STEM research

Annotated bibliography

Summary

Recent research indicates that quality learning for students can be enhanced through a STEM (Science, Technology, Engineering and Mathematics) environment. This annotated bibliography provides a summary of key ideas presented in research that may support Queensland schools' approaches to STEM education.

Sources of data include:

- government reports
- published research (i.e. peer-reviewed journals)
- independently published reports
- books
- media reports (where appropriate).

The annotated bibliography does not represent all possible resources, but provides an introduction, in the form of key ideas, to support further reading.

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Annotated bibliography

Anderson, J 2016, 'The STEM Teacher Enrichment Academy: Evaluating teachers' approaches to implementing STEM education in secondary school contexts', paper presented to ACER Research Conference, Brisbane, 7–9 August.

Website: http://research.acer.edu.au/research_conference/RC2016/8august/6/

Key ideas:

- This Australian research paper describes a program, the STEM Teacher Enrichment Academy, for enhancing STEM teaching in schools in Years 7–10.
- The program involved a three-day residential program at the University of Sydney. Cross-disciplinary school teams comprising two mathematics, two science and two technology teachers worked together to develop inquiry-based learning approaches to teaching both within their subject discipline as well as across the subject disciplines.

Australian Curriculum Assessment and Reporting Authority 2016, *STEM report*, ACARA, Sydney, NSW.

Website: www.australiancurriculum.edu.au/resources/stem/stem-report/

Key ideas:

- The STEM Connections Project was an initiative of the Australian Curriculum, Assessment and Reporting Authority (ACARA) in conjunction with the Australian Association of Mathematics Teachers.
- It was an action research project, which investigated the effectiveness of using an integrated approach to the teaching and learning of the Science, Technology, Mathematics and Work Studies curriculum disciplines from the Australian Curriculum in 13 secondary schools across Australia.
- The report describes the project aims, approaches for teaching, feedback on learnings that occurred in each of the learning areas, and the general capabilities, benefits and challenges that came from the STEM program. The report also considers advice on program implementation, industry engagement and staff.

Australian Industry Group 2013, *Lifting our Science, Technology, Engineering and Maths (STEM) skills*, Sydney, NSW.

Website: www.utas.edu.au/__data/assets/pdf_file/0005/368546/lifting_our_stem_skills_13.pdf

Key ideas:

- This Australian Industry Group report calls for the establishment of an industry led working group, in conjunction with the Office of the Chief Scientist, to
  - develop a national framework and strategies to implement school–industry STEM skills initiatives
  - support increased university and industry participation.
- Recommendations for schools include
  - support for a range of strategies to increase student participation in STEM skills, e.g. measures to lift teacher quality, capability and qualifications
  - innovative pedagogy that teaches STEM skills in an engaging and integrated way
  - measures that encourage girls to remain engaged in STEM skills
  - development of career advice relating to STEM occupations and careers
  - expanded engagement with STEM skills at primary school.

Bell, J, Frater, B, Butterfield, L, Cunningham, S, Dodgson, M, Fox, K, Spurling, T & Webster, E 2014, *The role of science, research and technology in lifting Australian productivity*, Australian Council of Learned Academies, Melbourne, Victoria.

Website: https://acola.org.au/wp/PDF/SAF04Reports/SAF04%20Role%20of%20SRT%20in%20lifting%20Aus%20Productivity%20FINAL%20REPORT.pdf

Key ideas:

- In this report, ACOLA examines the role of science, research and technology in lifting Australian productivity and provides some industry and broader context around the role of STEM.
- Building Australia's future industries depends on adopting technological innovation and improving collaboration.
- An innovative workforce that combines technical and non-technical disciplines and enables good business management is essential to underpin the competitive advantage of Australian industries and realise opportunities to lift productivity.

Berry, MR, Chalmers, C & Chandra, V 2012, 'STEM futures and practice: Can we teach STEM in a more meaningful and integrated way?', paper presented to 2nd International STEM in Education Conference, Beijing, China, 24–27 November.

Website: https://eprints.qut.edu.au/57318/

Key ideas:

- This paper argues for the interdisciplinary delivery and teaching of STEM disciplines to promote engagement, problem-solving, critical thinking skills and the development of real-world connections.
- Effective STEM practice includes
  - an interdisciplinary approach using a team of teachers
  - problem-based learning using 'real-life' open-ended design tasks
  - challenges that require logical thinking, creative inquiry and practical hands-on activities to develop design solutions.

Blackley, S & Howell, J 2015, 'A STEM narrative: 15 years in the making', *Australian Journal of Teacher Education,* vol. 40, no. 7, pp. 102−112.

Website: http://dx.doi.org/10.14221/ajte.2015v40n7.8 (DOI: 10.14221/ajte.2015v40n7.8)

Key ideas:

- This article provides an overview of the changes in the STEM debate across the preceding 15 years, highlighting five key stages in the movement from a political and economic agenda to integrated teaching practices.
- In schools, the major focus is on the teaching and assessment of science and mathematics, with engineering and technologies providing only incidental learning. In broader society, the focus is more on technologies and engineering. This highlights a disconnect between curriculum and economic motivations, resulting in a need to move towards models that support both integration and concentration in STEM teaching approaches.

Boaler, J 2014, *Changing the conversation about girls and STEM*, Washington, DC, The White House.

Website: https://bhi61nm2cr3mkdgk1dtaov18-wpengine.netdna-ssl.com/wp-content/uploads/Youcubed-STEM-white-house.pdf

Key ideas:

- This article focuses on girls and STEM achievement where inequalities persist in participation, especially at higher education levels.
- Features chosen by girls as leading to STEM engagement and positive identity formation included: hands-on experiences, project-based curriculum, curriculum with real-life applications and opportunities to work together.

