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Experiences with Teaching Introductory Product Design to Engineering Undergraduates

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Abstract: *This paper describes the guiding principles adopted in the teaching of introductory product design in the Design and Manufacturing Engineering and Biomedical Engineering departments at The University of Trinidad and Tobago. The experience over the first five years of delivering an introductory Product Development and Innovation course to Engineering undergraduates is described. The paper covers the general approach to design teaching based on Problem-Based Learning (PBL). Evidence from student work and student evaluations is presented to demonstrate the impact of the course on student learning. The paper concludes with a discussion on course improvements and the implications for further supporting product design education.*

Keywords: *Engineering Design Education, Product Design Education, Course Design*

1. Introduction

The Government of Trinidad and Tobago has outlined in its national vision that "through creativity, innovation and collaboration, we shall prosper together" and in its national mission that "the mission is to achieve economic inclusiveness in an innovation-driven growth economy with greater equity, more meaningful participation and a rising tide of prosperity for all in Trinidad and Tobago" (Ministry of Planning and the Economy, 2011). Importantly, creativity and innovation are central players in the vision and mission, which the Government has recognised as being key to building competitive advantage (Ministry of Planning and Sustainable Development, 2012). However, a recent survey of manufacturing firms in Trinidad and Tobago has shown that the country lags behind the rest of the world in utilising current manufacturing methods and tools, and that there is a dire need for the capability to design and develop innovative new products (Chowdary, 2009).

The University of Trinidad and Tobago (UTT) has been founded as an entrepreneurial university designed to train young engineers who are equipped to design, develop and eventually commercialise innovative new products and associated services. The Design and Manufacturing and Biomedical Engineering departments at The UTT aim to fill the human resource gap that exists with a new crop of engineers who are not only adept at engineering analysis, but who are also skilled in the art and science of design. A recent ASME survey on the future of Mechanical Engineering has shown that Engineering Design is the top enduring sub-field, indicating that design has been and will continue to be very important in the future (ASME, 2012). The trend world-wide has been in the direction of "Design Thinking" (Brown, 2008) which aims to apply the design approach to solve some of the most pressing problems in complex socio-technical systems. The value of design therefore cannot be overstated, and the challenge remains to train a new breed of effective design engineers.

This paper documents the experience over the past five years in teaching product design at The UTT. Specifically, the paper covers the general approach to design teaching and the implementation of an undergraduate Product Development and Innovation course. Student work and student course evaluations are presented to demonstrate the impact of the course on student learning. An end-of-course survey design is also included as contributions to the area of design education assessment. The paper concludes with a discussion on course improvements and the implications for further supporting product design education.

2. Literature Review

The essence of the engineering disciplines is design (Koen, 1994). Dym (2005) defines engineering design as follows: "Engineering design is 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.” Key to this definition is the idea that design is a *process* that is undertaken where the output is a plan or specification for the realisation of a product or system (Clarkson and Ekert, 2005). Another definition is given by Koen (1994): “The engineering method (often called engineering design) is the use of engineering heuristics to cause the best change in a poorly understood situation within the available resources. The heuristic is anything that is plausible, useful, based on experience but is in the final analysis unjustified, incapable of justification, and potentially fallible.” This definition stresses the use of various *heuristics* or strategies in creating a solution to a complex design problem, with the solution being impossible to judge as being correct in absolute terms.

There has always been a conflict between the area of engineering analysis and the area of engineering design (Dym, 2006). Engineering analysis is a predominantly deterministic approach based on engineering science which uses *convergent thinking* to arrive at a correct answer to a well constrained problem. Conversely, in engineering design, the main activities involve *synthesis* and *divergent thinking* where developed solutions are not necessarily verifiable (Dym, 2006). However, most of the engineering curricula is weighted toward analysis even though the essence of engineering lies in design (Dym, 2006, Dym et al., 2005). Design is therefore a cognitive process (a way of thinking) which proves difficult to learn and difficult to teach (Dym, 2006, Koen, 1994, Cross, 2011).

Given these difficulties, research to date has addressed pertinent questions related to the learning and teaching of engineering design by investigating both novice and expert designers in academic and industrial contexts. The literature provides guidance and recommendations on the key issues for developing effective teaching programmes in design education. In the following sections, these key principles will be presented.

2.1 Qualities of good designers

Koen argues that design is a complex set of behaviours given that it is *something that is done* by designers (Koen, 1994). This complex set of behaviours includes various habits of mind such as understanding systems dynamics (systems thinking), reasoning about uncertainty, making estimates, conducting experiments and making design decisions (Dym, 2006, Cross, 2011). Good designers also exhibit key design thinking skills. These include viewing design as inquiry with the ability to tolerate ambiguity, maintaining an awareness of the big picture, not assuming the world is deterministic, thinking and communicating in several languages of design and viewing design as a social process by working as a member of a team (Dym et al., 2005, Dym, 2006, Cross, 2011).

Mehalik and Schunn outline a comprehensive framework of fifteen common design process elements that could be used as a starting point for understanding the key skills required in design (Mehalik and Schunn, 2007). These fifteen elements are: (1) Explore problem representation, (2) Explore graphical representation/ visualization, (3) Use functional decomposition, (4) Explore engineering facts, (5) Explore issues of measurement, (6) Build normative model, (7) Explore scope of constraints, (8) Refine constraints, (9) Conduct failure analysis, (10) Validate assumptions and constraints, (11) Search the space (evaluate design alternatives), (12) Examine existing designs/artifacts, (13) Follow interactive/recursive/iterative design methodology, (14) Explore user perspective(s), and (15) Encourage reflection on design process (self-reflect). These fifteen elements are mutually exclusive in terms of identifying necessary skills in design, but in actuality multiple skills will be utilised in a particular design phase or activity (Mehalik and Schunn, 2007). This framework is a useful starting point for developing design instruction as it encompasses all the major capabilities required in executing the design process.

