AN OBSERVATIONAL STUDY OF INFUSING DESIGN THINKING INTO THE CDIO FRAMEWORK.

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ABSTRACT

Design Thinking (DT) is a human centric way of designing product, process, system and services, which has the potential to provide learning opportunities for engineering students to explore human desirability, technical feasibility and business viability. This paper attempts to outline how DT can be infused into a CDIO framework in the context of capstone projects since they allow students to appreciate the whole product lifecycle at logical stages (i.e. C-D-I-O). Engineering students were asked to innovate on ordinary consumer products in order to make explicit the effects of the Design Thinking process for *transformative* solutions based on the insights gained from ethnographic studies. Salient points for reflection, based on project supervisor's observation as well as students' feedback are also presented. While DT may leads to non technical solutions, the author feels a need to skilfully steer engineering students to utilise some of their disciplinary knowledge and skills.

KEYWORDS

CDIO, Teamwork, Capstone project, Design Thinking.

INTRODUCTION

The Singapore Polytechnic has always aimed to provide an education where students gain knowledge and skills for direct assimilation into the industry. Since 2007, the school of Mechanical and Aeronautical Engineering in the Singapore Polytechnic has, in stages, adopted and implemented CDIO approach into its curriculum. The CDIO framework has afforded the school, a means to balance engineering science (knowledge) and engineering practices (skills) during lectures, tutorial and laboratory sessions as reported by Chong et al. (2009),Linda et al. (2009),Christopher et al.(2009). The CDIO syllabus (part 4) focuses on the creation of product, process and system building skills, reflects the importance of a good grasp of a product lifecycle. Soh (2010) had demonstrated that CDIO could provide a meaningful framework for capstone projects in the context of product development and at the same time, able to cover most of the CDIO skill sets. The CDIO skill sets which codify the attributes of an engineer, underscore the importance of matching engineering education and industrial practices. While most engineering product developments focus on productivity, quality and cost efficiency; there is a trend among innovative companies to focus on customers' unmet needs as their business strategy. This will require an emphasis on consumer empathy more than mere marketing input to product, process, system and service design and development. Brown (2008) noted that:

> "Historically, design has been treated as a downstream step in the development process....as economies in the developed world shift from industrial manufacturing to knowledge work and service delivery, innovation's terrain is expanding. Its objectives are no longer just physical products; they are new sort of processes, services, IT-powered interaction, entertainments, and ways of communicating and collaborating...."

Kumar (2007) also highlighted that there is:

> “a tectonic power shift in the relationship between companies and consumers. New methods of being customer-oriented are needed....There has been a power shift from producers to consumers caused by decreases in production costs and increase in customer choice....now we possess a deep knowledge of how to make things and an inadequate understanding of how people are living their lives”.

Kumar (2007) further pointed out that research that:

> “leads to specific insights about *current* offering that will enable the company to make specific improvements....The trouble with this research is that it almost never leads to insights that could translate into *surprising* improvements or entirely new products”.

With the changing industrial landscape, educational approaches would need constant reviewing in order to provide students with meaningful learning experiences. Sternberg (2010), the author of “College Admissions For The 21st Century” pointed out that:

> “People need creative skills to generate new ideas, analytical skills to determine if they are good ideas, practical skills to implement their ideas, and wisdom to ensure that their ideas help achieve a common good”.

Lindberg et al. (2011) also noted that:

> “An isolated technical perspective entailing isolated analytical thinking can thus lead into an innovation trap: while spending much effort in the development of technically novel or reasonable solutions, the clients do not really see the solution’s distinctive value”.

Design Thinking (DT) with its emphasis in realizing human-centric (not technology-centric) products or services should be taught in schools. Of course, technology can be used to enable innovation. In most engineering product development, established needs are typically provided from marketing research. DT encourages engineering students to explore the *unmet* needs that consumers themselves may not be able to articulate. This would require students adopt an attitude of empathy and sometimes relying on a “team based intuition” in order to derive insightful problem statements. This is where engineering students in the Singapore Polytechnic often feel very uneasy.

Cheah (2010) noticed that:

> “Concepts such as ethnography (observation analysis of consumer behaviours to identify desired experiences) and designing consumer touch points (to deliver desired consumption experiences) prove too abstract to our students who are more acquainted to the systematic problem-solving of engineering education”.