Bruder, R & Prescott, A 2013, 'Research evidence on the benefits of IBL', *ZDM: Mathematics Education*, vol. 45, no. 6, pp. 811–822.

Website: www.researchgate.net/publication/271660668_Research_evidence_on_the_benefits_of_IBL (DOI: 10.1007/s11858-013-0542-2)

Key ideas:

- This paper analyses research in inquiry-based learning (IBL) in mathematics and science subjects in schools and universities.
- The paper discusses the advantages, disadvantages and effects on student outcomes of IBL in terms of developing quality teaching.

Burghardt, MD, Kennedy, M, McHugh, L, Lauckhardt, J & Hecht, D 2015, 'The effects of a mathematics infusion curriculum on middle school student mathematics achievement', *School Science and Mathematics*, vol. 115, no. 5, pp. 204–215.

Website: http://onlinelibrary.wiley.com/doi/10.1111/ssm.12123/abstract (DOI: 10.1111/ssm.12123)

Key ideas:

- Teaching mathematics and science in an integrated way enhances student learning, particularly reasoning skills.
- Integrated learning enhances understanding of mathematics and science and improves student perception that they are a relevant and necessary component of their lives.
- Practical application is an effective strategy when integrating mathematics and science learning.

Butler, AC, Marsh, EJ, Slavinsky, JP & Baraniuk, RG 2014, 'Integrating cognitive science and technology improves learning in a STEM classroom', *Educational Psychology Review*, vol. 26, no. 2, pp. 331–340.

Website: http://marshlab.psych.duke.edu/publications/ButlerMarshSlavinskyBaraniuk2014.pdf (DOI: 10.1007/s10648-014-9256-4)

Key ideas:

- Rice University implemented a simple, low-cost intervention program to increase higher-order thinking skills in STEM classes.
- The intervention
  - combined the principles of repeated retrieval practice, spacing and feedback
  - leveraged technology and cognitive science
  - was able to be implemented within any curriculum
  - caused minimal disruption to class and required only a modest amount of work by the teacher compared to other intervention programs.

Bybee, RW 2010, 'Advancing STEM education: A 2020 vision', *Technology and Engineering Teacher*, vol. 70, no. 1, pp. 30–35.

Website: https://eric.ed.gov/?id=EJ898909

Key ideas:

- This paper proposes an action plan for a greater focus on technology and engineering to improve the breadth of STEM education in schools. It suggests (United States context) that there has been an over-emphasis on science and mathematics rather than a balanced approach across all STEM discipline areas.
- In terms of STEM education, the paper proposes
  - an increased focus on technology
  - increased recognition of engineering
  - promotion of 21st century skills
  - delivery through an integrated approach using 'real world' contexts.

Bybee, RW 2013, *The Case for STEM Education: Challenges and opportunities*, NSTA Press, United States.

Website: www.nsta.org/store/product_detail.aspx?id=10.2505/9781936959259

Key ideas:

- This book details the current state of STEM education in schools, the challenges facing STEM education and contemporary STEM approaches to other education reforms.
- Diagrams and approaches to the teaching of STEM are included with detailed ideas for the development of action plans.
- The 4Ps of STEM education are described (purpose, policies, programs and practices) along with a discussion of the difficulties of STEM education.

Cantrell, P, Pekcan, G, Itani, A & Velasquez-Bryant, N 2006, 'The effects of engineering modules on student learning in middle school science classrooms', *Journal of Engineering Education* vol. 95, no. 4, pp. 301–309.

Website: onlinelibrary.wiley.com/doi/10.1002/j.2168-9830.2006.tb00905.x/pdf (DOI: 10.1002/j.2168-9830.2006.tb00905.x)

Key ideas:

- The Teachers Integrating Engineering into Science (TIES) program paired university faculties with middle school science teachers to create interactive engineering modules to engage a wide range of students. The program included four elements: (1) concrete experience, (2) reflective observation, (3) abstract conceptualisation and (4) active experimentation.
- Compared to standard science tests, TIES modules
  - diminished achievement gaps for low SES students
  - improved results for special education students
  - reduced gaps for Hispanic and African-American students, but gaps were increased for American-Indian and White students.

Caplan, S, Baxendale, H & Le Feuvre, P 2016, *Making STEM a primary priority*, Price Waterhouse Coopers, Australia.

Website: www.pwc.com.au/publications/education-stem-primary-priority.html

Key ideas:

- This report highlights the importance of high quality primary school science and mathematics education to Australia's future. It includes four key recommendations
  - provide access to a specialist STEM teacher for every Australian primary school
  - improve the standard of professional development in primary science and mathematics for all teachers
  - make better use of data for targeted teaching and enhanced learning in STEM
  - increase the quality and quantity of STEM instruction in Australian primary schools.

Chiu, A, Price, A & Ovrahim, E 2015, 'Supporting elementary and middle school STEM education at the whole-school level: A review of the literature', paper presented at NARST Annual Conference, Chicago, IL, 11–14 April.

Website:
www.msichicago.org/fileadmin/assets/educators/science_leadership_initiative/SLI_Lit_Review.pdf

Key ideas:

- This paper is a literature review on what makes STEM programs successful in Kindergarten–Year 8.
- Schools looking to support or increase STEM education need to know where to begin, what supports are needed and whom they can learn from.
- Key considerations for schools included
  - values, collaboration and planning
  - curriculum and instruction
  - professional learning
  - communication and technology
  - partners and funding.
- These are followed by a discussion about successful programs for STEM learning.

Dweck, CS 2008, 'Mindsets and math/science achievement', paper prepared for the Carnegie-Institute for Advanced Study Commission on Mathematics and Science Education.