In their meta-analysis of the literature, Mehalik and Schunn also identified the three top process elements for good design. These are: (1) Explore problem representation, (13) Follow interactive/recursive/iterative design methodology, and (11) Search the space (evaluate design alternatives). Both (1) and (11) represent the needs study and the conceptual design phases of the design process, lending support to the assertion that these up-front phases are critically important in achieving good design (Mehalik and Schunn, 2007, Cross, 2011).

2.2 Teaching Engineering Design

Given Koen’s argument that design is a complex set of behaviours that can differ between individual designers, he suggests that design instruction should be based around *changing behaviour*. In order to do this, the techniques of behaviour modification must be employed, and *engineering heuristics* are the behaviours that are required (Koen, 1994). The use of engineering design heuristics has proven to be useful in idea generation and in the production of more creative designs (Daly et al., 2012a, Daly et al., 2012b, Yilmaz et al., 2010). In other words, the aim of design education should be to gradually develop within the student a set of design behaviours that approach the repertoire of a good engineering designer through behaviour modification. Further, for reinforcement of these design behaviours, students must be exposed to the design process repeatedly through their educational experience with increasingly complex design problems (Koen, 1994, Cross, 2011).

Engineering design is then best taught with a Problem-Based Learning (PBL) pedagogy (Mafe, 2005, Dym et al., 2005, Dym et al., 2012, Savery, 2006). Originating in the medical field, PBL has been in use for over 30 years. The main characteristics of PBL include the role of the tutor as a learning facilitator, the responsibilities of the learner to be self-directed, and the driving force of inquiry being the design of ill-structured problems (Savery, 2006). The engineering design curricula itself needs to be carefully designed with these principles in mind. Design courses should form the backbone (cornerstone and capstone) of the Engineering curricula where students experience the design process, design thinking and how to learn what they need to know on an as needed basis (Dym et al., 2012).

In order to teach creativity in design, the Ten Maxims of Creativity in Education outlined by Kazerounian and Foley (2007) provide a useful guide as shown in Table 1. The maxims are presented in three categories reflecting thought processes, teaching style and motivational factors. There is a body of literature on creative methods such as analogical thinking, brainstorming, morphological analysis, SCAMPER, TRIZ, design heuristics etc. that all provide strategies for widely exploring the conceptual design space (Puccio et al., 2010, Daly et al., 2012b).

The four maxims for thought processes in Table 1 overlap with some of the fifteen design process elements already described. For design educators, the teaching style and motivational maxims are essential for establishing the right environment for creative design to flourish. Since students tend to be mostly extrinsically motivated, it is therefore left up to the design educator to inspire, motivate and influence students' perception of education (Savage et al., 2012). Educators also need to do their own self-reflection on how they can actively engage students (Savage et al., 2012). Only through stimulating engagement by providing students with active learning experiences can educators convey excitement and enthusiasm for the field of design (Pun, 2007).

Table 1. Ten Maxims of Creativity in Education

Thought Process for Students	
1. Keep an open mind	Students can be taught to see common things in a new light and that the best answer may not the most obvious one.
2. Ambiguity is good	The ambiguity between getting the question and the answer should be tolerated.
3. Iterative process that includes idea incubation	The creative process of preparation, incubation, illumination and verification must be allowed sufficient time.
4. Search for multiple answers	Teaching students to search for multiple alternative solutions through brainstorming and other techniques is critical rather than allowing them to quickly converge on one answer. This helps to foster creative problem solving skills.
Teaching/Learning Style Conductive to Creativity	
5. Reward for creativity	Explicitly reward creativity as a form of positive reinforcement.
6. Learning to fail	Mistakes should be allowed without punishment as a means to deeper understanding of the problem.
7. Encourage risk	Educators should encourage risk taking on difficult projects to foster creative solutions.
Encouraging Motivation and Inspiration	
8. Lead by example	Students will learn by example and inspiration from educators.
9. Internal motivation	Students can be more creative when internally motivated about a design problem. This can be achieved by allowing students to work on problems that they are interested in, or showing the impact of the design solution.
10. Ownership of learning	Students can be more creative when they feel ownership over their learning process and projects.

Source: Adapted from Kazerounian and Foley (2007)

Research has shown that early use of physical prototypes, hands-on model building and collaborative tools increases the likelihood of better design outcomes, especially in team work (Jang and Schunn, 2012). Physical model construction helps students to generate and evaluate ideas, better visualise their ideas, and uncover differences between real behaviour and their conceptual model to predict that behaviour. The act of making also enhances creative thinking and helps students to become more aware of their meta-cognitive strategies (Lemons et al., 2010). Making and testing physical models enhance the idea generation process thereby leading to higher quality ideas. Prototyping therefore leads to a higher probability of creating functional ideas and reduces design fixation (Viswanathan and Linsey, 2010).

Low fidelity prototyping in the early stages of conceptual design is critical as this correlates with better design outcomes (Yang, 2005). To avoid fixation on a particular design solution, designers should work in an environment that allows for easy prototyping, physical interaction and physical evaluations of potential designs. Humans seem to work best and prefer when they can touch and manipulate objects directly (Youmans, 2011). There is also a psychological effect of using low-fidelity prototyping, where failure is used as an opportunity to learn and there is a sense of moving forward. It also results in a strengthening of the belief in one's own creative ability (Gerber and Carroll, 2012).

Design generally takes place in teams, and design educators face a challenge of how best to assign members to student groups to maximise performance.

Studies have shown that students should not self-select themselves for design teams. Rather, students should be characterized before being assigned to teams (Hunkeler and Sharp, 1997, Brickell et al., 1994). In addition, four students per team is preferred, with groups all having an equal size. Academically outstanding students should be distributed evenly among groups, as well as students who are proficient with prototyping and model making. Smaller groups can have more of the academically outstanding students or students with “good hands” to make up (Hunkeler and Sharp, 1997).

