Increasing first-year student motivation and core technical knowledge through case studies

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Full Paper: Increasing First-Year Student Motivation and Core Technical Knowledge Through Case Studies

In engineering programs with a common first year, students may feel more like they are in Grade 13 than new members of an engineering community, working towards qualification to enter an exciting and impactful profession. A primary goal of "Engineering One" (EO) at Memorial University is to help students appreciate what an engineering degree, and engineering itself, entail. Students drawn to engineering because of high school success in math and science should leave first year informed about the other skills they will need if they are to thrive as engineers. Our first year must also prepare students for second-year specialization, both technically and in regards to the choice of department. Departments expect a certain level of readiness in numerical literacy, ability to use software tools, presentation and interpretation of data in graphical form, and ability to critically reflect on the reasonableness of results. To achieve these goals, an engineering practice and preparation half-course called "Thinking Like an Engineer" (TLE) has been developed. The centrepiece of TLE is a collection of case studies, with applications from different departments, that presents big-picture engineering problems to students in an analytically tractable form. The case studies i) show how real-world needs are turned into quantitative engineering problems with constraints, ii) give global learners a sense of the problems they will be able to tackle with more depth as they move through the program and beyond, iii) provide a context in which to learn computer tools, especially Microsoft Excel, and iv) provide opportunities to give formative feedback on graphical communication and data analysis, significant figures, estimation, basic statistical analysis, and so on.

The traditional engineering curriculum is a result of many shifts in emphasis over the years, an important one being the 1950's government funding of fundamental, as opposed to "applied" research; with a subsequent (further) shift away from hands-on experiences and towards engineering science as the curriculum core [1]. Heavy loading of first year programs with math and science has implications for persistence and recruitment of global learners [2] and certain underrepresented minorities such as females [3]. Felder and Brent [4] caution against a "trust me" approach to education in which students may have to persist for months or years before they see why what they've been taught is important. The proposed case-studies move instruction from deductive to inductive [5], with the goal of deeper retention and understanding as the information is more strongly linked to students' existing cognitive structures. Early links between course experiences and career goals are important, especially for underrepresented student groups [6]. In [7], 78% of female survey participants reported that it was "very important" for their future career to involve helping people. Females in particular are less likely than males to have "[seen] science and engineering as their future at a young age" [8]. Increasing K-12 efforts to increase female recruitment will ultimately be less effective if students experience a feeling of "bait-and-switch" [9] when open-ended hands-on pedagogies in high school are replaced with a sequence of out-of-context fundamentals in engineering first year. Many curricula require that students spend their first year showing that they have the "personal and intellectual discipline purportedly required to 'cut it' in engineering" [9]. The traditional curriculum appeals to sequential learners, and asks those motivated by social conscience to complete their introductory years on faith that by the end, they will see the impact of engineering on the world around them. In addition to motivating and engaging students, the first year must enable the transition from high school. While many skills are assumed to have been learned in high school, e.g., spreadsheet use, units, significant figures; this assumption is risky given the breadth of high school experiences of our incoming class.

Many programs are moving towards social responsibility education in first year, including ethics and societal impact. Ethics education has been correlated with increased measures of social responsibility, and greater student ranking of the importance of ethics relative to fundamental technical skills [7]. The case studies allow reflection on and discussion of ethics, economics, stakeholders, and impact of engineering projects; while providing a richer context for learning engineering math and science fundamentals. The term "case study" as used in this paper refers to an exercise that contains elements of "inquiry-based learning", "guided discovery learning", "problem-based learning", and "case-based learning" [5]. Our case studies at this point do not have the historical, decision-making, "how others dealt with the problem" aspects of case studies as in [10,11]; however, they do inform students about what to expect in an engineering career, introduce the disciplines, build analytical skills, and offer contextual information.

Case Studies: Development Methodology, Description, and Student Perceptions

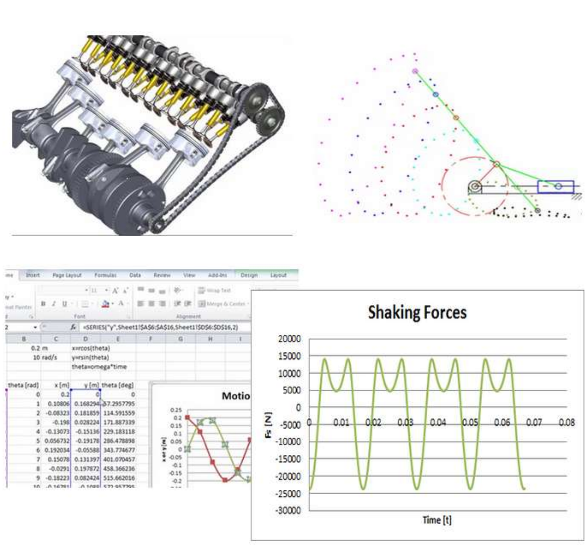
First-generation case studies were developed by full-time faculty, sessional instructors, and co-op interns. With the arrival of a First-Year Engagement Coordinator, a formal structure governed the hiring and deployment of co-op students for case study development [12]. Based on our experiences, we recommend that case study development proceed as follows:

