Targeting all of STEM in the primary school: Engineering design as a foundational process

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Abstract

With the increased national and international focus on advancing STEM education, it is important to ensure all of its disciplines are represented in the curriculum. To-date, the STEM acronym has been used largely in reference to science, with less emphasis on the remaining disciplines – especially engineering. Yet engineering design, a core component of engineering education, is now seen internationally as a foundational process linking the STEM disciplines, not just confined to engineering. Engineering concepts, design processes, representing, modelling, and innovative design-based problem-solving are all featured within the new Design and Technologies Curriculum. This paper will explore the nature and roles of these engineering components and discuss ways in which they might be integrated within primary school students' STEM learning. The paper will include findings from STEM-based problem-solving research with a focus on engineering learning.

Introduction

Promoting STEM education across the school years is a core goal of many nations (for example, Lucas, Claxton & Hanson, 2014; National Research Council, 2014; Office of the Chief Scientist, 2014; Office of the US President, 2013). 'Inspiring STEM literacy' is one of the pillars of Australia's recently released National Innovation and Science Agenda (7 Dec., 2015: http://www.innovation.gov.au/page/inspiring-nation-scientists), yet despite this increased focus on STEM education, not all of the disciplines are receiving equitable recognition.

One aspect that remains in need of greater attention is the relative lack of inclusion of engineering experiences in STEM curricula, especially in the primary grades, despite the contributions of engineering having been well documented. For example, the literature has indicated how engineering-based experiences can develop young students' appreciation and understanding of the roles of engineering in shaping our world, and how engineering can contextualise mathematics and science principles to improve achievement, motivation, and problem-solving (for example, English, 2016; Stohlmann, Moore & Roehrig, 2012). In particular, engineering design and thinking are not being capitalised on in school curricula, especially at the primary level, yet they are recognised as major components of engineering education across the school years, as well as being foundational processes for all citizens (for example, Next Generation Science Standards, 2014).

Engineering design and thinking

Engineering design is commonly described as comprising iterative processes involving (a) defining problems by specifying criteria and constraints for acceptable solutions, (b) generating a number of possible solutions and evaluating these to determine which ones best meet the given problem criteria and constraints, and (c) optimising the solution by systematically testing and refining, including overriding less significant features for the more important. Underpinning this design is engineering thinking or 'habits of mind', which includes systems thinking, innovative problem finding and solving, visualising, and collaborating and communicating (English & Gainsburg, 2016; Lucas et al., 2014).

Although traditional views have generally considered engineering design and thinking to be too complex to teach and learn, particularly for younger learners, recent research has revealed learners' capacity to undertake basic design work such as imagining, planning, constructing, and evaluating (for example, Dorie, Cardella & Svarovsky, 2014; Lachapelle & Cunningham, 2014). Young students' propensity for applying multiple ideas and approaches to innovative and creative problem-solving provides a rich foundation for fostering early design-based problem-solving (Lachapelle & Cunningham, 2014).

Integrating engineering design within the Australian Curriculum

Opportunities for integrating engineering design and thinking across STEM content areas appear in the new Australian Curriculum: Design and Technologies (version 8.1), beginning with the earliest grades, where it is recommended that young students 'experience designing and producing products' (p. 58). Given our increasingly technological and complex world, the Curriculum highlights the importance of students developing the knowledge and confidence to critically analyse and creatively respond to design challenges.

The integrative potential of engineering is evident in its definition in the Curriculum, namely '[t]he practical application of scientific and mathematical understanding and principles as part of the process of developing and maintaining solutions for an identified need or opportunity' (p. 22). Although much has been written on STEM integration (for example, English, 2016; Moore & Smith, 2014), the nature of such learning experiences and how these might be integrated within the curriculum remain open to debate. In the remainder of this paper, I address one example from a recent longitudinal study in which my colleagues and I implemented design-based engineering problems across grades 4–6 in multiple schools, including state and non-state. This study, as well as a prior three-year study in the middle/early secondary years, was supported by Linkage grants from the Australian Research Council. Strong support has also been received from the Queensland Department of Transport and Main Roads.

Underpinning each of the problems implemented throughout the study was students' appreciation and independent application of engineering design processes. Drawing on their learning in mathematics, science and technology, students were encouraged to apply their own ideas and approaches to designing and creating solutions. One of our goals was for the students to appreciate how their learning in these disciplines applies to solving problems in the outside world. We planned the learning experiences in consultation with the teachers, building on their existing curriculum programs. The teachers implemented each of the problem activities, and participated in regular briefing and debriefing meetings before and after each implementation.