Therefore, heterogeneous assignment with respect to GPA and homogeneous with respect to interest appears to be the most effective (Brickell et al., 1994). Students must be given the autonomy to manage their own design process while being taught three key project management techniques: (1) project scheduling, (2) regular project reviews and (3) design memos that document the design tasks (Moor and Drake, 2001). In this way, with the design educator acting in dual roles as both client and facilitator, students have shown to produce better work (Moor and Drake, 2001).

Finally, design students should work on real-world problems where they can teach themselves the design process while using their own creativity to produce a significant result (Mickle and Lovell, 2001). Immersive experiences involving real clients and users are important in allowing students to experience Human Centered Design (HCD) in more comprehensive ways where empathy could be developed (Zoltowski et al., 2012). Doing HCD requires the student to be either intrinsically or extrinsically motivated in the direction of a better understanding of and increased appreciation of the user (Zoltowski et al., 2012).

In the design process, more interactions with users are not associated with better design outcomes. Rather, the *quality* of interaction is more important, especially with getting feedback on conceptual design alternatives from the same users over a period of time (Lai et al., 2010). It becomes more of a co-design process where the user validates the design directions. Design educators should also try to structure courses to motivate students to use various HCD design methods, as students will not attempt to use them unless prompted (Lai et al., 2010).

3. A Product Development and Innovation Course

Based on the preceding review of good design education practice, the course design for the undergraduate 3rd year Product Development and Innovation course (first semester) in the Department of Design and Manufacturing will now be described.

The course is designed around the main principle of exposing students to design thinking and the design process, while introducing tools and techniques for each phase: need finding, conceptual design, detail design and design verification (Cross, 2008). Students also learn about certain Design for X topics, where special focus is given to User Centred /Inclusive Design (Clarkson et al., 2003) and Design for Sustainability (Bhamra and Lofthouse, 2007). These two topics were chosen as focus areas due to the impact they can have on producing breakthrough products and their social relevance. The course is also taught to 2nd year Biomedical Engineering undergraduates in the second semester under the course title Biomedical Engineering Design.

The course schedule is given in Table 2. It consists of a 13-week course with two types of sessions. The first weekly session is an activity session of 2 hours duration, while the second weekly session is a design project session that is 3 hours. The course is not a predominantly lecture based course. Rather, students are introduced to the design process and the design activities involved in those phases in the activity sessions. For the first 15-20 minutes of the activity session, students learn about design methods using videos, case studies and explanations/examples. After this, students do exercises using the design methods so that they get an immediate grasp of the methods and their application.

In the design project sessions, student teams work on their design projects while being facilitated in the process. A schedule is set forth as shown in Table 2 for the design projects, and student teams are also given a handbook that provides a guide of what activities they should be involved in each week. However, as expected, different teams work at different rates depending on their design problem and unique group challenges. Each team therefore requires individual mentoring through the design process while utilising and updating project management plans. Two hard deadlines are put in place that cannot be moved – the product proposal presentation and the final presentation and report submission. Allowing these deadlines to slip (except under extraneous circumstances) would amount to reinforcing the undesirable behaviour that deadlines could be easily moved around (Koen, 1994).

Since the first delivery of the course, projects have spanned areas such as household products, medical and assistive technology, sporting products, recreational products and toys. Students are given a central theme around which ideas for new products could be generated. They are also taken on a need finding activity depending on the theme for the course.

For example, a hospital visit is arranged for biomedical and assistive technology projects, or a visit to a toy shop is arranged for toy design projects. Contacts made for the need study are utilised throughout the course so that students have access to experts and users for validating their ideas. For example, if a hospital visit is arranged, the contact doctor or nurse assists with forming a patient user group. Students search for design problems and unmet needs while recording their observations with cameras and video recorders.

Table 2. Course Schedule for Product Development and Innovation

Wk	Activity Session (2 hours)	Design Project Session (3 hours)
1	**The Design Process:** Video case study of the design process.	**Product Analysis:** Analysis and critique of products.
2	**Need Finding:** Design requirements, products, patents and user research.	**Introduction to the Design Project** - Year's theme and review of past projects. Design project management techniques.
3	**Conceptual Design:** Generating product ideas and alternatives (functional modeling and morphological charts). Creativity methods.	**Conceptual Design** – Brainstorming, screening and short listing 3 to 5 product ideas.
4	**Concept Evaluation:** Methods for evaluating design alternatives.	**Conceptual Design** - Converge to overall idea.
5	**Material Selection and Design:** Identifying material properties and manufacturing processes that are important for a given list of components using material selection software (Cambridge Engineering Selector).	**Conceptual Design** - Produce conceptual sketches for design alternatives and low fidelity prototypes.
6	**Poka Yoke (Mistake Proofing):** Designing devices for prevention/detection of mistakes in use.	**Conceptual Evaluation** - Evaluate conceptual alternatives. Prepare project proposal presentation and low fidelity prototypes.
7	**Failure Studies: Failure Modes and Effects Analysis (FMEA):** Analysing how products can fail.	***Product Proposal Presentation:** Present concept, proposal review and finalisation.
8	**Design for Manufacturing and Process Planning:** Assessing manufacturability for a set of components. Preparation of routing and process sheets for a set of components. Visit to manufacturing facility.	**Concept Refinement and Detail Design** – Round 2 prototypes and product configurations.
9	**Inclusive Design:** Designing for users with reduced capabilities. **Sustainability:** Designing for reduced environmental impact. Mini conceptual design project and individual prototype.	**Concept Refinement and Detail Design** – Round 2 prototypes and product configurations. CAD drawings.
10	**Project Work** – CAD drawings, bill of materials, make vs. buy decisions, and process planning.	**Project Work** – Engineering drawings, bill of materials, make vs. buy decisions, and process planning.
11	**Project Work** – Final Prototype Fabrication.	**Project Work** – Final Prototype Fabrication.
12	**Project Work** - Final prototype fabrication, assembly, and testing.	**Project Work** - Final prototype fabrication, assembly, and testing.
13	**Project Work** – Finalise report and presentation.	***Final Presentation:** Final presentation and report submission.