1. Set top-level goals for case studies at the Core (or equivalent) department level.
2. Engage junior co-op student "engagement partners" in the search for topics and literature. Such students match the target audience in terms of maturity and technical ability.
3. Canvass faculty members for department-specific topics, while seeking interdisciplinary connections.
4. Connect engagement partners with faculty experts for first-draft technical vetting.
5. Focus group the first official draft by having
    a. Core faculty work through it, ensuring connection with desired course outcomes.
    b. Engagement partners' peers complete it, assessing time and difficulty.
6. Pilot within the course, with reflection and continuous improvement enabled by student feedback.

The four current case studies will now be described.

Mechanical: Students consider shaking forces in engines or compressors, and how engineers try to minimize them. For a slider-crank with varying connecting rod lengths, students plot piston motion and shaking forces versus time. Spreadsheets are used to perform numerical differentiation, manipulate and graph data, and interpret the results. A non-obvious revelation to the students is the presence of "second-order" vibrations at a frequency equal to twice the engine speed (Figure 1), which can lead to discussion about possible balancing methods and customer perceptions of quality. This case study appeals to students motivated by the details of traditional mechanical engineering, and emphasizes an introduction to spreadsheet use and applications of their introductory calculus course in a relatively closed-ended way.

Renewable Energy: This case study considers how engineers use data to make decisions about the orientation of solar-power collectors, and the selection of appropriate designs of solar panels for a given location and climate. Students download, sort and manipulate insolation data from Natural Resources Canada's website and use that data to calculate and graph energy, power and efficiency; for two different panel types at five different orientations. Students use the graphs they create to make recommendations for the orientation angle and type of technology most appropriate for use in Newfoundland, Canada. Figure 2 contains an excerpt from the problem statement and a student-generated energy savings curve. This case study reinforces use of units, defines efficiency, and introduces the finding, referencing, and manipulation of publicly-available data to support an engineering analysis and decision. The potential costs and benefits of solar implementation are revealed, showing the engineers' role in managing practical constraints when assessing popular green technologies.



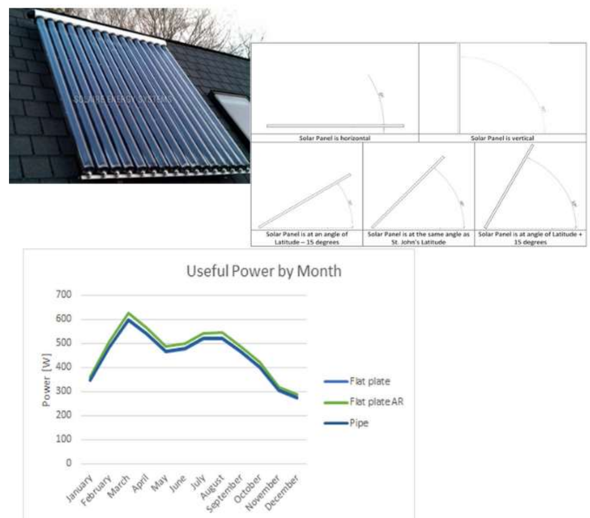


Figure 1 – Engine Shaking Force Case Study   Figure 2 – Solar Panel Case Study

Civil: Students learn how civil engineers use topographical maps to balance required cut-and-fill operations and make decisions about route-selection in highway design (Figure 3). Students create a mass diagram consisting of a cumulative plot of cuts and fills for a proposed road in Conception Bay South, Newfoundland. They use the resulting graph to optimize the balance of cuts and fills and to determine average haul distances. Students then make recommendations about route selection and offer commentary on factors that influence how civil engineers choose where roads are constructed.

Process: In a process engineering-based case study, students participate in processing raw materials into a finished product and consider the choices that process engineers make to enhance production operations. Students roast Guatemalan and Costa Rican coffee beans, grind the beans and sieve the grinds to determine particle sizes. Three different brewing methods are used, from which properties including caramelization, pH and total dissolved solids are measured (Figure 4). Students draw conclusions about how raw materials and production techniques impact the final product, and consider how subjective measurements like taste impact production decisions. This case study requires higher-level student decision making, as students have to choose on their own the most meaningful data to present in order to support their conclusions. Students read a journal paper prior to the exercise, and consult a web site for background information. The collective class data is used in lieu of instructor-supplied data, with transcription errors left uncorrected to test students' ability to troubleshoot and assess reasonableness. It was in this case study that students showed the greatest discomfort with the level of ambiguity in the possible answers and data analysis approaches. Intentionally pushing students beyond their comfort level in this way was motivated by exit interviews of senior students in which they expressed a desire for earlier exposure to the uncertainty of real engineering problems.