Website:
www.nd.gov/dpi/uploads/1381/Dweck2008MindsetsandMathScienceAchievemented.pdf

Key ideas:

- Carol Dweck researches and presents on the influence of mindset on learning.
- This article presents research showing that
  - mindsets can predict math/science achievement over time
  - mindsets can contribute to math/science achievement discrepancies for women and minorities
  - interventions that change mindsets can boost achievement and reduce achievement discrepancies
  - educators play a key role in shaping students' mindsets.

Education Council Australia 2015, *National STEM school education strategy, 2016–2026*, Victoria.

Website: www.educationcouncil.edu.au/EC-Reports-and-Publications.aspx

Key ideas:

- The Education Council of Australia prepared this document to set strategic direction for STEM education 2016–2026. This strategy will influence STEM education direction into the future and responds to government strategic priority and direction (see Office of the Chief Scientist, 2012 and 2016).
- Five areas for national action are described
  - Increasing student STEM ability, engagement, participation and aspiration
  - Increasing teacher capacity and STEM teaching quality
  - Supporting STEM education opportunities within school systems
  - Facilitating effective partnerships with tertiary education providers, business and industry
  - Building a strong evidence base.
- Guiding principles are outlined for schools to support STEM education.

Ellerton, P 2015, 'The skills and values of inquiry', paper presented at International Conference of the Philosophy and Education Society of Australasia, Melbourne, Victoria, 5–8 Dec.

Website: https://peter-ellerton.squarespace.com/s/Skills-and-values-of-Inquiry-APEL.pdf

Key ideas:

- The paper examines the teaching of critical thinking in relation to inquiry learning and provides insight into the contribution of STEM learning in regards to 21st century skills (Australian Curriculum general capabilities).
- Effective inquiry is represented as the effective use of a range of cognitive skills (e.g. analysing, synthesising, evaluating, justifying and inferring) to optimise students' thinking to develop meaningful learning experiences.
- A thinking matrix demonstrates the relationship between inquiry and cognitive skills.

English, LD 2015, ‘STEM: Challenges and opportunities for mathematics education’, paper presented to Conference of the International Group for the Psychology of Mathematics Education, Hobart, Tasmania, 13–18 Jul.

Website: https://eprints.qut.edu.au/87506/3/87506.pdf

Key ideas:

- This paper considers the interdisciplinary nature of STEM education.
- It argues that mathematics is being overshadowed by science in the global urgency to advance STEM competencies in schools and the workforce.
- The paper offers suggestions for lifting the profile of mathematics education within an integrated STEM context. Examples are drawn from sixth grade modelling data.

English, LD 2016, ‘STEM education K–12: Perspectives on integration’, *International Journal of STEM Education*, vol. 3, no. 3, pp. 1–8.

Website: https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-016-0036-1 (DOI: 10.1186/s40594-016-0036-1)

Key ideas:

- This article argues for a greater focus on STEM integration, with a more equitable representation of the four disciplines in studies that advance STEM learning.
- It suggests that mathematics learning benefits less than the other disciplines in programs focusing on STEM integration.
- The paper offers suggestions for addressing the challenges of integrating multiple disciplines faced by the STEM community.

English, LD & King, DT 2015, ‘STEM learning through engineering design: Fourth-grade students’ investigations in aerospace’, *International Journal of STEM Education*, vol. 2, no. 14, pp. 1–18.

Website: https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-015-0027-7 (DOI: 10.1186/s40594-015-0027-7)

Key ideas:

- This report describes an Australian research project on integrated STEM learning using the Australian Curriculum. It proposes an engineering design framework as a way to approach early engineering education. This framework aligns well with the Australian Curriculum: Technologies ‘Processes and Production Skills’ strand.
- The study describes fourth-grade students’ developments in working an aerospace engineering problem that required students to complete initial designs and redesigns of a model plane at varying levels of sophistication.
- Results showed young learners can engage and apply STEM disciplinary knowledge with an appropriate balance between teacher input of new concepts and student application of this learning.

Gillies, R & Nichols, K 2015, 'How to support primary teachers' implementation of inquiry: Teachers' reflections on teaching cooperative inquiry-based science', *Research in Science Education*, vol. 45, no. 2, pp. 171–191.

Website: www.researchgate.net/publication/272010248_How_to_Support_Primary_Teachers%27_Implementation_of_Inquiry_Teachers%27_Reflections_on_Teaching_Cooperative_Inquiry-Based_Science (DOI: 10.1007/s11165-014-9418-x)

Key ideas:

- This study reports on the reflections of Grade 6 teachers who taught two cooperative, inquiry science units, once a term, for two consecutive school terms. The study investigated the teachers' perceptions of teaching inquiry science, as well as the processes they employed.
- Although the teachers reflected positively on their experiences, they expressed concerns about the challenges that arose when teaching through inquiry.
- Implications for teacher education and use of cooperative learning are also considered.

Guzey, SS, Moore, TJ, Harwell, M & Moreno, M 2016, 'STEM integration in middle school life science: Student learning and attitudes', *Journal of Science Education and Technology*, vol. 25, no. 4, pp. 550–560.

Website: https://link.springer.com/article/10.1007/s10956-016-9612-x (DOI: 10.1007/s10956-016-9612-x)

Key ideas:

- This research evaluated the effects of an engineering design-based science curriculum on student learning and attitudes. The study was part of a larger study conducted by the National Research Council.
- Results showed implementing the engineering design-based science unit had a positive effect on student attitudes and learning for some groups. Significant gains were reported for special education groups.
- Teachers' pedagogical practices played a key role in facilitating deep student learning in integrated science and engineering classes.