Arrangements are made for students to visit a local manufacturing company toward the end of the course to better understand the link between design and manufacturing. In addition, students are able to get feedback on how to improve their prototypes and new design ideas based on the manufacturing perspective. These visits serve to make students accountable for their projects as they must have a working prototype to show to the manufacturing engineers. In addition, it also serves to engage the local manufacturing community in the design process and spark interest in the field of design.

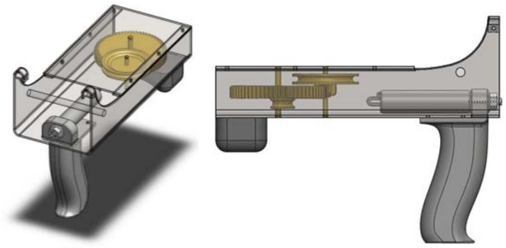
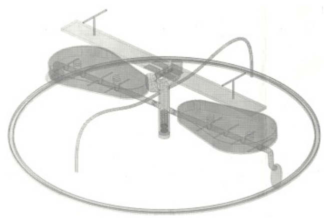
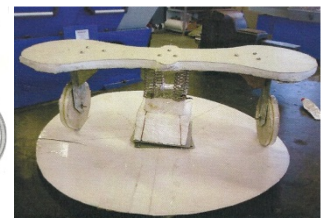
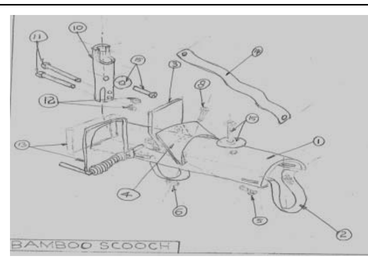
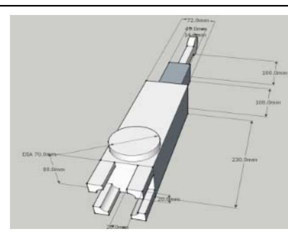
4. Assessment of Student Learning

Contemporary educational assessment approaches are carefully aligned with the most important things that students should learn. In addition, assessment should focus on thinking and performance skills, together with demonstrating the uniqueness of the program and how successful it is in meeting the needs of students and society (Suskie, 2009). The best assessment efforts also utilise diverse approaches. Evidence of student learning could be direct (samples of student work with rigorous grading standards) or indirect (proxy signs that students are learning (Suskie, 2009). Therefore, in order to assess thinking and performance skills in the Product Design and Innovation course, assignments with rubrics are employed. In order to assess attitudes, values, disposition and habits of mind, reflective writing is employed as part of student projects and also in an end-of-course survey (Suskie, 2009). Both direct and indirect evidence will be provided in the following sections to demonstrate the effectiveness of the course design on student learning.

4.1 Direct Evidence of Student Learning

Students are assessed both individually and as a group for all coursework. The course does not have a final examination, but rather assessment is conducted throughout the entire course for all exercises and group projects. Half of the overall assessment grade comes from exercises and group projects done during the course, and the other half comes from the assessment of the main group project report and presentation. Though design assessment is difficult (Koen, 1994), guidance is provided in the literature for developing rubrics which can be used (Platanitis and Pop-Iliev, 2010, Davis et al., 2002). A customised rubric has been developed for evaluating the semester-long design projects which is updated and reviewed after each course offering. Six exemplar group projects from the pool of past Design and Manufacturing and Biomedical Engineering design courses have been selected to demonstrate student work in Table 3. The exemplar projects were selected based on achieving an overall project grade greater than 75%, or if the design idea solved an important need and was novel in its conception and implementation.

Table 3. Exemplar final group projects with examples of student work

Compound Slingshot: The project investigated the need for a device to propel projectiles using the user's energy, with the primary use being for hunting small game. The final design combined the principles of a conventional slingshot and the principles of a compound bow. The new design harnesses the energy provided by the user more efficiently, and also increases the accuracy of the device compared to a traditional slingshot when hunting.	
Integrated Multi-Drafting Board: The project investigated the need for an integrated drawing board with drawing instruments for technical drawing in secondary schools and universities. The key innovation in the multi-drafter design consolidates traditional drawing instruments into a simple, compact device that subsumes the functions of the T-square, set squares, protractor, drawing board and rulers. It can be used to perform drawing operations that would traditionally require a number of drawing instruments while also addressing difficulties involved in setting up, packing up and transporting technical drawing equipment.	 
Rotating See-Saw: The project investigated the need for new interaction modes for the traditional see-saw in order to increase its play value and attractiveness. The key innovation is the addition of rotational motion and sinusoidal motion to the motion of a traditional see-saw. This allows the see-saw to move up and down while rotating in a circle around a track. The see-saw also tilts from side to side by using elliptical wheels.	 
Assistive Wheelchair Propulsion: The aim of the project was to find a low cost way to modify an existing wheelchair to accommodate users with upper limb motor capability loss. User research was conducted at the hospital to gain insights, and the resulting final design concept utilised available bicycle gear and chain mechanisms to provide lever actuated mechanisms for propulsion. User testing and feedback indicated that the design was usable and it had the potential to improve wheelchair mobility for users with upper limb motor capability loss.	 
Bamboo Scooch: There is a need for children to become more active in order to fight the increasing obesity rate in children and young teenagers. A new concept was developed incorporating the traditional game of "scooch" with a wearable projectile toy design that would appeal to children, motivating them to want to go outside and get active. The bamboo scooch utilises sustainable local bamboo in the construction of a projectile mechanism that is attached to the hand. Balls are loaded and shot with a trigger. Play testing with children indicated that the concept has potential for further development.	 
Faucet Assistant Device: People with loss of upper limb function experience difficulty in performing simple tasks, for example opening and closing a water faucet. A new design is envisioned using a multi-head clamp device which, when attached to different faucet heads, allows a user to easily open the faucet without the use of fine motor control. A wooden prototype was created for user testing and demonstration. Based on favourable results, further development would seek to refine the design to achieve ideal proportions and appropriate industrial design.	 

