A framework for promoting diverse voices in the design cycle

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STRUCTURED ABSTRACT

CONTEXT

Engineering professionals are critical to the future prosperity of the world – socially, culturally and economically (Office of the Chief Scientist, 2013). The future of the Australian engineering pipeline is uncertain and the profession does not reflect the diverse Australian population. Engineers create solutions through design. A core development process central to design is the process of iteration. There are dozens of instances of these design cycles and loops: for example, plan–do–study–act (Deming 2000), think-make-invent (Martinez & Stager 2013), and experience–observation–conceptualisation–experimentation (D. Kolb, 1984). While outreach activities across the country attempt to encourage young students to consider engineering as a career, the full design loop is often not completed, meaning that the full value of the activity is not realised, and diverse voices are not heard.

PURPOSE

We are investigating the role of targeted planning and reflection as part of the design cycle. The primary motivation for this investigation is to explore whether emphasising **individual** design during the planning and reflection stages of the design cycle encourages diverse viewpoints and demonstrates the benefit of these viewpoints through improvement in design outcomes.

APPROACH

We have investigated the design cycle as a tool for encouraging structured planning and reflection. We are conducting experiments through an Engineers Without Borders Australia outreach activity, targeted at primary school students. Students complete an individual worksheet during the activity that prompts planning prior to a build activity, and then reflection after testing a prototype design.

RESULTS

Results show that the iteration process and working in groups improved the designs of 42% of participants. They also showed no significant difference in the selection of ideas based on gender or age, which indicates good ideas are promoted regardless of gender and age through this process.

CONCLUSIONS

Prompting participants to plan and reflect during an engineering design cycle improves design outcomes in this learning activity and promotes diverse viewpoints. This presents insights into how outreach programs may be adapted to maximise the full benefits of the design activities, and encourage careers in engineering equally.

KEYWORDS

Education, mental models, outreach

Introduction

Engineering professionals are critical to the future prosperity of the world – socially, culturally and economically (Office of the Chief Scientist, 2013). In Australia, the pipeline of future engineers is increasing in uncertainty, coupling an ageing workforce and decreasing participation in senior mathematics and science in school (Kaspura, 2017). Furthermore, the profession itself lacks diversity, which has been linked to lower innovation, outcomes and decreased competitive edge (Horwitz & Horwitz, 2007). Currently, males are overrepresented in the profession, comprising 87.6% of the labour force, decreasing at only 0.1% each year (Kaspura, 2017).

Organisations like Engineers Without Borders Australia (EWB) work to diversify and increase interest in engineering through completing school outreach (SO) workshops. These workshops engage school students through hands-on, curriculum-linked activities, encouraging them to consider engineering as a career choice (Engineers Without Borders Australia, 2017). While these workshops highlight the work of engineers, they do not explicitly guide students through the iterative process engineers intuitively follow when developing a solution. This has led to observations that dominant group members, typically male, often drive design choices, and are not prompted to test assumptions, and collaboratively learn from other team members.

This paper examines the effect deliberately making individual design during the planning and reflection stages of the design cycle explicit during group school outreach activities. We have found that this process encourages more promising designs to be promoted and developed, regardless of the gender of participants.

Background

Diversity in engineering

Globally, men are overrepresented in the profession of engineering (United Nations Department of Economic and Social Affairs, 2015). This can be seen historically and currently in Australia, with little progress despite efforts of universities (Kaspura, 2017). Alongside this, it has been identified the engineering pipeline is reducing. Only 24% of year 12 students are participating in mathematics subjects required to study engineering at university, with significantly lower participation from females than males. (Kaspura, 2017). Male and female participation in mathematics and science has steadily decreased over the past 15 years (Kaspura, 2017).This further exacerbates the gender gap in engineering at university and in practice, with only a small cohort able to pursue further study in engineering.