Harwell, M, Moreno, M, Phillips, A, Guzey, SS, Moore, TJ & Roehrig, GH 2015, 'A study of STEM assessments in engineering, science, and mathematics for elementary and middle school students', *School Science and Mathematics*, vol. 115, no. 2, pp. 66–74.

Website: http://engrteams.mspnet.org/index.cfm/28013 (DOI: 10.1111/ssm.12105)

Key ideas:

- The purpose of this study was to develop, scale and validate assessments in engineering, science, and mathematics with grade-appropriate items that were sensitive to the curriculum developed by teachers. Item response theory was used to assess item functioning.
- This work was part of a larger project focused on increasing student learning in STEM-related areas in Grades 4–8 through an engineering design-based, integrated approach to STEM instruction and assessment.
- Results from the study showed the engineering design-based science unit may be particularly effective for reaching special education students, closing gender-based achievement gaps, increasing student attitudes toward STEM, and promoting academic achievement where student attitudes are favourable to content.

Holmes, NG, Wieman, CE & Bonn, DA 2015, 'Teaching critical thinking', *Proceedings of the National Academy of Sciences*, vol. 112, no. 36, pp. 11 199–11 204.

Website: http://www.pnas.org/content/112/36/11199.short (DOI: 10.1073/pnas.1505329112)

Key ideas:

- The ability to make decisions based on data (quantitative critical thinking) is a complex and vital skill in the modern world and occurs in many different contexts. Although it is an important educational goal, it is seldom being achieved.
- Developing critical thinking skills requires repeated practice in making and acting on quantitative comparisons between datasets or data and models. This was applied to a university introductory physics laboratory course where results showed students were more likely to
  - spontaneously propose or make changes to improve their experimental methods
  - identify and explain a limitation of a model using their data
  - be more sophisticated in reasoning about their data.

Honey, M, Pearson, G & Schweingruber, H 2014, *STEM integration in K–12 education: Status, prospects, and an agenda for research*, National Academies Press, Washington, DC.

Website: www.nap.edu/catalog/18612/stem-integration-in-k-12-education-status-prospects-and-an

Key ideas:

- The Committee on Integrated STEM Education identified and characterised existing approaches to integrated STEM education, in formal, after-school and informal settings.
- The evidence-based research of integrated approaches found positive improvements in: mathematics and science results, student awareness, interest, motivation, college-readiness skills, and increased number and quality of students who may consider a STEM-related career.
- Implementation of integrated STEM programs was also considered, including assessment of STEM learning.

King, J 2015, 'Australian Curriculum: Technologies with a focus on critical and creative thinking', *Australian Curriculum Studies Association (ACSA) News*, December, pp. 20–28.

Website: www.acsa.edu.au/pages/images/acsa_news_2015_december.pdf

Key ideas:

- This paper focuses on the thinking skills underpinning the Australian Curriculum: Technologies, how they were developed and what this means for teachers.
- The types of thinking used in technologies learning (e.g. systems thinking, design thinking and computational thinking) contribute to general capabilities for lifelong learning.
- Assessment opportunities can be provided for students to demonstrate critical and creative thinking skills in Technologies. Student work can demonstrate this at different levels of achievement.

Maaß, K & Artigue, M 2013, 'Implementation of inquiry-based learning in day-to-day teaching: A synthesis', *ZDM: Mathematics Education*, vol. 45, no. 6, pp. 779–795.

Website: https://link.springer.com/article/10.1007%2Fs11858-013-0528-0 (DOI: 10.1007/s11858-013-0528-0)

Key ideas:

- This report provides insight into large-scale implementation of inquiry-based learning.
- It proposes a conceptual framework that helps analyse and compare existing project strengths and support designers in developing new large-scale implementation models.
- Four exemplary projects demonstrate the framework parameters.

Marginson, S, Tytler, R, Freeman, B, Roberts, K 2013, *STEM: Country comparisons — International comparisons of science, technology, engineering and mathematics (STEM) education*, Final report, Australian Council of Learned Academies, Melbourne, Vic.

Website: www.acola.org.au/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf

Key ideas:

- The purpose of the STEM: Country comparisons project was to discover what other countries are doing to develop participation and performance in the STEM disciplines.
- Key findings for consideration in Australia included
  - improving the position of STEM in society, e.g. broadening STEM engagement and achievement, division at secondary school level between STEM and non-STEM tracks, compulsory STEM secondary subjects, STEM-specific higher education prerequisites
  - promoting STEM attitudes by building awareness of STEM disciplines and STEM-related occupations among young people
  - framing national STEM policy and strategy
  - focusing curriculum on innovation, creativity and reasoning, accompanied by a strong commitment to disciplinary knowledge
  - investing in teachers and teaching, e.g. STEM professional development, teaching science and mathematics in primary school
  - improving gender participation and participation by Indigenous students.

McClure, ER, Guernsey, L, Clements, DH, Bales, SN, Nichols, J, Kendall-Taylor, N & Levine, MH 2017, *STEM starts early: Grounding science, technology, engineering, and math education in early childhood*. The Joan Ganz Cooney Centre at Sesame Workshop, New York.

Website: www.joanganzcooneycenter.org/wp-content/uploads/2017/01/jgcc_stemstartsearly_final.pdf

Key ideas:

- This research-based study looked at the critical importance of STEM learning in early childhood education and the influence of early motivation in STEM on student learning.
- Recommendations included the need to
  - improve teacher professional learning in STEM
  - support parent involvement
  - build a sustainable and aligned system of high-quality early learning from birth through age 8
  - use communications science to build public will and understanding
  - expand the availability of external links to community to build interest and understanding.

McGaw, B 2013, 'Developing 21st century competencies through disciplines of knowledge', paper presented at the Education and 21st Century Competencies National Symposium, Muscat, Sultanate of Oman, 22–24 September.