These projects demonstrate design outputs at various stages of the design process, from sketches to CAD models, and from low-fidelity prototypes to high-fidelity prototypes. Importantly, every design project must be validated in some way, and students must present these validation results to prove the value of the design. This takes the form of demonstrating a working prototype, and also presenting evaluation results of user studies. This removes some of the subjectivity that invariably arises in assessing design projects, and also avoids the pitfalls associated with “paper-based” designs. For instance, the integrated multi-drafter project (as shown in Table 3) was taken further by an individual student in his final year design project, and it resulted in the first Industrial Design Patent for The UTT (Registration Number: TT/D/2010/00007). This occurred after the very first iteration of the course, demonstrating the potential of the approach to developing novel product ideas.

4.2 Indirect Evidence of Student Learning

Design thinking is a complex set of behaviours and habits of mind. The introductory product design course has been designed to teach students these behaviours. From an assessment viewpoint, direct evidence gives an incomplete picture of student learning, as it demonstrates *what* student have learnt, but it does not provide evidence of *why* students are or are not successful (Suskie, 2009). Indirect evidence comprising student reflection and self-assessment must be used.

5. Course Evaluation Survey

5.1 Method

An end of course evaluation survey was designed to measure the effectiveness of the course on student behaviour and thinking. The survey uses a combination of self-assessment rating scales for each skill area of the course, and four questions based on the minute paper concept (Suskie, 2009, Angelo and Cross, 1993) . The first part of the survey asks students to answer the following two questions for each of the 11 skill areas shown in Table 4: (1) *How strong are your skills in each of the following areas?* (2) *How much have the session(s) in this course helped you to develop each of the following skills?*

The second part of the survey asks students to respond with one sentence to each of the following four questions: (1) *What was the most important thing you learned during this course?* (2) *What was the second most important thing you learned during this course?* (3) *What important question remains uppermost in your mind as the course comes to an end?* (4) *What do you think makes a person a good designer?* These four questions were selected to measure students’ own perceptions as they reflected on what was learned during the course.

The survey was administered to the Biomedical Engineering year 2 students at the ending session of their Biomedical Engineering Design course. All 19 students filled out and returned the survey.

Table 4. Course self-assessment rating scales

	Your Skill Level?					**How much the sessions in this course have helped?**				
	Low				*High*	*Low*				*High*
1. Finding needs for new products by working with experts and users.	1	2	3	4	5	1	2	3	4	5
2. Finding and comparing technical information on existing products and patents.	1	2	3	4	5	1	2	3	4	5
3. Coming up with a range of design concept alternatives (using the combination of functional modeling, morphological charts and brainstorming).	1	2	3	4	5	1	2	3	4	5
4. Evaluating design alternatives using different methods (Pugh’s, Dominic’s and Pahl and Bietz).	1	2	3	4	5	1	2	3	4	5
5. Finding and selecting material properties and manufacturing processes using material selection software (CES).	1	2	3	4	5	1	2	3	4	5
6. Representing basic product ideas using computer aided design (CAD) software.	1	2	3	4	5	1	2	3	4	5
7. Analysing products for usage mistakes and failure (Poka Yoke and FMEA).	1	2	3	4	5	1	2	3	4	5
8. Design product features taking into account users with reduced capabilities (Inclusive Design).	1	2	3	4	5	1	2	3	4	5
9. Planning and executing all the stages in the design process for a given design problem.	1	2	3	4	5	1	2	3	4	5
10. Making design presentations to communicate design ideas to others.	1	2	3	4	5	1	2	3	4	5
11. Working effectively as a team/group member on a design project.	1	2	3	4	5	1	2	3	4	5

Skill level ratings and course session effectiveness ratings data were entered into IBM SPSS Statistics 20 software for data analysis, while textual answers to all questions were typed into a Microsoft Word file for analysis. Descriptive statistics and graphs for the ratings data were generated, while textual responses were analysed into grouped listings (Suskie, 2009). The results of the survey are presented in the following section.

5.2 Course Evaluation Results

Tables 5 and 6 show descriptive statistics for student skill level ratings and course session effectiveness ratings, respectively. Self-ratings data on a 5-point scale is considered ordinal level measurement, though most researchers treat it as interval level data in practice (Field, 2009). In this analysis, both the mode (appropriate for ordinal level data) and the mean (appropriate for interval level data) were evaluated as descriptors of the data. Mean ratings are plotted in Figures 1 and 2, respectively.

Benchmark levels for student ratings were also set in order to determine the effectiveness of the course (Suskie, 2009). Acceptable student skill level ratings were set at levels of 3 and above, as the course is an introductory design course that aims at basic proficiency in design thinking. Acceptable course session effectiveness ratings were set at levels 4 and above, as these should clearly show the impact of the teaching sessions on student learning. It was decided that 80% of the students should fall at or above the benchmarks and Table 7 shows a summary of these proportions.