The lower numbers of females studying intermediate and high-level mathematics, chemistry and physics in Australian schools is associated with students' self-efficacy. Self-efficacy relates heavily to students' perceived competence and subsequent confidence in their science abilities (Mantzicopoulos, Patrick, & Samarapungavan, 2008). These perceptions of ability in school subjects play an influential role in occupational development, pursuits and career aspirations (Bandura, Barbaranelli, Caprara, & Pastorelli, 2001). This behavioural and developmental psychology model of perceptions is underpinned by Piaget's (1964) model of cognitive constructivism, where learning about science and engineering will increase student's own understanding and awareness of scientific and technical careers (Beilin, 1992; Cunningham, 2007).

Further confounding this situation, Bohnet (2016) asserts that unconscious bias is a key factor in gender inequality in the world. Some of the gender biases and subsequent gender gaps that we see in the world come unconsciously to us. Bohnet's work focuses on making it easier for us to unconsciously do the right thing and eliminate biases. In particular, group-think behaviour in assessing decisions is incredibly detrimental. If a group gathers, no member will be able to have an unaffected point of view after hearing the others. Through allowing members to come to their own conclusions with the help of systematic methods prior to meeting with the group, such as checklists, the impacts of others' beliefs and biases can be minimised. Through designing systems that remove the ability for unconscious biases to play a part, greater opportunities are given to a more diverse group of people, inviting diversity of thought, experience and input.

Design improvement cycles

Engineers Without Borders Australia's approach to engineering is through a human-centred design approach (HCD). It was initially championed by IDEO and the Stanford d.school (2015) and focuses on the needs and input of the user at each stage. There are six key stages of the approach: discover, empathise, ideate, screen, prototype and communicate.

There are numerous design cycles and loops that focus on iteration such as plan–do–study–act (Deming, 2000), think-make-improve (Martinez & Stager, 2013), experience–observation–conceptualisation–experimentation (D. A. Kolb, 2014), and ask-imagine-plan-create-improve (Cunningham, 2007). However, in many design processes, the activities undertaken at each stage are implicit, and not conducted formally. This leads to the value at each stage of the design cycle not being fully realised, and opportunities for rapid learning missed.

Design cycles and higher-order thinking

There is limited evidence that proves design thinking and explicitly moving through the design cycle can help facilitate diversity of opinion and promotion of diverse opinions as dictated by mental models, which is an aim of this research.

As the learner builds their understanding of the situation in the design cycle, they will move to higher levels of understanding. We should expect to see students move up the categories of frameworks such as Bloom's Taxonomy: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. These speak to the depth of knowledge and understanding of students. The taxonomy has been frequently used to classify educational outcomes and learning, with the higher-order categories from comprehension onwards are often considered the most important goals of education (Krathwohl, 2002).

As students move to higher-order thinking, their mental models of the problem need to evolve. Piaget's (1964) constructivist model complements Gentner and Stevens (1983) theory of mental models. When applied to psychology, they assert mental models are naturally evolving conceptual models that reflect people's beliefs of a physical system, acquired through observation, instruction or interference (Gentner & Stevens, 2014, p. 12). These mental models shape the way you see the world and help to inform perceptions and behaviour (Wind & Crook, 2010). As mental models help to inform decision making, the more accurate the individual's model, the more likely they are adopt higher quality decision rules (Nelik & Zarreii, 2010).

Constructivism and mental models can be conceptualised as systems of understanding and behaviour, and can therefore be influenced at intervention points. Meadows (2008) highlighted twelve of the highest leverage points or points of intervention in a system to create change. The twelve points involve the flows of the system, types of feedback loops and the model of the system itself. Most influential intervention points involve the shifting of a system's goals and paradigms and ultimately, transcending those paradigms and beliefs about how the world works. As mental models are deep-held personal beliefs, the system will be highly resistant to change (Meadows, 2008, p. 105). Mental models are also self-reinforcing systems, where information and feedback loops evolve the system, and can therefore be a powerful intervention point when attempting to alter mental models.

Methodology

The methodology for this research aims to allow students to create, test and refine a design for a prototype of a floating house, made from household items and within an allocated budget. This research adapted an existing EWB workshop around designing a floating house in the context of the Tonlé Sap Lake in Cambodia. The workshop activity was designed to complete two cycles of the engineering design process stages of think-make-improve.

