Enhancing student engagement and connecting theory to practice in materials engineering: bridging experiential learning opportunities through a virtual "classroom" for first-year learners

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EXTENDED ABSTRACT

Title: Enhancing student engagement and connecting theory to practice in materials engineering: bridging experiential learning opportunities through a virtual “classroom” for first-year learners

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Abstract

This paper describes a multi-disciplinary, project-based engineering course (ENG 1P13) that is part of the first-year engineering program at McMaster University. This paper focuses specifically on the materials science and engineering (MSE) aspect of the course. First year students are exposed to MSE content through a series of realistic projects with supporting lab and lecture content. The course content has been adapted for online delivery during the pandemic. Insight into the effectiveness of teaching materials science within a multi-disciplinary project environment and best practices for remote learning will be highlighted.
1. Introduction

Modern tools and technologies that facilitate remote learning provide educators with exciting opportunities to transform traditional lecture-based education to be more engaging and experiential [1-3]. The traditional approach relies on a lesson sequence of lectures where the emphasis is placed on the delivery of the content and not on how the students learn this knowledge [4]. Unfortunately, this approach does not promote student engagement, putting learners in the mindset that lectures are simply a means of acquiring information to pass a final exam. This defeats the ultimate purpose of engineering education: connecting scientific theory to engineering practice while solving real-world problems. A more hands-on and experiential approach will increase student engagement and give students the confidence to tackle complex, open-ended, and multidisciplinary engineering challenges [1-5].

This year, McMaster University faced two concurrent challenges, which also served as an opportunity to reimagine the classroom:

1) Designing a curriculum for a first-year engineering design course (ENG 1P13) with a new focus on a project-based multidisciplinary approach to learning, for a cohort with a class size of ~1200 students. How can we encourage student engagement and student connection of theory to practice in lectures with such a large class size?

2) At the same time, the global pandemic forced a rapid transition to an online delivery mode of the content. How can we ensure students benefit from an interactive and collaborative learning experience, while dealing with screen fatigue and distractions from social media and other technology?

Although the global pandemic made the transition towards remote learning unavoidable, it is worth noting that leaders in engineering education had already been shifting towards a blend of in-person and online teaching components, to provide interactive, hands-on, multidisciplinary, and problem-based learning in a cost-effective, easily scalable, and personalized manner that prepares students for their future careers in an increasingly digital era [6].

Inspired by this innovative approach, we propose to develop a set of interactive online materials science lectures to promote student engagement and experiential learning. This extended abstract will discuss four ways in which we have reimagined the classroom: i) design projects, ii) science laboratories, iii) online lectures, iv) engagement outside of the classroom. The focus will be on the materials science aspects of the first-year engineering course.

2. Experiential Learning Through Multidisciplinary Cornerstone Design Projects

Engineers solve real-world problems (not exam questions)! Consequently, regardless of the engineering topic being taught, the teaching objectives should always align with real-world scenarios and prioritize creative thinking and teamwork, to encourage students to envision how they would solve problems as an engineer, i.e. experiential learning or situated learning [7, 8].

Although first-year engineering students may not have sufficient technical background to fully understand a specific industrial problem, they can be provided with enough context and background information to effectively analyze an engineering scenario. This is particularly effective if the scenario involves well-known problems that are discussed in society at large so that students have some familiarity with the topic. For example, the list of global development
challenges identified by the United Nations is an excellent starting point for designing engineering projects [4]. As a result, the authors and other co-instructors have developed four cornerstone projects which are rooted in challenges involving healthcare, community, waste management, and sustainability:

**Project 1:** Materials selection and design of a wind turbine blade for sustainable energy

**Project 2:** Mechanical design of a biomedical sanitizing box

**Project 3:** Mechatronic design of a recycling robot

**Project 4:** An open-ended design project to improve the standard of living for a given client within the local community.