Website:
https://acaraweb.blob.core.windows.net/resources/Developing_21st_century_competencies_Prof_Barry_McGaw.pdf

Key ideas:

- This paper examines the development of competencies in curriculum development.
- The paper discussed the Australian Curriculum general capabilities (ACARA's definition of the 21st century skills) and their connection to the curriculum learning areas.

McDonald, CV 2015, *International best practice in science, technology, engineering and mathematics (STEM) education*, Griffith Institute for Educational Research, Brisbane.

Website:
www.researchgate.net/publication/311107939_International_best_practice_in_science_technology_engineering_and_mathematics_STEM_education

Key ideas:

- This report examines international best practice in STEM education, including
  - key goals and reforms of the four disciplines
  - contextual factors influencing students' engagement in each STEM discipline
  - effective pedagogical practices and their influence on student learning and achievement
  - the pivotal role of the teacher.

McDonald, CV 2016, 'STEM education: A review of the contribution of the disciplines of science, technology, engineering and mathematics', *Science Education International*, 27(4), pp. 530–569.

Website: https://files.eric.ed.gov/fulltext/EJ1131146.pdf

Key ideas:

- This paper examines factors influencing students' engagement, effective pedagogical practices and their influence on student learning and achievement, and the role of the teacher in STEM education.
- Through a critical review of 235 studies, three key factors critical to STEM learning were identified
  - Importance of focusing on junior secondary phase of schooling to maintain student interest and motivation to engage in STEM
  - implementation of effective pedagogical practices to increase student interest and motivation, develop 21st century competencies and improve student achievement
  - development of high-quality teachers to positively affect students' attitudes and motivation towards STEM.

McKenna, RL 2016, ‘Girls and STEM (Science, Technology, Engineering, and Mathematics) in Catholic schools: A mixed methods exploration of interest, confidence, and perceptions of STEM’, Dissertation, The University of San Francisco, CA.

Website: http://repository.usfca.edu/diss/317/

Key ideas:

- This dissertation investigated the issue of under-representation of girls in STEM careers and achievement, despite outperformance in standardised testing. It investigated girls’ attitudes and confidence in STEM areas in Catholic schools in Grades 4–8.
- Recommendations included
  - aligning STEM learning with national programs
  - aligning administration to STEM opportunities
  - creating more specific STEM opportunities for girls, e.g. programming, networking, sharing resources
  - developing STEM professional learning for teachers
  - connecting with other high schools and universities.
- The author concluded that girls are influenced most directly by STEM teachers, their families and the Catholic school environment.

Means, B, Wang, H, Young, V, Peters, VL & Lynch, SJ 2016, ‘STEM-focused high schools as a strategy for enhancing readiness for post-secondary STEM programs’, *Journal of Research in Science Teaching*, vol. 53, no. 5, pp. 709–736.

Website: http://onlinelibrary.wiley.com/doi/10.1002/tea.21313/full (DOI: 10.1002/tea.21313)

Key ideas:

- Research found that attending an inclusive STEM high school
  - raised the likelihood that a student will complete pre-calculus or calculus and chemistry in high school
  - led to increased involvement in STEM extracurricular and out-of-class activities
  - enhanced interest in science careers and aspirations to earn a masters or higher degree
  - had a positive impact on grade point average.

Melchior, A, Burack, C, Hoover, M & Marcus, J 2016, *FIRST longitudinal study: Findings at follow-up (Year 3 report)*, Brandeis University, Waltham, MA Manchester, NH.

Website: www.firstinspires.org/sites/default/files/uploads/resource_library/impact/first-longitudinal-study-summary-of-preliminary-findings-year-3.pdf

Key ideas:

- This research relates to long-term impacts of FIRST (For Inspiration and Recognition of Science and Technology) on participants. FIRST is a non-profit organisation that operates after-school robotics programs for young people aged 6–18.
- The study found FIRST had a positive impact on participants’ interest in STEM, involvement in STEM-related activities, STEM identity, STEM knowledge, and interest in STEM careers.
- FIRST had significantly greater impacts on girls than their male counterparts.

Moore, TJ, Glancy, AW, Tank, KM, Kersten, JA, Smith, KA & Stohlmann, MS 2014, 'A framework for quality K–12 engineering education: Research and development', *Journal of Pre-College Engineering Education Research*, vol. 4, no. 1, article 2.

Website: https://doi.org/10.7771/2157-9288.1069 (DOI: 10.7771/2157-9288.1069)

Key ideas:

- The purpose of this research was to develop a framework for describing what constitutes a quality K–12 engineering education. The framework was developed from a research project focused on understanding and identifying the ways in which teachers and schools implement engineering and engineering design in their classrooms.
- The framework was designed to be used as a tool for evaluating the degree to which academic standards, curricula and teaching practices address the important components of a quality K–12 engineering education. Additionally, the framework can be used to inform the development and structure of future K–12 engineering and STEM education standards and initiatives.

Moore, TJ & Smith, KA 2014, 'Advancing the state of the art of STEM integration', *Journal of STEM Education: Innovations and Research*, vol. 15, no. 1, pp. 5–10.

Website:
www.researchgate.net/publication/294427783_Advancing_the_State_of_the_Art_of_STEM_Integration

Key ideas:

- This article outlines important considerations for STEM education. It describes integrated STEM education as an effort to combine the four disciplines into one class, unit or lesson based on connections among these disciplines and real-world problems.
- Integration of content and engineering thinking can be achieved through
  - context integration — integration of engineering design as a motivator to teach disciplinary content, i.e. using engineering design as a pedagogy to help students learn the content
  - content integration — integration of engineering thinking and mathematics/science content, i.e. the learning goals include mathematics and/or science content and also engineering learning.