Earthquake engineering problem

Multiple sixth-grade classes participated in the Earthquake Engineering problem, which was the seventh of eight comprehensive, multi-session problem activities implemented across the three years. Applying their preliminary learning about earthquakes, students designed and constructed a building that could withstand earthquake damage. Students applied engineering design processes and thinking to build their structures (using toothpicks and plasticine), which they subsequently tested using a shaker table to simulate an earthquake (the table comprised a platform and tab that when pulled simulated an earthquake measuring 4 or 8 on the Richter scale). The problem was presented within an AusAid context and included the problem description together with the materials to be used and their costs, as well as constraints to be met in designing their building (namely, at least two toothpicks high; must contain at least one triangle and one square; must contain cross-bracing to reinforce the structure; materials may be cut to size; and budget not to exceed $40).

The first part of the activity included earthquake video clips, together with hands-on activities where students explored techniques that make buildings earthquake-proof, including cross-bracing, tapered geometry, and base isolation. Understanding the properties of shapes and how combining shapes yields new properties (for example, increased strength) and relationships was also an important learning goal. In completing the second part, the students designed and built their first structure, and then discussed possible changes to their initial design to more effectively earthquake-proof their structures.

Students worked the problem in small groups, completing their responses in individual workbooks where they drew their initial designs and redesigns, and also answered a number of questions (for example, 'How will you make it [the building] strong?' 'What can you change to improve your design?' 'How will these changes make your structure better?') Data analysis drew upon the students' workbook responses, their initial and improved designs and constructions, and transcripts of student group and whole-class discussions.

Applying design processes

In analysing the group transcripts, the use of design processes became evident as students identified the problem goal and constraints, debated ideas on their designs and subsequent constructions, sketched and interpreted their designs, transformed their designs into their constructions, tested their first structure, and redesigned and tested their second. The application of STEM concepts was also evident in, and essential to, their solutions.

As an example, I briefly report on Catherine's group (Catherine is a pseudonym). Catherine's group engaged in substantial debate throughout their design, while keeping in mind the problem goal and constraints, in particular their budget limit. In designing their first structure, the group noted that the placement of cross-bracing 'will be important' and decided to cross-brace all sides, bottom and top. They then considered base isolation, commenting that it 'will be the bottom because we will have the square pyramid. And then at the bottom [of the structure] will be the cross-bracing.' Considerable time was spent deciding where the cross-bracing would go, how much material would be used, and the costs involved. Figure 1 presents Catherine's first design sketch, where she labelled the materials and their costs, and indicated where cross-bracing was to be placed.

On testing the group's structure on the shaker table at Richter scale 4, then 8, Catherine recorded in her workbook, '[e]ven though our design was very rigid, the force of the earthquake allowed it to topple over onto its side because it had no base isolation.' The group welcomed a second design opportunity, with Catherine explaining, '[t]he good thing about doing two designs is that you can actually see where the flaws are and you can actually make it better ... because the first time you don't know what the flaws are; you haven't tested it. We do know now ... it needs supporters (pointing to base of structure), but it's very rigid, which is good.' Catherine's enhanced second design appears in Figure 2.