This extended abstract will highlight Project 1 as an example. In this project, the prime teaching objectives were to introduce learners to the design philosophy including concepts from design thinking such as function, constraints, and objectives. The course did not simply outline the steps of the materials selection process and define what constitutes function, constraints, and objectives. Instead, a project was designed such that learners could envision themselves as future engineers working in a team designing a turbine blade for one of four distinct windmill energy applications. The project guided them through the steps of the materials selection process and provided tangible examples of how function, constraints, and objectives can be determined in a particular scenario. Since four distinct engineering scenarios were developed, different groups of students had different design objectives (e.g., efficient, lightweight, low cost, compactness/size, or using sustainable materials) and this led to a variety of different materials being selected for the design by the different student groups (Fig. A1 in Appendix). This approach also allowed students to exercise their creativity by answering open-ended questions, which increased the level of student engagement and made the educational experience more meaningful.

All four cornerstone projects are currently implemented using virtual design tools to accommodate an online environment. For instance, in Project 1, students learned to use virtual engineering design tools such as ANSYS-Granta EduPack (Fig. A2 in Appendix) as well as Adobe Inventor, which allowed them to work together to create conceptual engineering designs from any location in the world. Design studios were run on MS team channels where Teaching Assistants (TAs; typically graduate students) and Instructional Assistant Interns (IAIs; full-time undergraduate co-op students) served as helpers to guide the students in their learning. With ~1200 students enrolled in the course, even when split into 3 sections for the lectures, the ratio of instructor to students is 1:400 over 3 hours a week. In contrast, the design studio and labs offer a ratio of TA/IAI to students of 1:12 over 2-3 hours a week. This provides students with ample contact hours to ask questions, receive personalized feedback, and benefit from the mentoring of the TAs/IAIs. Having a strong team of teaching assistants is crucial to facilitate this kind of student-centered active learning [9]. It is important to highlight a novel aspect of this course. Whereas in a more traditional approach, the lecture content is seen as the core of the course and the associated labs and projects support this lecture content, the new first-year engineering course at McMaster University prioritizes project-based learning. The core of the course focuses on students “learning by doing”, exercising their creativity, and working collaboratively on their projects, with the lectures and labs specifically designed to support the projects and teach foundational concepts that the students can easily connect to the real-world applications they are exploring in their projects.
3. Materials Science Laboratories – Physical Demonstrations of Scientific Principles During the COVID-19 Global Pandemic Lockdown

For this project-based learning course, students obtained scientific knowledge and practical guidance for their design projects through a series of laboratory activities. To help learners better understand how the design philosophy of materials science integrates with the specific challenges they were facing in their design projects, a set of eight materials science laboratories was developed. The main goal of these laboratory activities was to engage students in learning about the learning objectives (materials selection and structure-properties relationships) that were initially delivered in lecture format, with the laboratory activities providing an environment in which experiential learning could take place. The interactive and hands-on nature of the laboratories helped reinforce the lecture contents and connect them to real-world engineering applications. Similar to several previous studies [9-14], the experiential learning environment was introduced by a set of physical demonstrations. A unique challenge for these laboratories was to virtualize the physical demonstrations to accommodate learners all around the world (due to the pandemic lockdown, but also as part of a shift towards a distance-learning context in the future [15]). To do so, three sets of activities were developed (see Fig.1).

![Diagram of lab activities](image)

**Fig. 1 Conceptual breakdown of the lab activities**

First, three of the eight labs were associated with the teaching objectives of materials selection, in which learners were using the virtual design tool ANSYS-Granta EduPack to work on several small-scale design problems focusing on: i) mechanical structures, ii) biomedical materials and devices, iii) and life cycle analysis (all of which align with the teaching objectives of Projects 1, 2 and 3, respectively). The remaining five labs were associated with the teaching objectives of scientific principles in engineering designs.