Moroney, T, Czaplinski, I, Burrage, P & Yang, Q 2016 'How (well) are we assisting our students in becoming 21st century STEM graduates?', paper presented at The Australian Conference on Science and Mathematics Education, The University of Queensland, Brisbane, 28–30 September.

Website: http://eprints.qut.edu.au/99486/

Key ideas:

- The investigation examined student preparation for future employment with skills that allowed them to adapt to the needs of the economy and equipped them with strategies for lifelong learning. This was applied to the context of a first-year Computational Science unit.
- Conclusions showed contemporary higher education institutions need to assist students with becoming both discipline experts and expert learners through the acquisition and development of 21st century skills.
- Opportunity exists for 21st century skills to be implicitly included in discipline unit design.

National Research Council, 2011, *Successful K–12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*, National Academies Press, Washington DC.

Website: www.nap.edu/catalog/13158/successful-k-12-stem-education-identifying-effective-approaches-in-science

- This report outlines the need for STEM education and proposes criteria for the identification of highly successful K–12 schools.
- Schools and districts are critical to supporting effective STEM education.
- Key elements for successful STEM instruction include: curriculum standards, high capacity teachers, system supports, instruction time, high quality opportunities, and school conditions and culture that support the learning.

National Research Council 2011, *Successful STEM education: A workshop summary*, National Academies Press, Washington, DC.

Website: www.nap.edu/catalog/13230/successful-stem-education-a-workshop-summary

Key ideas:

- The Committee on Highly Successful Schools or Programs for K-12 STEM Education was created to explore what makes STEM education successful in schools.
- School pedagogy, practice and assessment need to support STEM education.
- Formative assessment is effective in increasing student performance.
- STEM success in schools requires school leadership, professional capacity, partnerships with parents/community, student-centred learning and support for teachers.

Office of the Chief Scientist 2012, *Health of Australian Science*, Australian Government, Canberra.

Website: www.chiefscientist.gov.au/2012/05/health-of-australian-science-report-2/

The Chief Scientist provides high-level independent advice to the Prime Minister and other ministers on matters relating to science, technology and innovation.

Key ideas:

- This report provides a comprehensive picture of science in Australia. The observations informed subsequent reports by the Chief Scientist about STEM. The main findings include
  - Australian science is generally in good health: school students generally compare well internationally, there is science enrolment growth in universities, Australian researchers produce more per capita than researchers in most other nations.
  - Science participation rates have fallen.
  - Compared with other nations, secondary school performance in science literacy is slipping.
  - Australia’s output of research publications is high and world class. However, the research community funding has been under increasing pressure.
  - Fields at risk in the short to medium term include: agriculture, chemistry, mathematics and physics; mathematics, physics and chemistry form the basis of education and research in all science.
- There needs to be a focus on education and research to secure Australia’s future and place in the world.

Office of the Chief Scientist 2016, *Australia's STEM workforce*, Australian Government, Canberra.

Website: www.chiefscientist.gov.au/wp-content/uploads/Australias-STEM-workforce_full-report.pdf

Key ideas:

- This report analyses data collected by the Office of the Chief Scientist and measures Australia's capability for STEM-led change.
- It provides a foundation for public policy decisions about skills that need to be developed. Part 1 looks at STEM capability in Australia, while Part 2 looks at pathways for university graduates.
- The report examines the capabilities developed in STEM learning, including deep knowledge of a subject, creativity, problem-solving, critical thinking and communication skills, and how these relate to the future workforce.

Peters-Burton, EE, Lynch, SJ, Behrend, TS & Means, BB 2014, 'Inclusive STEM high school design: 10 critical components', *Theory in Practice*, vol. 53, pp. 64–71.

Website:
www.researchgate.net/publication/275265375_Inclusive_STEM_High_School_Design_10_Critical_Components (DOI: 10.1080/00405841.2014.862125)

Key ideas:

- The article identifies 10 critical components across three dimensions (design, implementation and outcomes) to create a theory of action for inclusive STEM high schools in the United States.
- The 10 research-based components are: STEM-focused curriculum, reformed instructional strategies and project-based learning, use of integrated and innovative technology, blended formal/informal learning beyond the typical school program, real-world STEM partnerships, early college-level coursework, well prepared STEM teaching staff, inclusive STEM mission, supportive administrative structure and supports for underrepresented students.

Prinsley, R & Baranyai, K 2015, *STEM skills in the workforce: What do employers want?* Office of the Chief Scientist, Canberra, Australia.

Website: www.chiefscientist.gov.au/wp-content/uploads/OPS09_02Mar2015_Web.pdf

- This paper reports on survey results for employer perceptions of STEM qualified people, including the skills and attributes that they bring to the workplace, the value that employers place on STEM graduates and expectations of future demand.

Prinsley, R & Johnston, E 2015, *Transforming STEM teaching in Australian primary schools: Everybody's business*, Office of the Chief Scientist, Canberra, Australia.

Website: www.chiefscientist.gov.au/wp-content/uploads/Transforming-STEM-teaching_FINAL.pdf

Key ideas:

- This is a government position paper on initiatives for STEM teaching in primary schools.
- The paper suggests the following strategies
  - raise the prestige and preparedness of teachers by attracting STEM high achievers to primary school teaching and increasing science, technology and mathematics in pre-service teaching
  - transform STEM education in primary schools by supporting with STEM specialist teachers, creating a national professional development program and educating principals as STEM leaders
  - think bold, collaborate and lead change.

Purzer, Ş, Goldstein, MH, Adams, RS, Xie, C & Nourian, S 2015, 'An exploratory study of informed engineering design behaviours associated with scientific explanations', *International Journal of STEM Education*, vol. 2, no. 1, p. 9.