Infusing DT into CDIO framework in the context of capstone project could be one way to provide a systematic approach that engineering students can readily accept. DT also promotes teamwork, critical thinking and communication skills as Dym (2005) pointed out:

> ”Design Thinking reflects the complex processes of inquiry and learning that designers perform in a systems context, making decision as they proceed, often working collaboratively on teams in a social process, and “speaking” several languages with each other (and to themselves)”.

This paper attempts to outline how DT can be infused into a CDIO framework to impact on user experiences. Capstone projects were used for the study as they allow students to see the whole product lifecycle at logical stages (i.e C-D-I-O). Engineering students were asked to innovate on ordinary consumer products in order to bring out the effect of the Design Thinking process for *transformative* solutions based on the insights gained from ethnographic studies

DESIGN THINKING AND ENGINEERING DESIGN PROJECT

Design Thinking is a human centric way of designing product, process, system and services. It is usually deployed to generate users' unmet needs. Methods may vary and evolving, but they have specific framework: Empathy – Ideation - quick prototyping – test/feedback. It is worth pointing out that *quick prototyping* refers to creating many inexpensive and rough conceptual artefacts, to promote deep thinking of issues and generation of ideas. Brown (2008) called DT "a methodology that imbues the full spectrum of innovation activities with a human-centred design ethos….it is a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunities". Dym (2005) defines Engineering Design define as "a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints".
A quick cross reference of the characteristics between Design thinking and Engineering Design in the context of school projects is illustrated by table 1.
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	Engineering Design Project	Design Thinking Project
Objectives	Specific (starts with design briefs)	Fuzzy (establish design briefs)
Intention	Improve current needs	Derive unmet needs
Inputs	marketing research/ Supervisors	Ethnography
Members	From related fields (technical)	Prefers multidisciplinary teams
Process	Systematic	Chaotic
Solution	Technical	Depends on ethnographic insights

Table 1: Characteristics of Engineering Design versus Design Thinking Projects

From table 1, DT activities can be a good complement to engineering design project and it is clear that DT activities must precede engineering activities. As both design thinking and engineering design have "design" as a crucial component, design activities can be the coupling point in the CDIO framework (see figure 1). Hence, conceiving of engineering concepts can be part of the DT activities. For engineering students, it provides opportunity to explore and think beyond technological solutions. Design Thinking promotes holistic and creative ways in analysing problems. It typically gathers inputs from the people, cultures, objects, media, space and services. Students will learn about teamwork and be humbled to value opinions from all walks of life. The story telling session (i.e group sharing of insights gained during ethnography) also serves to sharpen students' presentation, communication and critical reasoning skills. Highly hands-on, DT process promotes active and experiential learning. Being holistic in its approach also promotes integrated learning experience.

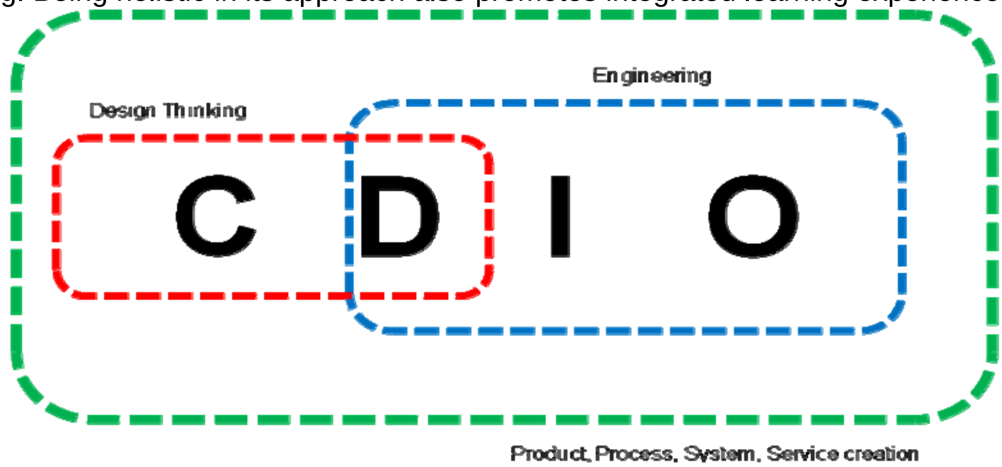


Figure 1: Design activities as coupling point.