Two methods were used to deliver the teaching objectives: i) physical science demos in a virtual environment, and ii) virtual science emulators. For these labs, a set of new physical demos (e.g. Fig. A3 in Appendix) were designed by modifying demos from existing literature [11-14] and inspired by modern popular science video channels [16-21]. These demos needed to be designed to be complex enough to effectively demonstrate the scientific principle being taught, while also being simple enough so that TAs can assemble them live during the labs (via MS team meetings) to give students the experience of an in-class demo. The goal of these demos is not only to demonstrate the scientific principles of a device but also to demystify this principle by building the setup in front of the students in real-time (e.g. Fig. A2 in Appendix).
Another challenge of these science labs is to introduce hands-on experience to the students during the COVID-19 lockdown. To achieve this, we have utilized several science emulators from Wolfram Demonstrations Project [22] and have developed 2 new science emulators of our own. For instance, in one mechanical lab, students used an emulator that demonstrated an iterative process of cold rolling and tensile testing to design an aluminum sheet (see Fig. A3 in the Appendix). In the emulator, each time-step as the tensile test is being performed is illustrated with realistic animations, the aluminum specimen image on screen is updated, and a portion of the stress-strain curve is drawn.

Thus, learners can experience the operation of engineering equipment via a virtual experience. After the labs, learners were asked to use these science emulators to solve experiential learning questions that build an understanding of the operation of the devices and the concepts behind these engineering setups.

4. Gamified Lectures and Storytelling in Online Lectures

The goal of a lecture in an experiential learning course is to introduce students to the necessary engineering and scientific concepts that they need to complete their design projects. To ensure that students remain engaged with the material, we developed a set of interactive lectures that are either gamified or presented in a storytelling format. 

**Gamified Lectures:** The instructor performed a set of in-class physical demos in the form of an educational game played with the learners (e.g. Fig. A4 in Appendix). These physical demos serve as illustrations of the scientific principles and help to visually reinforce the students’ memories. These demos have been a highlight of the students' learning experience this year, according to the class evaluation (see Section 6).

**Storytelling in the Classroom:** Some lectures were framed in a storytelling manner, to enhance student engagement and allow students to appreciate how a given topic has been historically significant in engineering (e.g. a forensic investigation of the sinking of the Titanic; see Fig. A5 in Appendix). People tend to remember stories better than facts, so this approach helps students to build their understanding naturally, instead of relying on pure memorization.

5. Science Engagement Outside of the Classroom – The Power of Social Media

Project-based learning requires learners to engage in self-directed learning on their own when working on the design project. To accommodate this, traditional lecture-style contact hours would naturally be reduced. Education need not stop once students leave the classroom. The current generation of learners tends to obtain information from social media. We are taking advantage of social media by creating novel science-related posts every few weeks, to encourage learners to engage with the subject and conduct further research about various scientific concepts that are related to the course content but are outside the syllabus. The goal of these social media posts is to make students excited about learning and guide their self-directed studies in materials science (see Instagram posts in Fig. A6). It is also worth mentioning that some learners have privately mentioned to the instructor that they appreciate the additional content, which provides a personal touch and demonstrates a sense of caring for the students during the global pandemic.
6. Student Evaluations and Teaching Reflections

In general, the design projects, materials science labs, and materials science lectures were all very well-received by the learners. Students’ evaluations were performed using both anonymous student surveys and focus group interviews hosted by class representatives (without instructor involvement). The appendix below shows some selected excerpts of the student evaluations that are relevant to the materials science part of this multidisciplinary course (see Fig. A7). It is worth noting that the science emulators and in-class live demonstrations were a highlight of the students’ experience in this course, and that the students appreciated the help provided by TAs/IAIs and Professors as part of the project-based learning approach. The overall rating of the entire course can be seen in Fig. 2.

The authors are pleased with the positive results of this new course, which was launched during the especially difficult circumstances of the global pandemic. For future years, the authors are focused on improving the alignment of the materials science lectures and labs with the contents of Projects 2, 3, and 4. It will be important to showcase the value of materials science in a variety of engineering applications.

