FIRST YEAR ENGINEERING DESIGN – GUELPH'S TEDDY BEAR WHEEL CHAIR EXPERIENCE

Warren Stiver
School of Engineering, University of Guelph
wstiver@uoguelph.ca

Abstract – *First year engineering design courses are now common across Canadian engineering schools. These courses can be challenging to develop and deliver. They are often stuck in the chicken versus egg problem. Can I teach design with no engineering? Can I teach engineering with no design? How does one introduce four years of engineering education and an engineering career in one course? How to do so across many or all engineering disciplines? How to do so in a foundational manner? Can it be done in a meaningful way? Can it be engaging and fun? A Teddy Bear Wheel Chair (TBWC) design project is the focal point of Guelph's first year engineering design course. The TBWC integrates computers, mechanics, biomechanics (Teddy Bear style), environment, safety, sustainability, materials, costing, hands-on, perseverance, ethics and DESIGN. The TBWC participates in curling, sprinting and scoring goals. The result is a challenging and fun competition that introduces all of Guelph's engineering students to their engineering design careers. This paper and presentation will share one instructor's efforts to make all of this work.*

Keywords: Design, First Year, Project Based Learning, Engineering Profession

1. INTRODUCTION

Engineering design is integral to the practice of engineering. Engineering design education ought then to be integral to engineering education. A number of engineering schools deliver a sequence of design courses starting early in a student's program. Some schools have been doing so for several decades [1]. The School of Engineering at the University of Guelph is one of those Schools. First year engineering design courses are now common among many engineering programs even at Schools without a fully developed design sequence. Bazylak & Wild [2] have reviewed first year design practices.

Although first year design courses have become common they are variable in their nature. The variability partially linked to the presence and structure of other design courses in the program. It depends on whether the course is discipline specific or a course that serves multiple engineering programs. The variability also derives from different design education philosophies.

The goal of this paper is to share one approach that continues as a work in progress. The goal is not to suggest that this singular approach should be adopted elsewhere. It is hoped that other design instructors find value in some of the elements, potentially choose to adopt some elements or that some elements aid in their own reflection and approach evolution.

The format of the paper describes the course and the TBWC design project, followed by reflections on positive and negative aspects to this point in the experience.

2. GUELPH'S TEDDY BEAR WHEEL CHAIR DESIGN

Guelph's Teddy Bear Wheel Chair (TBWC) design project is a focal point of our first year, first semester design course (Engineering & Design I, ENGG*1100). In this section, the context of the course is provided followed by a description of the project.

2.1. Engineering & Design I

Engineering & Design I is a first year, first semester course required for all engineering students, in all engineering programs, at the University of Guelph. The aim is introduce students to engineering design, to the expectations of the engineering profession in spirit and specifics, to establish a collaborative and team philosophy around learning and engineering, and to stimulate enthusiasm. Finally, the course is to initiate the development of independent learning skills that are essential for success in engineering education and engineering careers.

The course is taught through 2 h of lecture time and 4 h of lab time per week. It has a weighting equivalent to 1.5 times the typical Guelph course. The final exam is worth 20%, the term work in support of design and engineering drawings is worth 40% and the design project is worth 40%.

The lectures cover engineering design concepts, engineering design processes, engineering profession, introduction to project management, engineering's role in society and ethics.

The term work introduces CAD tools (AutoCAD and SolidWorks), sketching and engineering drawings across engineering disciplines. Engineering design exercises help to coach students through relevant steps in their design project.

The design project itself is the Teddy Bear Wheel Chair.

2.2. Teddy Bear Wheel Chair

The Teddy Bear Wheel Chair (TBWC) is the design project within the course. The TBWC is designed, built, demonstrated and participates in a competition. The 40% grade for the project is split between 20% for the final report and 20% for the demonstrated performance of the TBWC.

Students are provided a description of the competition event. The description includes overall context, the TBWC standards, supplies, competition event setup, criteria for winning the competition (and performance grading), and requirements for the final report.

The TBWC competition each year involves two events. In Fall 2013, the events were a sprint (A to B and back to A) and curling (over a ramp and stopping closest to the center of a set of rings). In Fall 2014, the events were a sprint (A to B to A to C and back to A) and shooting (over a ramp and shooting a ping pong ball into a small soccer or hockey net). The performance of the design was assessed based on the performance on the two events, plus striving for a lowest mass design and to be the most aesthetically pleasing design. The mass and race performance are competitive. The team's grade was based on relative performance among all of the TBWCs in the class. The curling / shooting and aesthetics were scored in absolute terms. Team grade on the shooting depended on their shooting performance alone, independent of how many goals other TBWCs were able to get.

