Lachapelle, C., Oh, Y., Shams, M., Hertel, J. & Cunningham, C. (2015). *HLM modeling of pre/post- assessment results from a large-scale efficacy study of elementary engineering*. Presented at the 122nd ASEE Annual Conference and Exposition, Seattle, WA: American Society for Engineering Education. doi:10.18260/p.24185

Lottero-Perdue, P. (2016). *Fifth graders' perceptions about failure and mindsets before and after learning to engineer*. Paper presented at the National Association for Research in Science Teaching Annual International Conference 2016, Baltimore, MD. Retrieved from http://www.eie.org/sites/default/files/research_article/research_file/narst_2016_lottero-perdue_failure_mindset_final.pdf

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education. Retrieved from http://hdl.handle.net/10536/DRO/DU:30059041

Masters, G. (2016). *Five challenges in Australian school education*. Retrieved from http://research.acer.edu.au/policyinsights/5

Mathematical modelling framework. (2016). Retrieved from https://www.immchallenge.org.au/supporting-resources/mathematical-modelling-framework

Morgan, P. L., Farkas, G., Hillemeier, M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher*, *45*(1), 18–35. doi:10.3102/0013189X16633182

NSW Department of Education and Training, (2010). Action research in education: guidelines 2nd ed. Retrieved from https://www.det.nsw.edu.au/proflearn/docs/pdf/actreguide.pdf

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. (2010). Impact of robotics and geospatial technology on youth STEM learning and attitudes. *Journal of Research on Technology in Education*, *42*(4), 391–408. doi:10.1080/15391523.2010.10782557

Office of the Chief Scientist. (2014). Science, Technology, Engineering and Mathematics: Australia's Future. Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/STEM_AustraliasFuture_Sept2014_Web.pdf

Office of the Chief Scientist. (2016). *SPI 2016. Stem Programme Index 2016*. Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/SPI2016_release.pdf

Organisation for Economic Co-operation and Development (OECD). (2013). PISA 2012 Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy. OECD Publishing. doi: 10.1787/9789264190511-en

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20–26. Retrieved from http://hdl.handle.net/10919/51616

Sirinterlikci, A., Zane, L., & Sirinterlikci, A. (2009). Active learning through toy design and development. *Journal of Technology Studies*, *35*(2), 14–22. Retrieved from http://scholar.lib.vt.edu/ejournals/JOTS/v35/v35n2/pdf/sirinterlikci.pdf

Skamp, K. (2012). *Teaching primary science: Trial-teacher feedback on the implementation of Primary Connections and the 5E model.* Retrieved from https://www.primaryconnections.org.au/about/history/research-and-evaluation/teaching-primary-science.pdf

Sullivan, F. (2008). Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, *45*(3), 373–394. Retrieved from http://people.umass.edu/florence/jrst.pdf

Tomas, L., Jackson, C., & Carlisle, K. (2014). The transformative potential of engaging in science inquiry-based challenges: The ATSE Wonder of Science Challenge. *Teaching Science*, *60*(2), 48–57. doi:10.1080/15391523.2010.10782557

Tout, D. & Motteram, G. (2006). Foundation numeracy in context. Melbourne: Australian Council for Educational Research.

Victoria University. (2015). Active and inquiry based learning. Retrieved from https://www.vu.edu.au/learning-teaching/improving-learning-teaching/teaching-approaches/active-and-inquiry-based-learning

What Works Clearinghouse Procedures and Standards Handbook v.3.0. (2014). Retrieved from http://ies.ed.gov/ncee/wwc/DocumentSum.aspx?sid=19

Zucker, A., Tinker, R., Staudt, C., Mansfield, A., & Metcalf, S. (2008). Learning science in grades 3–8 using probeware and computers: Findings from the TEEMSS II project. *Journal of Science Education and Technology*, *17*(1), 42–48. doi:10.1007/s10956-007-9086-y