Website: https://link.springer.com/article/10.1186/s40594-015-0019-7 (DOI: 10.1186/s40594-015-0019-7)

Key ideas:

- In this study, the relationship between design behaviours and scientific explanations is examined in terms of engineering practice. Data on student design processes was collected as students engaged in a project on designing energy-efficient buildings.
- Opportunities for meaningful science learning through engineering design occurred when students attempted to balance design benefits and trade-offs.
- Results suggest design projects should emphasise trade-off analysis and include time and resources for supporting these decisions through experimentation and reflection.

Rehmat, AP 2015, 'Engineering the path to higher-order thinking in elementary education: A problem-based learning approach for STEM integration', Dissertation, University of Nevada, Las Vegas.

Website: http://digitalscholarship.unlv.edu/thesesdissertations/2497/

Key ideas:

- This study conducted with fourth grade students was based on the desire to improve 21st century, higher-order thinking skills and achievement in science and math (essential for STEM careers). It explored students' experiences of STEM integration in a problem-based learning (PBL) environment.
- Three themes emerged
  - the PBL approach encouraged constructive learning, where students used their existing knowledge to make inferences about the new knowledge to problem solve
  - increased teacher interaction as a result of PBL instruction improved critical thinking skills
  - implementation of engineering and design through PBL promoted positive attitudes in STEM content areas, which can lead to interest in STEM careers.

Robinson, N 2016, ‘A case study exploring the effects of using an integrative STEM curriculum on eighth grade students’ performance and engagement in the mathematics classroom’, Dissertation, Georgia State University, Atlanta.

Website: http://scholarworks.gsu.edu/mse_diss/32/

Key ideas:

- This study examines the effects of using a Robotics and Engineering Design Curriculum (integrated STEM learning) on eighth grade students’ performance and engagement.
- The curriculum enhanced engagement through purposeful and intentional physical action and collaboration through the construction of meaning and interaction.
- Success was attributed to the transformative learning environment, design learning experiences and contextual relevance as students designed their learning journey.

Rockland, R, Bloom, D, Carpinelli, S, Burr-Alexander, J, Hirsch, LS & Kimmel, H 2010, ‘Advancing the “E” in K–12 STEM education’, *Journal of Technology Studies*, vol. 36, no. 1, pp. 53–64.

Website: https://scholar.lib.vt.edu/ejournals/JOTS/v36/v36n1/pdf/rockland.pdf (DOI: 10.21061/jots.v36i1.a.7)

Key ideas:

- This study explores best practice for bringing engineering into the science and mathematics curriculum of secondary school classrooms. The project uses concepts representing the merger of medicine, robotics and information technology. Specific examples demonstrate how this can be integrated into the teaching of physics, biology and chemistry.
- A framework is also included for pre-service teachers to blend engineering concepts as an instructional strategy and to compare engineering design and scientific inquiry.

Roehrig, GH, Moore, TJ, Wang, H-H & Park, MS 2012, ‘Is adding the E enough? Investigating the impact of K–12 engineering standards on the implementation of STEM integration’, *School Science and Mathematics*, vol. 112, no. 1, pp. 31–44.

Website: http://onlinelibrary.wiley.com/doi/10.1111/j.1949-8594.2011.00112.x/abstract (DOI: 10.1111/j.1949-8594.2011.00112.x)

Key ideas:

- This study discusses STEM education integration with state-level policies and implementation within K–12 classrooms.
- It investigated secondary STEM teachers’ implementation of STEM integration in their classrooms during a year-long professional development program using an interpretive approach.
- The case studies suggested that STEM integration can be implemented most successfully when mathematics and science teachers work together, both in a single classroom (co-teaching) and in multiple classrooms (content teaching with a common theme).

Rosicka, C 2016, *Translating STEM education research into practice*, Australian Council for Educational Research, Camberwell, Victoria.

Website: http://research.acer.edu.au/professional_dev/10/

Key ideas:

- This review considers the importance of STEM education for Australia's future workforce within a context of falling student participation numbers in STEM studies. It represents research commissioned and published by the Australian Council for Educational Research (ACER).
- STEM programs investigated from across the country included: Primary Connections, Eng Quest, CS Unplugged, Robotics in Primary Schools, Aerospace Engineering Challenge Framework, Wonder of Science Challenge.
- The review examines STEM interventions in primary classes and includes practical ideas for teachers, and recommendations about the provision of professional development and support, learning integration, active learning and student engagement and participation.

Stohlmann, M, Moore, TJ & Roehrig, GH 2012, 'Considerations for teaching integrated STEM', *Journal of Pre-College Engineering Education Research* (J-PEER), vol. 2, no. 1, article 4.

Website: http://docs.lib.purdue.edu/jpeer/vol2/iss1/4/ (DOI: 10.5703/1288284314653)

Key ideas:

- This article outlines a model for teaching integrated STEM education that was developed through a year-long partnership with a middle school. It was developed to make learning more connected and relevant for students.
- A theoretical framework is included which provides useful background support for integrated STEM. Effective practice and teacher efficacy is also discussed within the context of STEM integration.

Tsupros, N, Kohler, R & Hallinen, J 2009, 'STEM education in Southwestern Pennsylvania: Report of a project to identify the missing components', Intermediate Unit 1, Center for STEM Education and Leonard Gelfand Center for Service Learning and Outreach, Carnegie Mellon University, Pennsylvania.