The TBWC are required to comply with the TBWC standards in order to be considered eligible for competition. The spirit of these standards is to ensure the safety and comfort of the Teddy Bear. The Teddy Bear cannot fall out during the events for safety reasons and also cannot be strapped in for comfort reasons. The wheel chair must pass a static tilt test (30°) to be eligible to compete in the ramp events.

The students are provided with the following supplies: one Arduino Mega2560 microcontroller, one Meccano Super Set, a DC Motor, a breadboard, a motor controller, a series of capacitors and resistors. Students supply batteries and they are free to use modest other materials. The capital cost to set up this infrastructure was about $40 per student with a replacement / supplies cost of about $8 per student per year.

The project is completed in teams of 5 throughout the semester. The demonstration and testing is completed over a period of 5 days in the School's Atrium.

The final report is submitted on the last day of classes. It requires the documentation of the design result, reflection on the design's performance, and documentation of engineering analysis in support of the design. The reflection component requires the team to articulate how they would improve their design. The engineering analysis included the overall mass of their TBWC (tested against the measured value on competition day), the center of mass and tipping point (in all 4 directions) and Life Cycle Greenhouse Gas Emissions.

3. RESULTS and REFLECTIONS

The results of the TBWC and my reflections are provided from a number of interconnected perspectives. As this is an introduction to engineering and design, the project's capacity to reflect the engineering profession is important. It should provide an engineering design process experience. The course serves all engineering programs and as such it should be relevant to all programs. The pedagogical merits of the structure and delivery are discussed. Finally, the project should reflect Guelph's design education structure and philosophy. The section closes with thoughts on overall success.

3.1 Reflecting Engineering Profession

There have been many descriptions of the practice of engineering. In Canada, the provinces govern the practice of professional engineering. The Ontario's Professional Engineers Act [3] identifies the "practice of professional engineering means any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising **that** requires the application of engineering principles **and** concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment, or the managing of any such act". It is important for students to see and make connections between their engineering education at the formative stages and the expectations of their future professional career. In the TBWC project attention was paid to safeguarding life and health, to public welfare and to the environment.

Safeguarding life and health connections for the project lead to requirements that the TB remains safe while using the wheelchair. The TBWC requires the students to consider safety in two key respects. One, their design is to prevent the TB from falling out throughout the competition. Two, the TBWC must pass the static tilt test. These requirements are documented for the student in the form of TBWC performance standards as a means to introduce students to the role of standards in their design work. The "falling out" requirement is tested during the competition. The static tilt test is assessed using a ramp on competition day and through their engineering analysis in their final report. One of the lab exercises provides guidance on these calculations.

The public welfare is addressed through the strategic choice of the Teddy Bear. The TB is meant to represent individuals without a voice (not at the design table, without the capacity to speak for themselves including future generations) and individuals with different abilities. Encouraging engineers at the earliest stage in their career to be advocates for the TBs involved in all of their designs will establish our service to society responsibilities.

Most teams treated these safety requirements and the welfare of the TB in a progressive manner. However, most teams did not use engineering analysis to help them in this task. They treated the TB with respect and diligently strived to protect the TB. However, not all teams did, some saw the TB as the equivalent of a rock.

The connection to the environment is made through a life cycle analysis requirement. Teams quantify the life cycle greenhouse gas emissions of their overall TBWC. Importantly, this result was reinforced by the reflection component of the final report. Teams are required to reflect on how they would reduce their emissions.

Few teams paid any attention to greenhouse gas emission performance while designing and building their TBWC. Even the Environmental Engineering students didn't give this much thought during the term. However, a very large majority of teams recognized key aspects during their reflections. They consistently noted that using less material and being selective about the materials they did choose offered significant opportunities to reduce impact. Many teams recognized that thinking about materials more carefully during the design process would have improved their design's performance in mass and speed terms as well. If this reflection stays with these teams then success will have been realized.

3.2 Engineering Design Process

There is not a singular description of "the" engineering design process. There are some common elements among the various efforts to capture the process. The following discusses to what extent each of these common elements is included in the TBWC project.