DESIGN THINKING PROCESS

Usually, a commercial product, process, system or service development starts with some marketing inputs and engineers would dive straight into generating technical concepts and solutions. Creative ideas would still typically revolve around technical issues rather than some innate needs of consumers. In design thinking, team members are encouraged (preferably from different background) to use designer's sensibility to derive problem statements through a rigorous ethnographic process. Ethnography involves studying subjects in their natural settings, which usually include a field trip to *observe* human behaviours, *interacting* with them and *shadow* their lifestyles. Ethnography promotes looking at an issue much deeper than the symptoms faced at hand. Designers record all observations into their journals and prepare storyboards comprising of elements such as journey maps, mind maps and photographs. These storyboards help to prepare students for their story telling sessions. In the story telling session, team members share all insights they have gained to generate "bug list" or issues. The issues are then categorised. With issues identified, the team will work on a user centric problem statement which follows by brainstorming for ideas. Ideas were later categorised/ filter off (not meeting vision) and converge into key functions of the product. Next, the tinkering process encourages thinking by doing. Team members will make rough sketches, low resolution models (using cardboard, clay, wire, stick...), and sometimes even act out a scenario to illustrate their concepts. New insights may pop up. Another story telling session follows. By then, the team will have some consensus on what they WANT to do. NOT what they CAN do. By leaving no stone unturned, engineering development process can now begin. From figure 2, DT is represented by the C-D stages whereas Engineering Design is represented by the D-I-O stages. While "Design" in DT focuses on user desirability, "Design" in engineering design would touch on technical feasibility.

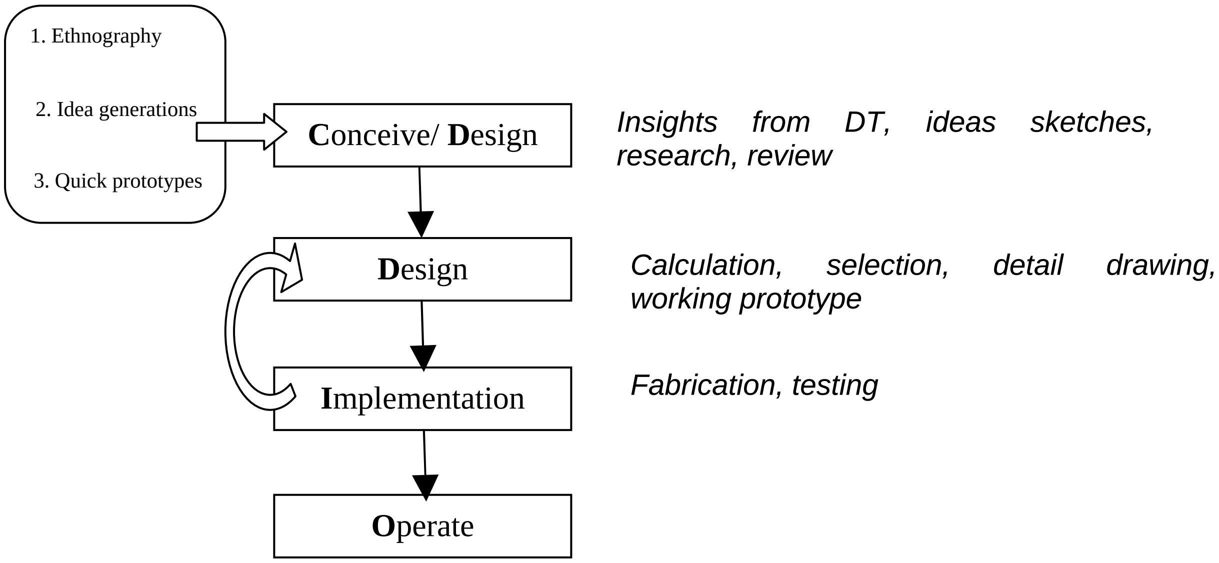


Figure 2: Coupling DT into CDIO workflow.

A CASE STUDY OF DT CAPSTONE PROJECT FOR ENGINEERING STUDENTS

The school of Mechanical and Aeronautical Engineering in 2010 had piloted DT activities by identifying 10 capstone projects to innovate on various mechanical products falling under the category of "green", rehabilitation and recreation products. The following figures illustrate some major milestones of a DT project by a group of aeronautical students who were asked to innovate on new concepts of playing toy guns.