Website: www.cmu.edu/gelfand/documents/stem-survey-report-cmu-iu1.pdf

Key ideas:

- This report was published by a group that were trying to introduce major improvements to STEM levels in Pennsylvania (PA).
- The Pennsylvania STEM Initiative identified four goals to accomplish their mission
  - increase the number and diversity of PA residents and workers with high quality STEM education and training
  - ensure that all graduates from PA's high schools are proficient in STEM content areas
  - increase the number of well-prepared STEM teachers working in PA's K–12 educational institutions
  - secure broad public support for STEM education as a priority for PA's citizens.

Tytler, R, Osborne, PJ, Williams, DG, Tytler, DK & Clark, DJC 2008, *Opening up pathways: Engagement in STEM across the primary–secondary school transition*, Department of Education, Employment and Workplace Relations, Canberra.

Website: www.voced.edu.au/content/ngv%3A52073

Key ideas:

- A comprehensive literature review on the barriers and supports that young people encounter in pursuing studies in STEM disciplines in Australia. Findings include
  - engaging students in STEM pathways becomes increasingly difficult after the early secondary school years
  - pedagogy and the quality of classroom teaching is critical to student engagement with mathematics or science in opening up pathways into STEM.

Tytler, R, Symington, D, Williams, G, White, P, Campbell, C, Chittleborough, G, Upstill, G, Roper, E & Dziadkiewicz, N 2016, *Building productive partnerships for STEM education: Evaluating the model & outcomes of the Scientists and Mathematicians in Schools program 2015*, Deakin University, Burwood, Australia.

Website: www.csiro.au/~/media/Education-media/Files/STEM-Prof-Schools/Productive-Partnerships-STEM-Education-PDF.pdf

Key ideas:

- The Scientists and Mathematicians in Schools (SMiS) program is a major Australian initiative funded by the Australian Government Department of Education and Training in conjunction with CSIRO.
- A number of key strengths were reported
  - partnerships were collaborative between individual STEM professionals and teachers
  - partnerships were responsive to local contexts and had national reach
  - for students, outcomes included increased engagement with science, mathematics and ICT learning and reasoning; increased interest, enjoyment, knowledge and confidence in STEM subjects; awareness of how scientists and mathematicians think and work; increased appreciation of STEM professionals as people; and knowledge of, and enhanced attitudes towards, STEM pathways and careers
  - teachers reported improved motivation and engagement in science and mathematics teaching, enjoyment in working with STEM professionals, increased engagement of their students, improved teaching processes and, for primary teachers especially, increased confidence with teaching.

Vasquez, JA 2013, *STEM Lesson Essentials, Grades 3–8: Integrating science, technology, engineering, and mathematics*, Heinemann, Portsmouth, NH.

Website: www.heinemann.com/products/e04358.aspx

Key ideas:

- This book provides tools and strategies to design integrated, interdisciplinary STEM lessons and units. It includes guiding principles for effective STEM instruction, sample activities and lesson planning templates.
- The authors argue that STEM in itself is not a curriculum, but rather a way of organising and delivering instruction by weaving the four disciplines together in intentional ways.
- Explicit connections are made among the STEM practices, including the Common Core Standards for Mathematical Practice and the Framework for K–12 Science Education.

Vasquez, JA 2015, ‘STEM: Beyond the acronym’, *Educational Leadership*, vol. 72, no. 4, pp. 10–15.

Website: http://www.ascd.org/publications/educational-leadership/dec14/vol72/num04/STEM%E2%80%94Beyond-the-Acronym.aspx

Key ideas:

- This article introduces some important but simple ideas for implementing STEM in a primary setting.
- It discusses the various integration models (disciplinary to trans-disciplinary), including practical suggestions for moving between the different models.

Wang, HH 2012, ‘A new era of science education: Science teachers’ perceptions and classroom practices of science, technology, engineering, and mathematics (STEM) integration’, Dissertation, University of Minnesota, Minneapolis.

Website: https://conservancy.umn.edu/handle/120980

Key ideas:

- This multiple-case study was conducted with five secondary school science teachers to gain a better understanding of teachers’ perceptions and classroom practices in using STEM integration.
- The results suggest that teachers view the integration of science and engineering as the most important aspect of STEM integration. Mathematics and technology were considered secondary as tools to solve a problem/challenge for science or engineering.
- Focuses identified for STEM integration included: problem-solving, application, engineering design, life skills and connections to science content.

Williams, J 2011, ‘STEM education: Proceed with caution’, *Design and Technology Education: an International Journal,* vol. 16, no. 1, pp. 26–35.

Website: https://ojs.lboro.ac.uk/DATE/article/view/1590

Key ideas:

- This article looks at the rationale behind the STEM movement. In the context of the global financial crisis, coordination and integration of STEM activities may better equip a workforce to deal with the contemporary nature of business and industry, and encourage more school leavers to seek employment in areas of engineering and science.
- Rather than integration, a more reasonable approach may be to develop interaction between STEM subjects by fostering cross-curricular links that still respect the integrity of each subject.
- There are many impediments to interaction: rigid school timetables and curriculum structures, deficient awareness by teachers of other subject areas, inflexible classroom design, and assessment. Driven by teachers, interventions can be developed that will overcome these impediments.

Wirkala, C & Kuhn, D 2011, ‘Problem-based learning in K–12 education: Is it effective and how does it achieve its effects?', *American Educational Research Journal*, vol. 48, no. 5, pp. 1157–1186.

Website: http://journals.sagepub.com/doi/abs/10.3102/0002831211419491

Key ideas:

- This article outlines the benefits of problem-based learning (PBL) identified in a controlled study of PBL in a middle school population. There has previously been little rigorous experimental evidence of its effectiveness, especially in K–12 populations.
- Assessments of comprehension and application of concepts in a new context showed superior mastery in PBL conditions. Results showed that the social component of PBL is not a critical feature of its effectiveness.