3.2.1 Problem Definition. The problem is defined and provided to the students and all teams pursue the same problem. The students identify the project constraints and criteria as they are conveyed in the project overview document. This approach offers a number of advantages. As a common problem, students are able to learn from other teams. They benefit from clearly seeing that open-ended design problems lead to many different solutions. The best solutions trigger the question: why didn't we think about that? Finally, the common problem is also less resource intensive.

The provided common problem also recognizes that Guelph's third and fourth year design courses require a substantial problem definition role.

3.2.2 Idea Generation. Idea generation sessions follow in the weeks after the project is released. A sketching lab includes techniques to rapidly sketch ideas. Another lab requires teams to generate at least 5 independent and complete sketches of possible solutions. This session also provides practice with idea generation techniques ranging from simple brainstorming through to the 6-3-5 method.

3.2.3 Design Building. Meccano is an easy system to build with – suitable for ages 8 and up. However, an Arduino microcontroller and electric circuits are almost completely new to our students. The Arduino is introduced to the students over two labs. In the first lab, students are introduced to some Arduino programming concepts, coached to control and blink LEDs and then encouraged to be creative with the blinking. Many choose to learn Morse Code and they successfully blink their name in Morse Code.

The second lab connects the Arduino to controlling a motor. Students are introduced to breadboard usage, provided the motor controller circuit diagram and the truth table. They are encouraged to build the circuit in the standard setup configuration and start / stop their motor.

This second lab is a struggle for more than half the teams. Stripping wires, differentiating resistors from diodes, using a breadboard, counting pins, reading a circuit and following instructions are all stumbling points. The difficulties provide an opportunity to introduce troubleshooting strategies. Eventually all teams reach success and many (but not all) learn that attention to detail matters in some circumstances.

Unfortunately, many students and teams come out of these two Arduino lab exercises with a tenuous grasp of what they have done. Some are stuck in the expectations of being hand held through all steps.

Once they have their Arduino talking to their motors and they have their Meccano kits they jump into the designing and building domain.

3.2.4 Design Analysis. During the mid semester labs, students are introduced to tipping calculations and life cycle analysis. The labs introduce the calculations in simple contexts and then require the students to apply the analysis to a few components of their designs. Students are coached to set all of these calculations up in a spreadsheet to support continuous additions.

It is hoped that they would keep these two calculations current as they progress in their designs. It is hoped that they would see the mass, the tipping point and greenhouse gas emissions respond to their design changes. It is hoped that teams would adjust their designs in positive ways as a result of this information. Unfortunately few teams achieved any of these hopes. For a large proportion of teams, the supporting engineering analysis was forgotten after the lab exercise and only revisited in preparation for the final report.

3.2.5 Design Iterations. As midterm season in their other courses passes, the teams are actively designing, building, testing and adapting. The most proactive teams start having success and rumours spread through the class regarding speed and capabilities. Iteration and troubleshooting become the norm. An electrical troubleshooting station is set up in the student shop space. The station includes instructions to test for many but not all possible component or system malfunctions.

Approximately two weeks prior to final testing day, teams are required to submit one slide and one tweet depicting their design for the purposes of aesthetic assessment. This deadline serves two purposes. The first purpose is that this deadline triggers accelerated action particular for teams that have been procrastinating to some extent. It is somewhat surprising how motivational 2 marks are or how motivational showing your design to your peers is. The second purpose is to encourage some creative fun around unique branding of individual designs. The assessment of the aesthetics is split between members of the class and instructors.

The down side of the aesthetic element is that a small fraction of students get to hung up on the quality of the assessment by their peers and instructors. They struggle with the inherently subjective nature of what some people think is good looking!

The opportunity for iteration is an essential element of design. In some design contexts the iteration cycles are large and cover fairly long time spans. This permits things like observation of full-scale performance and customer feedback. In a course, the iteration cycle must be rapid and students must be able to self assess performance to drive the changes. The TBWC project permits most teams to go through many iteration cycles.

Unfortunately, most teams complete these iterations in an immature manner. They fall into the trap of rapid changes without thoughtful reflection. They do not draw from engineering analysis and they don't build heuristics.

3.2.6 Design Testing. Testing days are an exciting and daunting time for both the students and the instructional team. Eleven sessions (2 h each) are completed over a period five days. The teams arrive nervous and their designs are weighed in. The race event is completed, followed by tilt test and then the curling / shooting event. Finally, TBWC disassembly, design inventory and kit returns.