This research differs from the existing EWB workshop through the addition of an activity worksheet that prompts the participants explicitly through the design process. This worksheet enables consistent testing between groups. No comparison has been made between the current workshop and this workshop.

The workshop begins with a small presentation, introducing students to engineering, EWB's work, the context of the activity and basic physics around buoyancy. Each participant completes a worksheet individually, but work in small groups of 3-4 to test and create a final design that is later tested in a small tub of water to see how many marbles it can hold before failure. Initially, participants draw their own personal design on the sheet, then test one part of the design as a group, reflect upon the outcome and then adapt their design again to create, test and reflect with a group.

The individual component allows participants to generate their own ideas and test their own mental models without the influence and bias of others, inviting greater diversity of ideas (Wind & Crook, 2010). Through allowing participants space to use their individual mental models and test their design, it brings a greater diversity of ideas to the groupwork (Bohnet, 2016). Further, by prompting explanation of ideas through drawings, search processes and deductive reasoning are enhanced and a platform is facilitated for each group member's voice. The information gathered from the first round of testing may also work to balance ideas, as all participants know how each component bears load in the water, evening the playing field against loud and overbearing team members. The groupwork component also allows students to collaborate and rapidly adapt their designs by hearing from a diverse group of people and through understanding the outcomes of the first round of testing.

The think-make-improve approach focuses on the higher order Bloom's taxonomy in synthesis and evaluation is producing a plan and making judgements of the design in terms of external criteria. Through creating a design, each student is synthesising what they know and what is available to them, which is further reinforced by the restrictions placed on the design.

For this research, the diversity area of gender will be explored with respect to the activity, as it presents key socio-prevalent assumptions and authority in STEM.

Results

From a sample size of n=249 across 13 workshops, 52 groups created and tested final designs. As gender is a main focus for this study, Female and male are used as the predominant categories of analysis as only 12 participants (4.8% of the sample) did not fall into these categories, shown in Table 1. Males made up a majority of the population (59%), with females making over a third (36%). However, females were active members in 75% of the groups. As a majority of groups were mixed gender, the impact of heterogeneity in gender could not be investigated.

Table 1 Gender demographic data for sample

	Reported as	**% (n)**
Gender	Female	36.1 (90)
	Male	59.0 (147)
	Other	1.6 (4)
	N/A	3.2 (8)

The participants' designs were characterised into seven key categories of design, based on the primary method of flotation. Figure 1 visually represents the changes from initial to final designs of the participants.