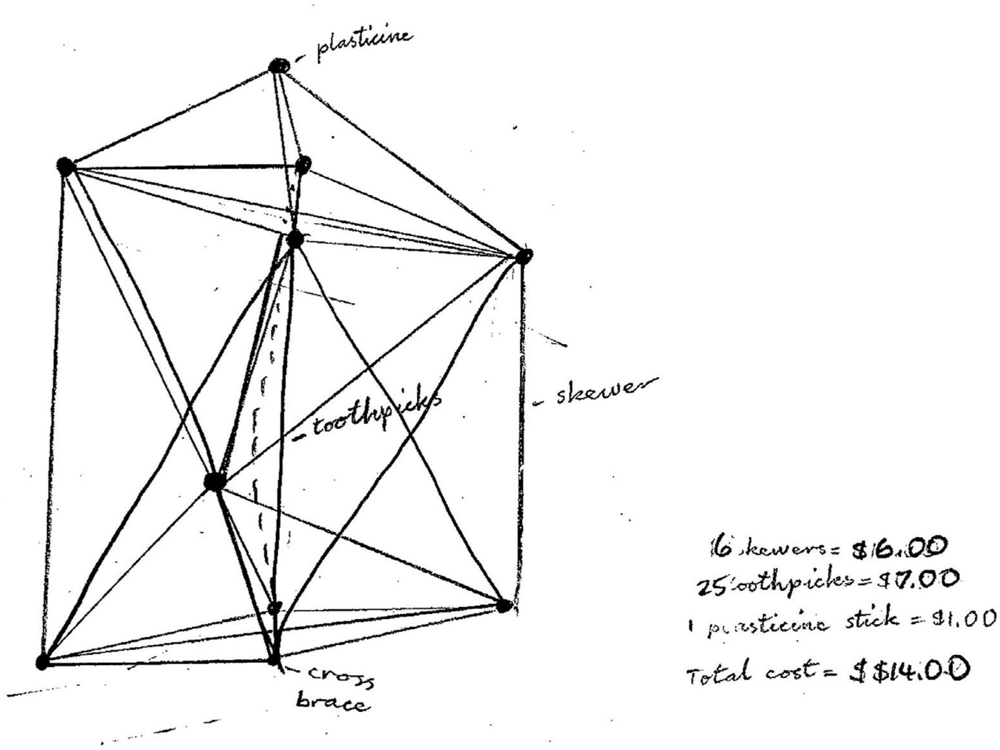

Figure 1 Catherine's first design

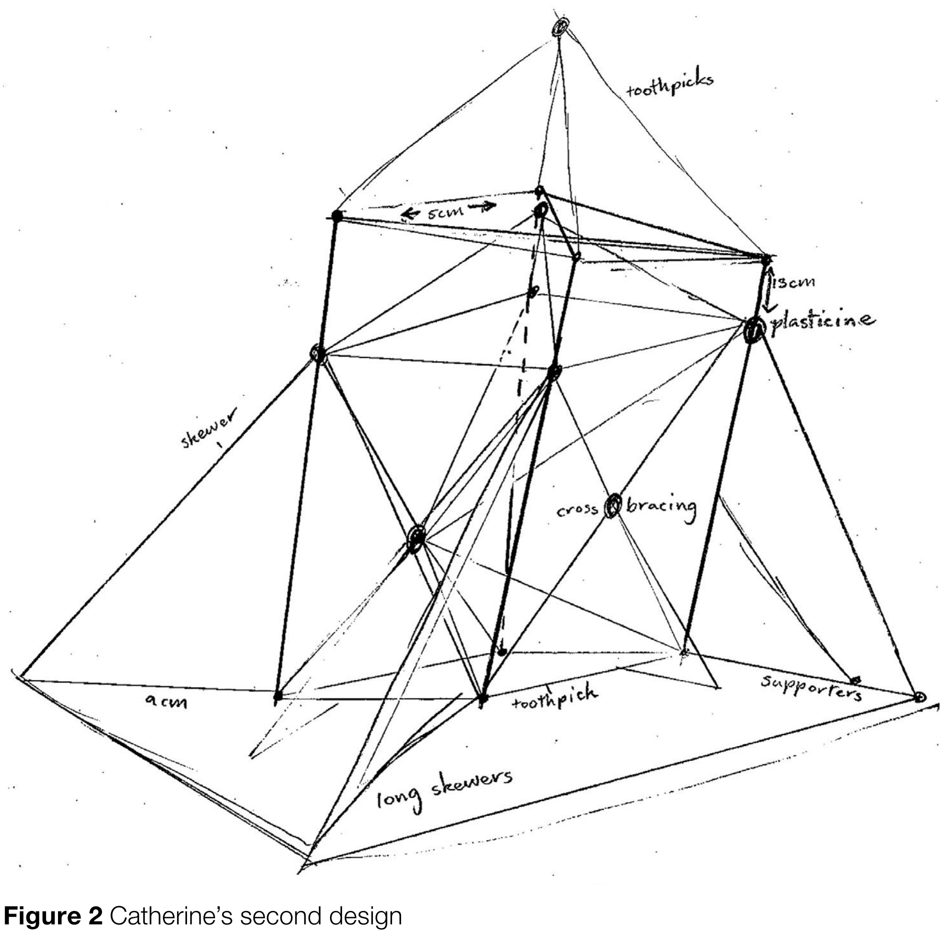

Figure 2 Catherine's second design

Concluding points

Engineering is an ideal field for developing design-based problems that draw not only upon the STEM disciplines, but also other areas, including literacy. Our programs have been enriched through Andrew King's engineering-based story books (2013; 2014; in press). By their very nature, these problems are complex and often ambiguous, and require students to apply both STEM content knowledge as well as engineering design processes and thinking. Furthermore, these engineering experiences incorporate 21st century skills called for by employers (Partnership for 21st Century Skills, 2011).

The engineering education programs we have implemented across several grade levels have revealed young learners' potential for engaging in design-based problem-solving, applying their STEM content knowledge in doing so (for example, English & King, 2015). Although these problem experiences are intended for student groups to solve independently, our research has shown that an appropriate balance is often needed between teacher input of new concepts and students' application of their learning in ways they choose.

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