The Atrium setting is large enough for the session's forty participating students and many observers (other students in the class, upper class students and many staff and faculty). The race events draw polite applause while the curling / shooting trigger cheers heard throughout the halls of the building when there is a curl right to the dot or a goal is scored. The major successes are great to see and it is tough to see the agony of defeat for the teams that had expected their TBWC to perform much better.

The TBWC project and its multiple objectives challenge the students. Design education projects must be challenging in order to instill valuable design skills. A core attribute of successful engineering designers is perseverance. Engineers have an unwillingness to give up character that we develop through challenges we face and our success in overcoming these challenges. Designing projects for design classes needs to a strike just the right balance – challenging but not impossible. If all teams completely succeed then it likely wasn't challenging enough and if no teams do then that sends the wrong message as well. Rewards for partial success are better than an all or nothing reward structure.

The TBWC events have struck a reasonable balance. Only a few teams were able to stop right on the center of the rings and nearly 20% of the teams scored a goal. There were lots of teams inside the 2 meter ring and lots of goal posts hit and shots just wide. On the other side of success, there were some stalled and runaway wheelchairs and some shooting whiffs.

3.2.7 Design Documentation. The final report required is not a full design report. Through lectures and a guidance document, the students are provided with a description of the common elements and structures of design reports. However, in balancing student time demands, the required final report is streamlined. They are required to document their TBWC in terms of its construction (an inventory of components and top, side, front view pictures) and its performance. The report requires teams to reflect on their design and argue in 20-20 hindsight ways that they could improve their design. This reflection is required to be structured along the lines of the key performance objectives for the design. The report is also required to include an appendix of the supporting engineering analysis – mass, centre of mass, tipping point and greenhouse gas emissions.

The streamlined report is effective in terms of the reflection. Some of the reflections are excellent. Teams with both good and bad performance are able to recognize and effectively articulate significant opportunities to improve their performance. Some of this reflection, if deeply recognized, will change and improve how they approach their future design work. However, some of the reflections are shallow, limited to describing what they did with few ideas to improve. Some teams have reflections that are mostly full of excuses and placing blame for poor performance elsewhere.

3.3 Reflecting Engineering Disciplines

All engineering students at Guelph take this common design course. As common courses are created it is essential to attempt to make a meaningful connections to each participating discipline. Civil and Mechanical Engineering disciplines are ideally suited to small scale, design projects. Popsicle sticks, to Lego, to Meccano are ideally suited to supporting projects in these disciplines. Electrical Engineering disciplines are equally readily supported through the low cost of simple electrical components and the availability of breadboards to rapidly prototype. These simple electrical means to build are analogous to the Lego/Meccano context except for the lack of prior childhood experience among the students. Computer Engineering connections are facilitated by platforms such as Raspberry Pi and Arduino. They are built to experiment and they are supported by lots of open source resources. The most difficult disciplines to connect to at this scale and in a safe manner are Chemical Engineering and Process Engineering. The life cycle analysis component of the project is an attempt in this direction. It partially connects to the process domain and while also providing an environmental dimension.

The TBWC does make these connections. It serves the mix of Guelph's engineering programs: Biological, Biomedical, Computer, Engineering Systems and Computing, Environmental, Mechanical and Water Resources. The process emphasis of Environmental and Biological are little less served but both programs draw also from Mechanical, Electrical and Civil Engineering to varying degrees.

It is equally important for students to experience a breadth of engineering fields. There is more in common among different engineering programs, particularly in terms of design, than what differentiates programs. Plus, in practice interdisciplinary domains are common.

3.4 Pedagogy

Chickering and Gamson [4] articulated seven principles of effective undergraduate education.

3.4.1 Encourages Contact. Faculty – Student contact is frequent with substantial faculty participation in the labs throughout the semester. Faculty led the labs for four of the weeks and provided a secondary support to several other weeks. Faculty met each team twice to discuss team dynamics and project progress. At least two instructors (combination of GTAs, staff and faculty), and sometimes three, supported each lab session with 40 students.

3.4.2 Collaborative learning. The design teams themselves provided a collaborative learning environment. This was extended through sharing strategies across teams during some of the lab exercises. The performance assessment does have a competitive domain between teams but this represents just 10% of their overall course grade.

3.4.3 Active learning. The hands-on labs through to final project testing and demonstration are inherently active learning experiences. However, members within teams can take a passive role. Efforts to reduce and catch participation that is too low are not completely effective. Potentially about 10 students (of 400) were not sufficiently adequate active contributors.