The mean ratings for student skill level show that all skills except Computer Aided Design (CAD) received a mean rating above 3. Analysis of the mode also shows ratings of 3 or 4 for all the skill areas. Coming up with conceptual alternatives and working effectively in a team received the highest mean ratings from the class. This is desirable as it demonstrates that students are confident in their ability to use creativity techniques to explore the design space and also do so in the context of teamwork. Such skills as CAD, material selection and design evaluation received the lowest mean ratings and also fell below the course benchmarks indicating low confidence in these areas. This is most likely due to the lack of basic courses and practice in CAD and engineering materials in Biomedical Engineering as compared to Design and Manufacturing. Students therefore found it difficult to develop these skills while also doing their projects. Low ratings for evaluation methods may be indicative of difficulty in choosing which evaluation method is appropriate for different situations.

The mean ratings for course effectiveness show that all sessions except CAD and materials selection received a mean rating above 4. Analysis of the mode also shows the most frequent ratings of 4 or 5 for all the course sessions except CAD which had a mode of 2.

Table 5. Descriptive statistics for student skill level rating

	N		Mean	Std. Error of Mean	Mode	Std. Deviation	Minimum	Maximum
	Valid	Missing						
S1_Needs	18	1	3.6667	.21390	4.00	.90749	2.00	5.00
S2_FindProdPatent	19	0	3.5263	.20758	3.00	.90483	2.00	5.00
S3_ConceptAlternatives	19	0	4.1053	.22807	4.00	.99413	1.00	5.00
S4_Evaluation	19	0	3.3158	.30639	4.00	1.33552	1.00	5.00
S5_MaterialSelection	18	1	3.2222	.23647	4.00	1.00326	1.00	5.00
S6_CAD	19	0	2.8421	.25664	3.00	1.11869	1.00	5.00
S7_MistakeFailure	19	0	3.7895	.29199	4.00	1.27275	1.00	5.00
S8_InclusiveDesign	19	0	3.7895	.22399	4.00	.97633	1.00	5.00
S9_ProjectPlanning	19	0	3.5789	.22052	4.00	.96124	1.00	5.00
S10_Communication	18	1	3.6667	.16169	4.00	.68599	2.00	5.00
S11_GroupWork	19	0	4.1053	.16919	4.00	.73747	3.00	5.00

Table 6. Descriptive statistics of student ratings for course session effectiveness ratings

	N		Mean	Std. Error of Mean	Mode	Std. Deviation	Minimum	Maximum
	Valid	Missing						
C1_Needs	19	0	4.1579	.19138	4.00	.83421	2.00	5.00
C2_FindProdPatent	19	0	4.2105	.21053	5.00	.91766	2.00	5.00
C3_ConceptAlternatives	19	0	4.5789	.13925	5.00	.60698	3.00	5.00
C4_Evaluation	19	0	4.4211	.19218	5.00	.83771	2.00	5.00
C5_MaterialSelection	18	1	3.9444	.24882	5.00	1.05564	2.00	5.00
C6_CAD	19	0	3.1053	.27460	2.00	1.19697	1.00	5.00
C7_MistakeFailure	19	0	4.4211	.11637	4.00	.50726	4.00	5.00
C8_InclusiveDesign	19	0	4.5789	.13925	5.00	.60698	3.00	5.00
C9_ProjectPlanning	19	0	4.5263	.14035	5.00	.61178	3.00	5.00
C10_Communication	19	0	4.4211	.13925	4.00[a]	.60698	3.00	5.00
C11_GroupWork	19	0	4.2105	.16364	4.00	.71328	3.00	5.00

Remarks: [a.] Multiple modes exist. The smallest value is shown

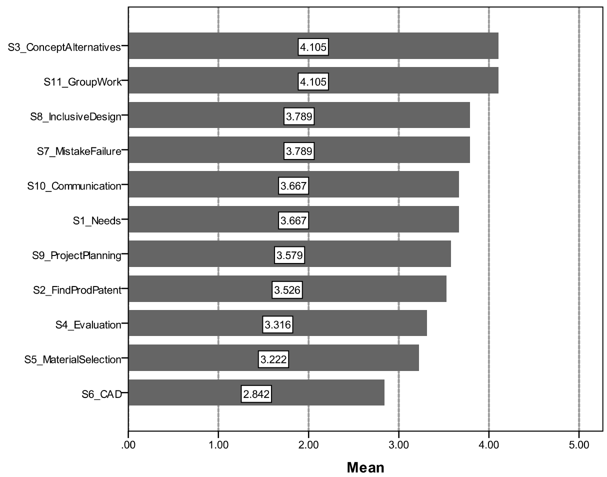


Figure 1. Mean ratings for student skill level

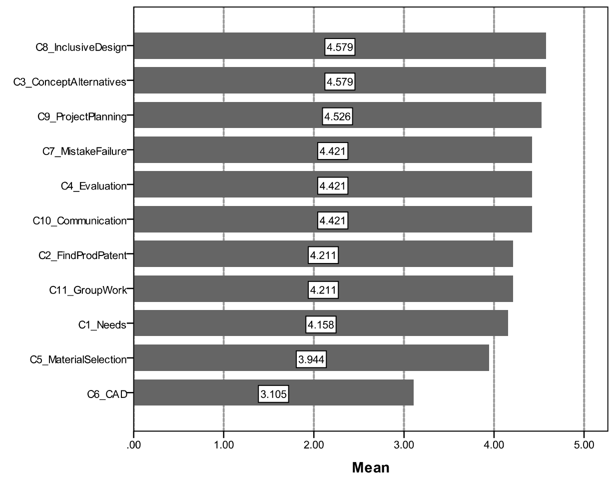


Figure 2. Mean ratings for session effectiveness

Table 7. Percentage of students rating above course benchmark targets (values below 80% are in bold)