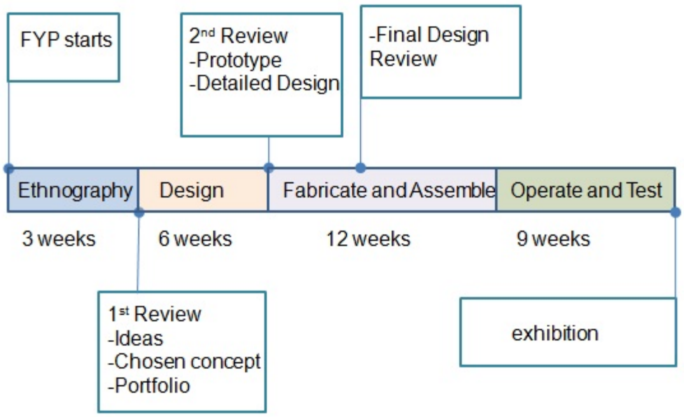


Figure 3: Capstone project time schedule.

Ethnography

There are many tools available for effective ethnography. The author had introduced his students to the Contextual Design Technique developed by Beyer et al. (1998). Contextual Design captures the field observation data into 5 Work Models (i.e. Flow, Sequence, Physical, Artefact, and Cultural). The work models allowed the teams to focus on interaction between humans, equipments, process and environments. They also enabled research on artefacts, cultures, philosophy, arts, history. Figure 3 illustrates how ethnographic studies are transformed into storyboards using the work models. During the field trip, photographs were taken, sorted and pasted on five A1 size board corresponding to the 5 Work Models. This was an uneasy stage as members do not have an idea where they are heading. Much motivation was needed.

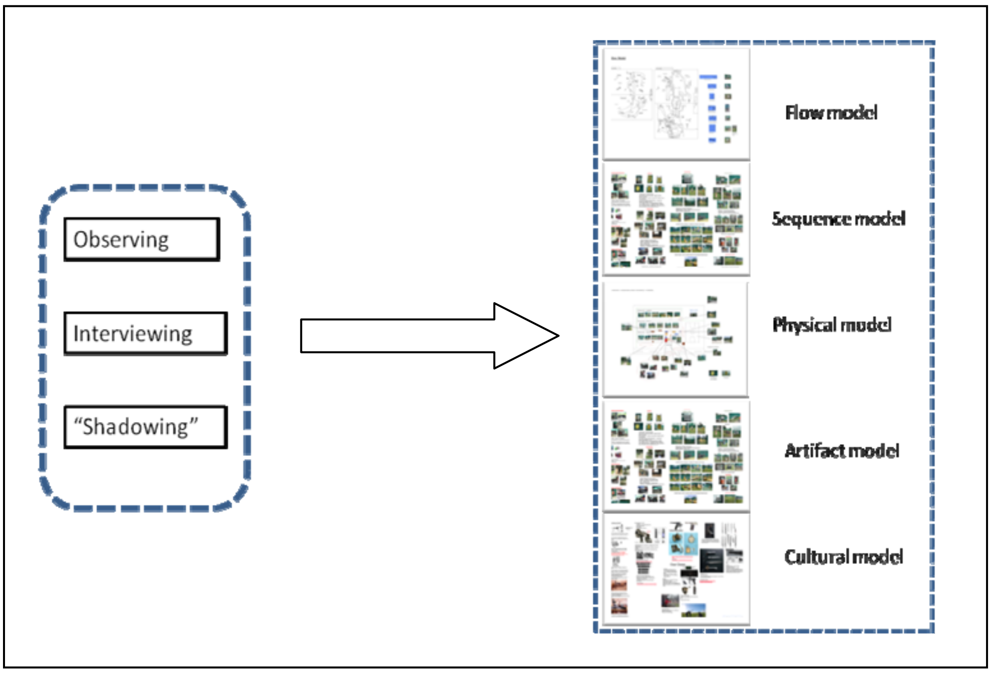


Figure 4: Transforming field data into storyboards.

Storytelling 1 (review)

Figure 5: Story telling

Team members took turn to share their respective models derived from field trips. Any issues and insights generated are immediately recorded on Post-It pad and pasted on the storyboards. Insights are keys to breakthrough concepts. For example during an informal discussion, it was realised that besides shooting "enemies", an interesting theme plus social interaction can value add to the gaming experience. This had led to the incorporation of Cosplay and Gladiator elements into current paint ball game.