3.4.4 Prompt Feedback. Every lab session provided feedback that is either graded and provides other overtly tangible evidence. The control of the spinning motor is an example of the later in which students know whether they achieved this or not. The weekly feedback isn't sufficient to tell individuals or teams whether they have left sufficient time for the troubleshooting task that is sure to come or to tell if whether they will win the competitive events. The feedback during TBWC assessment week is almost immediate – they know right away if their TBWC has performed well. Only the feedback associated with the final report is delayed, as it typically requires a couple of weeks to judge.

3.4.5 Time on task. The lab exercises provide the context needed for much of the TBWC project. However, some teams struggle extending the simpler tasks to the more open-ended project. Some teams time management goes awry when they get stuck in a troubleshooting mode. Troubleshooting and perseverance are essential for engineers but lines can be crossed. Teams can also get stuck on occasion with one or two actively working while three or four are actively watching. Making sure all team members know how to contribute is something that requires more attention.

3.4.6 High Expectations. The expectations of the TBWC performance are challenging. It motivates and challenges students and performance success is a thrill. However, the complementary design analysis, engineering drawing skills and lecture elements are not as effective in pushing the students to reach higher.

3.4.7 Diverse learning styles. Success in the TBWC project does require hands-on skills and an openness to try new things. The electrical, Arduino and Meccano elements intimidate some students. These students struggle to contribute and to demonstrate capabilities.

Beyond Chickering and Gamson, engineering design educators argue that assessment should emphasize student process over end product performance. This perspective is a balancing act. Most certainly it is important to build process skills. However, in the absence of performance measures, students can get the message that going through the motions is sufficient based on performance not influencing assessment. Under these circumstances, there is little value of perseverance, judgment and iterations. In this course, 20% of the grade is design performance, 20% design documentation and about 20% associated with design process lab exercises. The lab exercises loosely guide or provide exercises for the students that support relevant design process tasks. Fully scripting the process is problematic in a few respects. Fully scripted implies that design is a linear exercise that everyone follows a singular path. Equally, it is impossible to block students from diverging. Permitting divergence while still exposing students to valuable process steps is an important choice in recognizing the open-ended and creative aspects of design.

3.5 Guelph

The collaborative learning environment that prevails throughout the engineering programs is one of Guelph's strongest aspects. This first course needs to establish this collaborative perspective from the start.

3.6 Success?

Is the TBWC project successful? Yes, No and Maybe.

Yes. The TBWC uses an academically contrived project to introduce students to a genuine engineering design problem. It is genuine in character owing to the collection of constraints and standards that must be satisfied, the multiple objective criteria that must be pursued and balanced, the diversity of possible solutions, the expected combination of engineering analysis and build/test, the opportunity for iteration and the final documentation. The project connects to our expected professional engineering roles, it is challenging and most students it is a lot of fun.

No. Some students take the agony of defeat too deeply. Some students see the project only performance and pay too little attention to other elements in the design project and course. Some teams do not function well – some of this due to dormant members and some due to personality clashes.

Maybe. It is difficult and maybe impossible to measure. Grades certainly offer little insight. The number of goals scored by the TBWCs would be a false measure – greater hand holding on our part would lead to more goals but this would certainly be less pedagogically effective. Student survey of their self-efficacy could be executed but would raise at least as many questions as it potentially answers. The real measures will be whether the students are better designers when they are 25, 35 and 45 years old. However, it is impossible to distinguish the impact of this one course on that performance. The real impact is associated how receptive they are to learn from their next experiences and what directions do they take with these experiences. Do they pay greater attention to design for accessibility, design for the environment as a result of a buried memory of their TBWC? Do they demonstrate greater perseverance and greater confidence as they face their future engineering challenges?

4. CONCLUDING THOUGHTS

The TBWC project welcomes students to engineering at Guelph. They work collaboratively in teams to meet the challenge. The project is contrived but it is framed in the expectations of professional engineering. The TBWC project crosses disciplines, requires pursuit of multiple objectives and pushes students to learn and use all of what they know. They fail, they adapt and they persevere. They succeed. They document and they reflect. In the end, they learn that engineering design is hard work but that work is rewarding and fun.

Acknowledgements

The support of Guelph Engineering students over the years is gratefully acknowledged. My graduate teaching assistants, Alex Galvez, colleagues at Guelph, NSERC Chairs in Design Engineering, C^2E^2, CDEN and CEEA have all helped to shape and inform my design instructional strategies.

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