Content Area	Percentage of students rating 3 and above for skill level (%)	Percentage of students rating 4 and above for course session effectiveness (%)
1. Needs	89	84
2. Finding Products and Patents	89	**79**
3. Conceptual Alternatives	95	95
4. Evaluation	**74**	89
5. Material Selection	**78**	**67**
6. CAD	**63**	**37**
7. Mistake Proofing and Failure Analysis	84	100
8. Inclusive Design	95	95
9. Project Planning	89	95
10. Communication	89	95
11. Group Work	100	84

The sessions on CAD, materials selection and finding products and patents fell below the benchmark targets set for the course. These results indicate that poor CAD and materials selection ratings are possibly due to the reasons previously outlined, and the session on products and patents could be improved with more examples and exercises on how to search for and benchmark existing products and patents. The mean ratings for course effectiveness show that all sessions except CAD and materials selection received a mean rating above 4. Analysis of the mode also shows the most frequent ratings of 4 or 5 for all the course sessions except CAD which had a mode of 2. The sessions on CAD, materials selection and finding products and patents fell below the benchmark targets set for the course. These results indicate that poor CAD and materials selection ratings are possibly due to the reasons previously outlined, and the session on products and patents could be improved with more examples and exercises on how to search for and benchmark existing products and patents.

In terms of the four-minute paper questions, Tables 8 and 9 show grouped listings of student responses to questions about the most important things learned in the course. The responses indicate that students found the systematic design process and design tools/methods the most useful things they learned in the course. The importance of group work and the need for clear design communication were also key take-away points. The results therefore illustrate a clear alignment with course goals.

Table 10 shows a grouped listing for the most important question that remains uppermost in students' mind at the end of the course. These questions were largely about issues arising from the design process and the use of associated methods/tools (38%), questions about the next stages in the product development process and how to commercialise developed ideas (25%), and reflections on being a good designer and a future career in design (25%). These questions are desirable outcomes at the end of the introductory course, as they lead directly into follow-up courses on detail design and entrepreneurship built into the curriculum.

Table 11 shows grouped listings for what students think makes a person a good designer. Student responses were broken into key phrases representing design traits or qualities. Each phrase was categorised and the number of mentions in each category was recorded.

Table 8. Grouped listing for the most important thing learned during the course

DESIGN PROCESS RELATED (11 of 19 responses, 58%)
• Following the design process aids in design much more efficiently than just trying to design wholesale. • How to go about designing a product using the stages in the design process. • There is much more to the design process than I initially thought. • I learned how to think and work in a sequential order for a project. • The actual procedure of designing a product. Things that should and should not be there, etc. • Design involves a lot of trial and error. The first attempt is never 100% perfect. • The design process steps from start to finish. • The manner of changing an idea into the final product. • The process involved in planning and executing a design. • The different steps you need to undergo to product an effective design. • How important and difficult the design process is for the simplest ideas.
DESIGN METHOD/TOOL RELATED (5 of 19 responses, 26%)
• The correct way to design a product is not based on just the outer appearance but is actually meeting the needs of the users. • Analysing and evaluating designs and materials to be used which are most suitable • Learning to explore and identify materials for use in a design approach. • How to use Sketchup software. Very useful to a Biomedical Engineer to design their own products or improve on existing products. • Representing basic product ideas using CAD software.
REFLECTION ON EFFORT AND CAPABILITES (3 of 19 responses, 16%)
• It is not easy to manufacture or design a new product. • Never underestimate my capabilities in terms of designing and manufacturing new products • Meeting deadlines.

Table 9. Group listing for the second most important thing you learned during the course

GROUP WORK (7 of 17 responses, 41%)
• The teammates all have important ideas adding towards the final efficient design. • You need a team of people to do this course. • Learning to communicate with my fellow colleagues. • I learned how to work in a group and presentation skills. • To work with different team members. • How to overcome challenges presented, and how to accommodate others in your group. • Teamwork and brainstorming when evaluating an idea.
DESIGN METHOD/TOOL RELATED (6 of 17 responses, 35%)
• There are many different tools available that can be used to structure the development process. • Using CAD software to represent ideas as a 3D model. • I never knew how to use a drill until having to do so myself. “Guys” were not readily available as well as using a hacksaw. • Making your design easy to operate for people of all ages and abilities. • Inclusive design and its uses in real life as well as generating design alternatives and the ideas involved in carrying it out. • The way to include specific requirements of a product to final design.
DESIGN COMMUNICATION/PRESENTATION (3 of 17 responses, 18%)
• Physically building prototypes and using it for presentations can greatly enhance the presentation. • The procedure of a proper presentation. • Making design presentations to communicate design ideas to others.
DESIGN PROCESS RELATED (1 of 17 responses, 6%)
• Different aspects of the design process.

Characteristics related to design thinking were mentioned the most (50% of mentions), followed by being able to understand needs and users (28% of mentions) and being able to follow a systematic design process (16% of mentions). These results clearly indicate that students have imbibed the main message of the course and developed an understanding of the behavioural characteristics or habits of mind that are required to be a successful designer. In addition, students demonstrate that they have learnt that understanding the problem and the needs of users is the most critical step in the design process.

6. Discussion

The general approach to teaching an introductory undergraduate course in product design has been presented. Based on the direct and indirect evidence compiled, the strategies employed for teaching product design are successfully impacting student learning in most areas. With an eye for continuous improvement in the delivery of engineering design education, the course offerings could be gradually improved through iteration. Steps are being taken to address the shortcomings in the existing course design by improving the delivery of sessions and time spent on CAD, materials selection and searching products and patents.