Classification of issues

Issues generated during the story telling session were classified into SPEC (Social, Physical, Emotional and Communication).

Figure 6: Classification of issues

Establish problem statement and needs

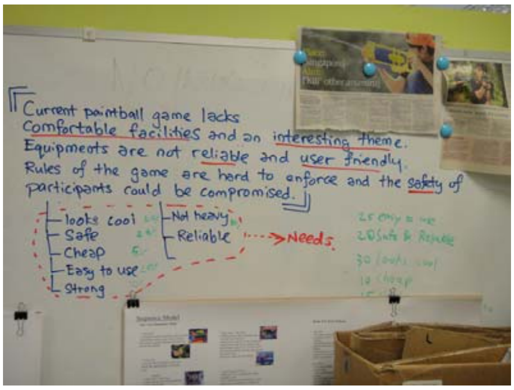


Figure 7: Problem statement

Students at this stage had acquired a certain level of understanding of the current situation and trends. Equipped with storyboards, derived issues and some intuition, the team spent many hours working on a good problem statement which addresses the most significant issues. User needs were also generated which will be transformed into engineering design metrics (i.e. measurable) during the engineering design stage for the purpose of selecting competing concepts.

Ideation

Figure 8: Brainstorming

Guided by the problem statement and user needs, students spent about 1 hour to brainstorm on various ideas. Students were given a target of 100 ideas.

More concrete ideas were derived by crafting out low resolution models during the tinkering session as shown in figure 10. Usual building materials for tinkering are foam, paper, cardboard, and acrylic. Various competing ideas can be selected by reasoning or through a voting system.

Figure 9: Voting ideas

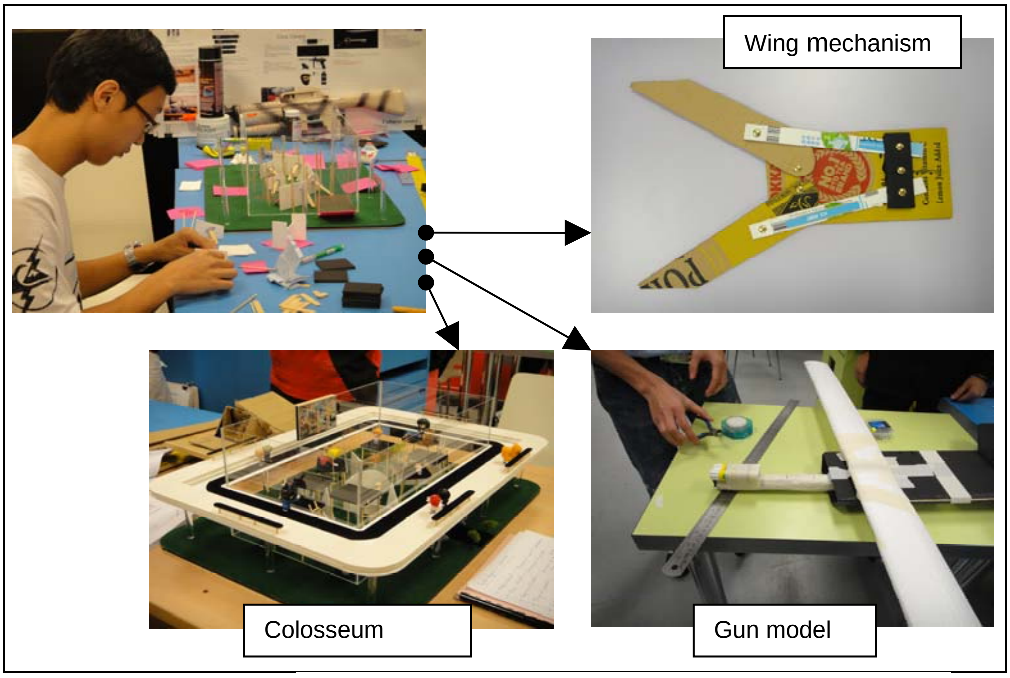


Figure 10: Tinkering on low resolution models

Storytelling 2 (review)

Figure 11: Second review

Students' ideas had converged at this point to a more feasible *product functions*. A second review was put in place where supervisor and co-examiner go through their "product and services" and share their thoughts on the technical aspect of the project. Iteration seemed capable of going forever and supervisor would have to steer them to complete their Conceive phase and move into the Design phase.