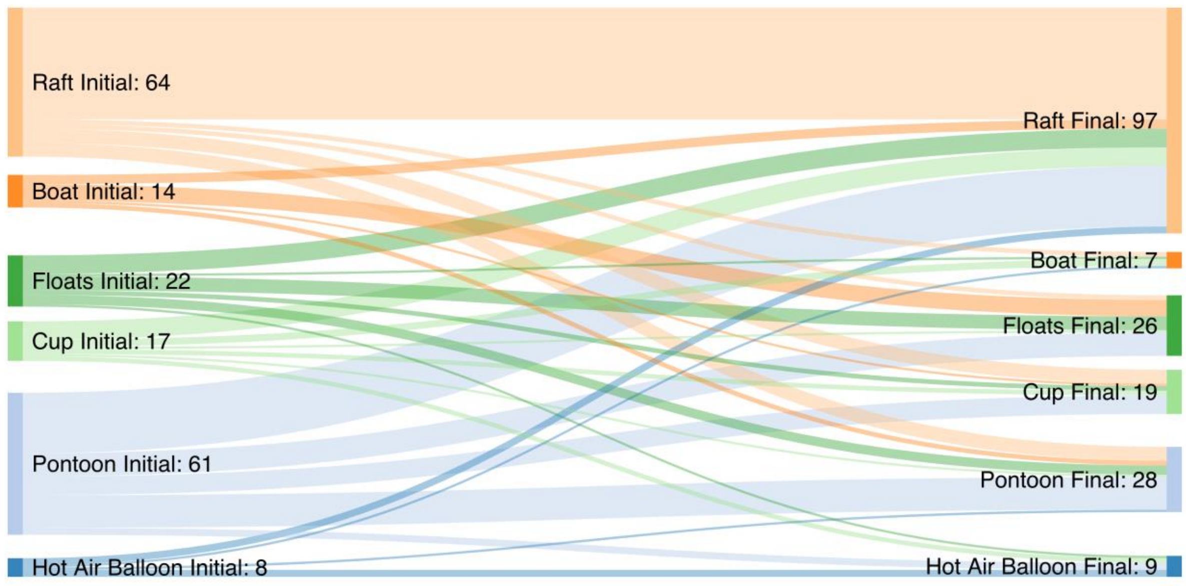

Figure 1: Sankey diagram of participants' initial and final designs

To date, two key types of participants have emerged: those whose initial designs did change as a result of the first round of testing, and those who did not. These two examples are illustrated in Figures 2 and 3.

The initial design in Figure 2 shows a raft-like structure made from popsicle sticks with a cup sitting on top. However, after testing the cup and talking with their group, their design used 11 straws to create a raft-like structure. This change could be for a number of reasons such as a result of seeing how a cup is quite imbalanced when loaded, how poorly popsicle sticks float in water, or the influence of other team members' design. What can be seen is a change from the initial to final design, and therefore a development of their mental model of the situation.

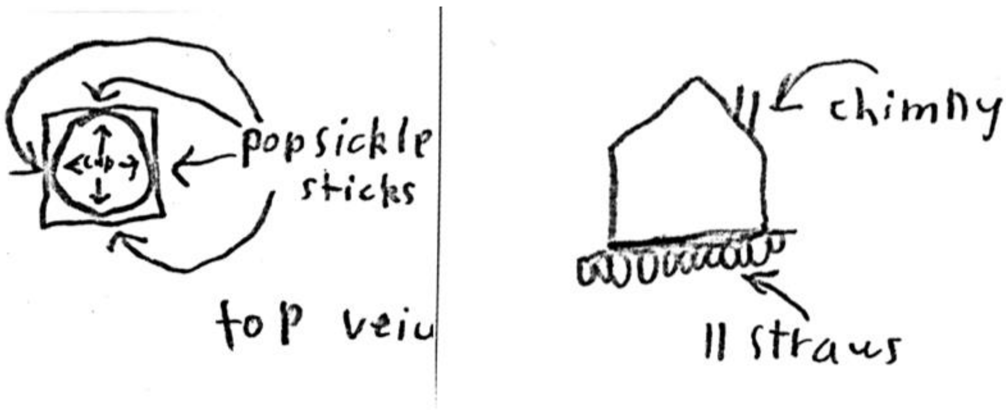

Figure 2: Participant S2B1e comparison of drawings from Think 1 and Think 2, before and after testing the cup, balloons and straws with weight in water, showing a change in the materials used

In contrast, Figure 3 shows that the participant did not change their design from the first and second iteration, other than to add sticky tape to tie the straws together. This does show an element of refinement, but not a large shift in thinking.