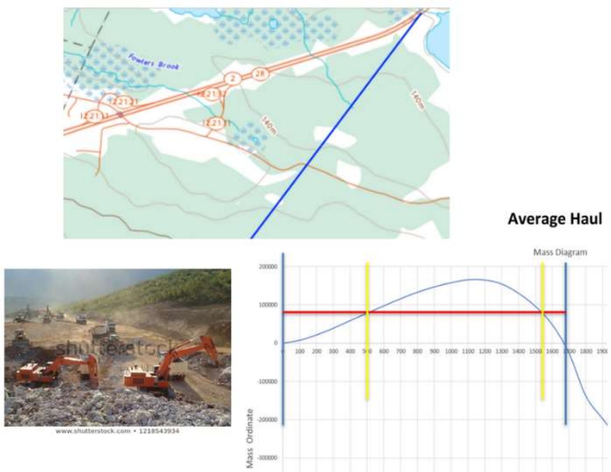


Figure 3 – Highway Design Case Study

Figure 4 – Coffee Processing Case Study

Instructional team support is delivered in several ways. Some students prefer to learn software tools in a face-to-face, small group setting. Students have optional scheduled sessions with the instructor and TAs present, to which they bring their laptops and work through the case studies. Some students prefer online support, and videos were created to teach spreadsheets and graphing tools while placing the case studies in a wider context. Students can avail of the online help during the tutorial session, or outside of class time.

A survey consisting of thirteen 5-point Likert scale questions was developed and administered using the Brightspace® survey tool. 65 students out of a possible 214 responded, for a 31.3% response rate. Highlights are presented in Table 1.

Discussion and Conclusions

In addition to the formal survey feedback, the instructional team has received informal feedback that is guiding evolution of the case studies. Early versions contained an excessive number of steps, and "micro-managed" the students through the process. As a result, students would work through a sequence of tasks and abruptly end when the last step was completed. More open-endedness was needed, the big picture outcomes for students were not as strong as desired, and the loop was not adequately closed via reflection. The case studies are moving towards more decision-making, and we are working to maximize reflection on possible opposing viewpoints and complexities inherent to engineering problems that affect society. The quality of the reflection, discussion, and connection to the profession is improving now that full-time, committed faculty with industrial experience and demonstrated interest in pedagogy form the instructional team.

Table 1 – Highlights of Survey of Student Perceptions of Case Studies

Already knew what type of engineering they wanted to study	58%	Case studies affected / reaffirmed choice of discipline	42%
Positively impacted by case studies re: interest in practicing engineering	31%	Case studies and TLE lectures helped them to better understand what engineering is	32%
Case studies helped them to learn how to use engineering tools like spreadsheets	81%	Case studies helped them to learn how to effectively communicate data	77%
Real-world engineering problems do not have one, indisputable "right" answer	90%	Ability to collect, interpret and communicate data is an important skill for engineers	97%
Case studies helped to better understand how engineers turn real-world problems into equations and numbers for analysis	79%	Increased awareness of the engineering importance of estimating, assessing reasonableness, and making judgements	63%
Being able to think like an engineer requires a strong foundation in professional ethics	73%	Disagreed that "if you are not extremely good at Math and Science, then you can't be a good engineer."	39%

A point of contention among colleagues who oppose the creation and expansion of the TLE course is that the material is delivered at the expense of technical fundamentals, thereby "watering down" the program. The authors believe that engineering education faces a challenge akin to that of law schools, stated eloquently by Grasso [13]:

> *"Legal educators faced the impossible task of teaching technical legal details of thousands of individual laws created during the 19th century and so moved their educational program to a fundamentals-based paradigm instructing students to learn how to "think like lawyers." Similarly, the engineering profession should not stand in the way of its own growth with an argument that it must teach more and more technology."*

To summarize, a case study-driven half-course currently entitled "Thinking Like an Engineer" has been developed to contextualize acquisition of knowledge of software tools, core technical skills, the different disciplines, and the profession. Future students will be able to select case studies related to disciplines that are of interest to them, or from disciplines about which they would like to know more. The lecture experience of TLE has introduced and motivated the ethics with which engineers must practice; however, weaving ethical discussions into the Case Studies is a work in progress. While the case study context varies, the outcomes remain consistent. Students learn to use engineering tools to create, manipulate, analyze and present data; visually communicate technical concepts, and make engineering judgements and recommendations. Students create a technical report where they are formally assessed on their competence in discussing and interpreting equations, calculations and data. Survey results indicate positive outcomes in students' awareness of the profession, skills required of an engineer, different disciplines, ethics, use of computer tools, core technical skills, and what real engineering problem look like. It is hoped that giving students a holistic view of engineering in their first year, while helping them acquire the "habits of mind" [3] of professional practitioners, will provide them with a foundation for approaching the remaining curriculum with motivation and increased capacity to connect course material with their life experiences and aspirations.

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