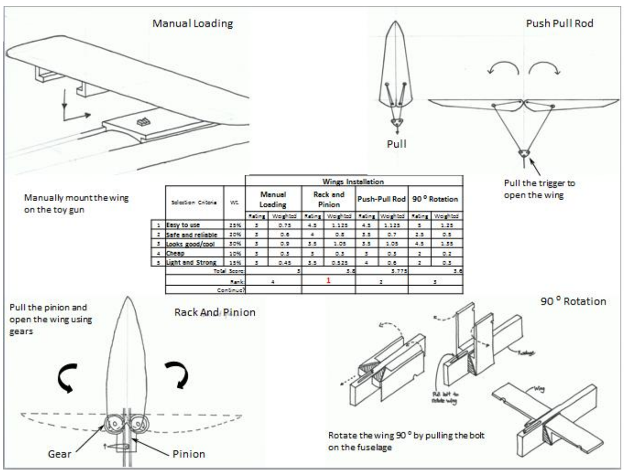


Figure 12: Selection of concepts

Within each product function (e.g Wing setting), there may be many *technical* concepts to choose from. The students used a weighted ranking technique against user needs (figure 12) to select the best solution. This is a popular concept selection method used in most engineering development process.

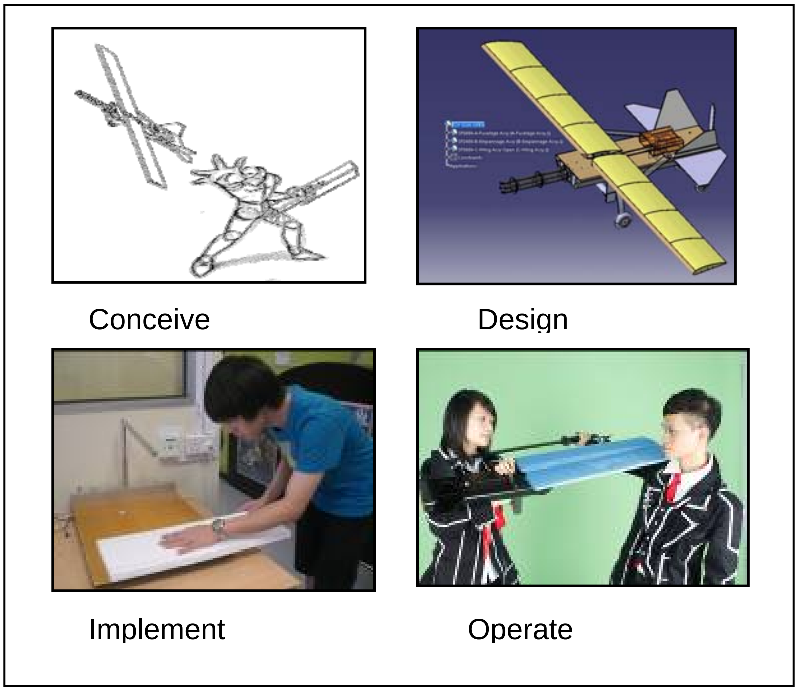


Figure 13: CDIO as milestones for capstone project

OBSERVATION AND DISCUSSION

Students' feedback

Upon completion of the DT capstone projects, selected students were asked to provide feedback on their learning journey.

[Tan Yu Da]: "The main problem faced including the design thinking is the extra time needed to discover the needs of the consumers. The research done on consumers was time consuming and sometimes we did not know what we were doing while other groups (i.e the non DT group) were progressing well. It also did not help that the judges for the progress review did not understand the design thinking process and gave us the same requirements as the others. The idea of design thinking did not go well with my group members initially, but after we got our final design, we felt that the design thinking helped us to make something that consumers would appreciate compared to what other groups were doing which have little market value. I feel that the design thinking process really force engineering students to be creative and be more mindful of the looks of the product rather than just focusing on the functionality of the product".

[Xavier Soh]: "It can be frustrating that the ideas that came to our mind cannot be implemented immediately as design thinking required discipline to press on for more solutions from various angles. Nevertheless, Design Thinking enables us to generate far more ideas even when some might not be practical or realistic. I have this feeling that somehow; they can come in handy at some point".