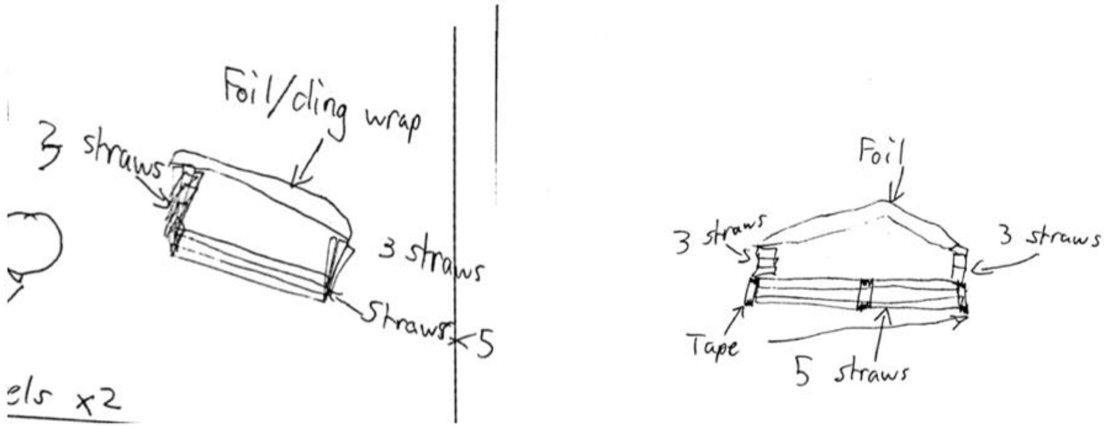

Figure 3: Participant S2B2b comparison of drawings from Think 1 and Think 2, before and after testing the cup, balloons and straws with weight in water, showing a change in the materials used

To understand the degree of design improvement, designs were categorised and scored, based on the typical performance for the given design. The design score was used to understand the impact of iteration on the success of designs. Shown in Table 2, it was found a majority of participants improved their design potential (37.5%) or remained with their best design (25%). A minority (37.5%) showed no improvement or decreased their potential outcome from initial to final. The improvement or surety in a design is statistically significant ($p<0.05$) compared to reduction in design potential. Furthermore, an improvement in design is more likely than a decrease in design outcome, at 95% confidence. This shows that the iteration process has a positive impact upon the potential success of design in this activity.

Table 2: Total population and gender data for improvement of designs

Best/Improved	% total (n)	Female % (n)	Male % (n)
Improved	37.5 (81)	40.0 (30)	36.4 (47)
Decreased	22.7 (49)	17.3 (13)	27.1 (35)
Stayed at best	25.0 (54)	28.0 (21)	21.7 (28)
Same - not best	14.8 (32)	14.7 (11)	14.7 (19)
Total	100.0 (216)	(75)	(129)

To understand how this iteration framework promoted different—both female and male ideas—the degree of change between initial and final designs was analysed, as shown in Table 3. Proportionally in the sample, females were twice as likely to have their designs selected with no change than males, while both males and females appear to collaborate and re-design at similar levels. This indicates that this process promoted the ideas of female participants equally or better than the ideas of male participants.

Table 3: Level of change from initial to final designs by gender

How much change?	% (n)	Female % (n)	Male % (n)
Interchanging parts	30.8 (60)	30.6 (22)	31.9 (36)
Total redesign	54.4 (106)	51.4 (37)	57.5 (65)
No change	14.9 (29)	18.1 (13)	9.7 (11)
Total	100.0 (195)	100.0 (72)	100.0 (113)

Another noticeable outcome is that the majority of participants, regardless of gender, completely redesigned their designs. We believe that this is due to the combined testing that allowed for all participants to see the results of all groups' ideas. This is consistent with the idea that teamwork and diverse ideas can improve designs, as on average, groups did improve their average performance. It is also consistent with their mental models being questioned and need for new explanations. The large number of people who collaborated also shows that group members had voices and their ideas were valued.

Conclusion

Through adapting an EWB activity, participants were explicitly guided through a think–make–improve approach that encouraged them to reflect and alter their understanding and mental models. The research has shown that, on average, the potential of designs was increased as a result of iteration and ideas were promoted regardless of gender. This type of outcome has the potential to promote positive feelings and high self-efficacy in the females about this activity and, in turn, a career in STEM.

By providing individuals to express their mental models through drawings, it made explicit the ideas of all members of the group. There appears to be a connection between the power individuals have in creating their own personal design and testing a portion of this: it acts as a filtering mechanism that the group uses to inform their design choices. In this way, this process allows participants to filter ideas through the information discovered in initial testing and improve their own design outcomes.

We observed that the process of explicitly stepping through the design cycle allows different voices to be heard when the activity moves from the individual to the group activity. Through receiving feedback on ideas and then collaborating with others, the potential of the final design increases. In bringing together a diverse group of ideas and mental models, the potential likelihood for success of the design increases.

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