Table 10. Grouped listing for the most important question that remains uppermost in students' mind

QUESTIONS AND REFLECTION ON DESIGN PROCESS, METHODS AND TOOLS (6 of 16 responses, 38%)
• Did we really complete our designs in the time frame given?
• Why weren't we able to have more patient interaction or doctors to assist in improving our design?
• How to test the device's usability and not focus on what I think is right?
• How to come up with a range of design alternatives when brainstorming?
• As an aspiring biomedical engineer, would the information learnt be adequate to design new medical devices?
• Still need to review how to do a 3D design image and play around with the program to search for materials.
QUESTIONS ABOUT NEXT STEPS AND ENTREPRENEURSHIP (4 of 16 responses, 25%)
• How to move from a prototype to a mass produced product? What are the best steps take?
• Should I move this design into the next stage since no other like it exists and the feedback for it is great?
• My group's design project and whether we can truly bring that product to the market and gain actual sales?
• Will we be given another course like this in our final year under the guidance of our teachers to build something in the BME world that can actually go to the markets?
QUESTIONS ABOUT SELF IMPROVEMENT (2 of 16 responses, 12.5%)
• How can one person become a good designer?
• How can I become a better designer?
QUESTIONS ABOUT FUTURE CAREER (2 of 16 responses, 12.5%)
• How did this course link to my future and my work for final year also my working future?
• What kind of job market exists locally for this type of conceptualization and design?
QUESTIONS ABOUT PERFORMANCE (1 of 16 responses, 6%)
• Did I do well?
NO QUESTIONS (1 of 16 responses, 6%)
• Nothing of note.

Table 11. Grouped listing for what makes a person a good designer

DESIGN THINKING (16 of 32 characteristics mentioned, 50%)
• Having patience; open minded; a good imagination; mind open to new thoughts and ideas; attitude; mindset; creativity; an innovative mind; ability to come up with good ideas; the ability to continually come up with not only ideas but involving originality; think out of the box; able to think that further step; not afraid to make mistakes; ability to cope well with challenges, visualize an idea to fill that need, I think a good designer can visualize his/her design.
UNDERSTAND NEEDS AND USERS (9 of 32 characteristics mentioned, 28%)
• A good designer is someone who understands the situation; being able to meet the needs and requirements of the users; understands the problem they are trying to solve; researching and concluding the needs of a population and establishing ideas that work toward this need; ability to interact with the people or a customer and find their needs; their ability to accommodate the entire vision of an idea for a product in a user friendly way; the ability to identify a need; seeing a problem and finding solutions to the problem by design; the person's ability to produce an all inclusive design.
DESIGN PROCESS (5 of 32 characteristics mentioned, 16%)
• Following standard structure; use established methods of the design process to validate the idea; ability to incorporate as many of these tools as possible in the design process to get the best product; modify good ideas using proper techniques to come up with a final product; be ready to make necessary adjustments to improve that design with the use of definite evaluation methods.
DESIGN COMMUNICATION (1 of 32 characteristics mentioned, 3%)
• Sketch/draw to explain the design
TEAMWORK (1 of 32 characteristics mentioned, 3%)
• Working effectively as a team member on a design project.

The course evaluation survey presented appears to capture the deeper issues of student learning adequately with a minimum of administration time and analysis effort. It provides valuable information on the behaviours and habits of mind that completes the picture of student learning. Further work on the survey involves comparing results between the Design and Manufacturing department and the Biomedical Engineering department to determine if there are differences in learning outcomes for the same general course design. Based on the results of such a study, it may be necessary to customise the course further based on the specific needs of students in each department.

Based on the authors' teaching experience, the ability of students to use engineering heuristics effectively in learning design thinking and conceptual design is of paramount importance. Teaching design courses is difficult because it requires much more than just content delivery. It requires that a design educator inspires and motivates students when they turn up at a blind alley or experience the failure of an idea. It also requires that students imbibe the design strategies exhibited by the design educator as he or she facilitates team design projects. For this to occur, design faculty must be experienced in the design process and they must be able to articulate their thought processes clearly in the classroom. Design educators must also teach students how to ask appropriate questions at relevant points in the design process, and how to make decisions in the face of uncertainty (Cross, 2011).

For all design projects, students are encouraged to examine local needs with an eye to developing design solutions that could be marketed both locally, regionally and also in other international contexts with similar needs. In order to design and develop endogenous product solutions (Mafe, 2005), students are driven to consider the use of locally available materials and manufacturing processes together with ideas on how they can further develop their product ideas and take them to market. Evidence of this was demonstrated in the exemplar projects presented in Table 3. True success would eventually be determined by success in the marketplace where products actually make it into the hands of users. For this to occur, mechanisms must be put in place to allow for the further development of design projects into commercial ventures. The example of the multi-drafter project shows the development from introductory design project, through to capstone design project and then eventually to Industrial Design Patent. The UTT provides further support structures for students wanting to commercialise their design ideas.

There is a move to make design more ubiquitous in engineering curricula (Dym et al., 2012). To this end, students have requested that the introductory Product Development and Innovation course be offered in their second year and a simpler version of the course in the first year of the Design and Manufacturing degree programme. This suggestion is under active consideration with the aim of building the degree programme around cornerstone design courses in each year of study (Platanitis and Pop-Iliev, 2010).

Design is a resource intensive activity, and challenges include finding resources, personnel and spaces for teaching design. These considerations are crucial for ensuring that students have a positive design experience. The authors concur with Dym (2006) who states that there is a pressing need to expand the number of faculty capable of teaching design, together with the creation of design studios and prototyping facilities. University administrators, faculty members and the Design and Manufacturing industry need to come together to make design pedagogy the highest priority, and this must be reflected in resource allocations (Dym, 2006).

7. Conclusions

This paper presented an overall strategy, the key principles and the experience with teaching introductory product design at The University of Trinidad and Tobago. It demonstrated successful outcomes to date in design education based on student work, student evaluations and the generation of intellectual property for the university. The paper also contributed an end-of-course survey design that could be customised for evaluating introductory product design courses. The authors hope that the experience documented in this paper would provide a springboard for other product design educators to be guided by current thinking in the field and innovate in their course planning and delivery. Only if design pedagogy is made the highest priority would the national vision be eventually achieved.

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