[Liew Chen Hao]: "Design thinking teaches me how to solve problems from consumers'/ users' point of view. Taking up a design thinking project was a challenge to me. Not only I have to constantly open to new ideas and solution, we also need to be mindful on technical feasibility of the ideas itself at some point in time. The idea generation often led us into the unknown field. I realised that having good knowledge of how common things works (from simple ball pen to sophisticated electronic equipment) is very helpful in the generation of ideas. Engineering students tend to solve problems for from technical viewpoint and ignore users' experience. Through design thinking, I have learnt how to appreciate both knowledge and use them together to solve problems. The impression I had on design thinking is that, in today's context, making a product is no longer just to satisfy the intended application or functions of the product but to satisfy the users' experience".

[Enrico Aeria]: "I think infusing design thinking into an Engineering project is useful and can be methodical. It encompasses all aspects of a product, making sure that every aspect is thought through. However, a problem that could arise from design thinking is the fact that there could be an overwhelming amount of details and so many aspects to look into that it can get rather tedious initially. In addition, design thinking generates so many radical ideas that sometimes it may be hard to carry it out in terms of current state of arts and social norms. I think the design thinking philosophy is a great approach towards creating a new product. Occasionally, it helps reveal problems that might be possibly encountered in the future. This gives the ability to come up with a solution earlier on and think of alternative ways. Design thinking revolutionizes products and makes them different, unique and interesting".

From the students' feedback and the author's observation during the 30 weeks (excluding vacation) long capstone project, the following issues were identified and discussed:

1. Students were generally appreciative of DT but were worried about DT activities encroaching into their Engineering activities. DT activities were perceived as "extra works" when compared to engineering activities.
    - The students spent about 3 weeks on DT activities. This was partly due to the fact that they were not trained in DT methodologies. Extra lessons were needed to cater for all "pioneer" batches of DT final year project students. It is advisable that DT activities should be intensive and within a timeframe of not more than 2 weeks. If situation permits, ethnography can be carried out during vacation just before the beginning of new semester. The current CDIO assessment rubric for final year projects in the school does contain some features that mitigate the wide spectrum of projects undertaken by difference groups. For example, marks for the Conceive and Design stage can be adjusted with higher weightages by the supervisor and co-examiner. Nevertheless, a separate rubric for DT engineering projects would be perceived to be a fairer assessment scheme which could alleviate students' anxiety.

2. Students were also concerned that faculty members assessing them may not be well versed with DT methodologies resulting in their grades being adversely affected.
    - DT projects with its high demand in exploring consumer desirability should not be treated as another engineering project. Only supervisors who are trained in DT should supervise or co-examine the project group. Number of DT engineering projects must be managed. Dym et al. (2005) concludes that for long term sustenance of cornerstone and design courses, "there is a clear need to expand the number of faculty members interested in and capable of teaching design, and to create the facilities such as design studios and associated shops needed for modern, project-based design courses". At the moment, the School of Mechanical and Aeronautical Engineering has trained almost 50% of its staff on DT literacy. This has been achieved by way of workshops, seminars and clinical sessions.

3. Engineering students generally find difficulties articulating the emotional aspect when empathizing with users during their field trip.
    - For example, when the team were asked to categorise the issues into "SPEC"-Social, Physical, Emotion and Communication; none were found

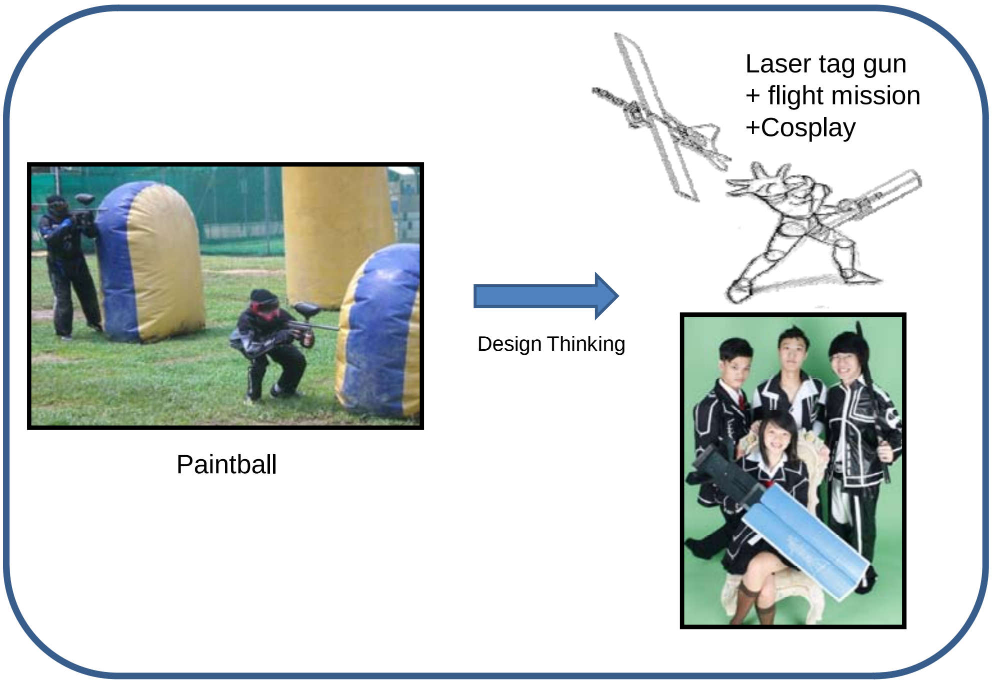
under the “Emotion” category. In the “Toy Gun” project, the supervisor had to change the “Emotion” into the “Environment”. Exposing students with DT concepts using cornerstone projects before proceeding to a capstone projects could be useful in equipping students with the “correct” mental attitude. A new course structure has been revamped to include DT content in the Introduction to Engineering module. On a social level, such inability to discern emotional elements could be linked to the general characteristics of the so called “Generation Y” and not just confined to engineering students. More studies may be needed to establish a correlation.

4. Tendencies for engineering students to think “within the box”.
    - In course of project, it became clear that students had a strong tendency to use their “expert” knowledge to solve an open ended problem. For instance, while brainstorming for a unique toy gun gaming concepts, the aeronautical students suggested developing a toy gun capable of flying as part of the mission in the game. This was followed by a strong bias among team members during voting of various concepts. Using “expert” knowledge is not wrong in itself. Nevertheless, project supervisors should be mindful to steer the team, based on human centric approach. Forming a project group comprises of team members from different schools (i.e. multidisciplinary) is another way to force an “out of the box” thinking. In fact, this is a preferred setting in running a DT project. However, administrative issues such as uniform marking scheme, funding procedures, rapport, interest, school cultures etc have to be properly considered and managed.

5. DT process may end up with non-engineering solutions.
    - Establishing the scope of a DT capstone project in the context of Engineering may not be straight forward. If the project is not well guided, it might end up with non-engineering (sometimes trivial) solutions. One might argue that to be truthful to DT, project supervisors should not interfere with the nature of the outcomes. However, it seems proper to steer engineering students towards engineering solutions because first of all, a capstone project provides an excellent platform for engineering students to put in practice the engineering theories they have gained from classroom learning. Secondly, as Armstrong et al (2005) has pointed out, “capstone project was felt to have the greatest potential for addressing a significant number of the CDIO Standards in a single initiative”. Thirdly, engineering students generally feel motivated doing “relevant” activities. Furthermore, allowing development of engineering products by using DT methodologies helps to convince engineering students how DT could complement and enhance engineering product development. Hence, it becomes an art for the project supervisor to return an “off-tracked” team back to the engineering path “naturally”. One technique is to declare at the onset, that the main outcome is to develop physical *products*. The author would usually ask engineering students to innovate on ordinary products with no details provided in order to maintain a level of fuzziness and students were left to “realise” their own design briefs or problem statements.

CONCLUSION

Design Thinking has the potential to provide learning opportunities for engineering students to explore human desirability, technical feasibility and business viability. With CDIO being the context of our education, infusing Design Thinking into CDIO framework has many challenges. Most pressing issue is students' and staff's DT literacy. Engineering students generally feel uneasy working on open ended projects where they are responsible in defining their own project scope. Dym et al. (2005) highlighted that "the real challenge is not the adoption of the principles of divergent-convergent inquiry; rather, it is the integration of divergent-convergent inquiry into the existing engineering curricula". While it may seems easier to infuse DT into capstone projects, earlier exposures are needed for effectiveness. Existing cornerstone projects in the "Introduction to Engineering" module and "Design and Build" module appear to be able to provide windows of opportunities, to train engineering students in DT literacy.



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