![48% rated between “8-10” for this question](Chart)

Fig. 2 Rating of the entire course

7. Conclusion

This work highlights an innovative and transformative approach to first-year engineering education, moving from traditional lecture-style education to project-based and experiential learning strategies in a virtual learning environment. In particular, this work focuses on the following components of the newly-developed first-year engineering course (ENG 1P13) at McMaster University: design projects, science laboratories and emulators, online lectures, and engagement outside of the classroom. The methods described have been successfully implemented within the 2020-2021 academic calendar year. Initial feedback from learners highlights a positive trend in the implementation of these strategies, though future surveying will compare the perceived experiences of learners over longer periods of time, including upper years who experienced face-to-face traditional learning styles in their first year as a benchmark comparison. The initial strategies used in the development of this goal are intended to be applied to McMaster University’s whole engineering curriculum in the future with the aim to introduce more experiential learning and problem-based learning strategies to our program.
References


## Appendix

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<tr>
<td>You have been contracted by a large hydro company to design durable wind turbines that generate large amounts of electric power for the entire city of Kingston, Ontario.</td>
<td>The Guatemalan city of Quetzaltenango is currently off the grid and your volunteer group, Engineers Without Borders (EWB), aims to build a wind turbine that can provide enough energy to power simple electrical devices like LED lights.</td>
<td>Residential homeowners want to take advantage of the strong winds to reduce their electricity bills in Calgary. You have been contracted to design a mini wind turbine that can be easily installed on a residential roof.</td>
<td>Sweden aims to reduce its net emissions of greenhouse gases to zero, by 2045. Working with the Swedish Wind Energy Association (SWEA), you have been contracted to design wind turbines in a new wind farm.</td>
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<td>To fully take advantage of the wind pressures in the area, your turbine blades should minimize inertia to maximize efficiency.</td>
<td>The design must be simple enough so that multiple units can be assembled from widely available materials by local workers. At the same time, the turbines should be long lasting and require little maintenance.</td>
<td>Space considerations must be made since some houses are closely packed and the roof turbine must not collide with neighboring turbines or roofs.</td>
<td>The wind turbines must be clean and sustainable while efficiently providing power to multiple cities.</td>
</tr>
<tr>
<td>Design efficient wind turbines to be built in the nearby Wolfe Island wind farm</td>
<td>Design a simple wind turbine design that is suitable for easy assembly by village locals</td>
<td>Design a suitable wind turbine to be installed on residential housing roofs for homeowners</td>
<td>Design a clean wind turbine to generate large amounts of power</td>
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Fig. A1 The four engineering scenarios in Project 1, the materials selection project
Fig. A2 Examples of “quarantine physical demos” in materials science labs

Fig. A3 Examples of in-house developed science emulators in materials science labs
Fig. A4 An example of in-class games in materials science lectures

Fig. A5 An example of in-class storytelling in materials science lectures
Fig. A6 Examples of science-related social media posts outside of the classroom
Excerpts from focus group interviews:

**Project:** For Project 1, 1P13 was tasked with making groups out of students who had never met and have them feel safe and comfortable in this new environment. The IAIs, TAs, and Professors made this transition very easy and helped students feel welcome. There was a great emphasis on helping students create relationships with their team members. This proved to be extremely beneficial as the majority of students found that the dynamic of their Project 1 groups. Project 1 was the groundwork necessary to introduce the students to the concept of Design Studios and Labs, and for this reason, the instructions for every milestone reason, the instructions for every milestone were very clear, efficient and effective. This helped students navigate through the unchartered territory of 1P13. Through the data collected, there were not many points of improvement brought up for the Project 1 milestones, other than a few minor enhancements.

**Labs:** The materials science labs have had the greatest feedback from the students. The concepts are interesting and not too difficult to grasp, and the software (*Granta Edupack* and especially designed software *science emulator*) are easy to work with and fun to use. Overall, the feedback for materials science labs were almost unanimously positive.

**Lectures:** Students have thoroughly engaged with this extremely unique content that they have been exposed to. The *live demonstrations* have become a *student favorite*, and the *ease of accessibility to office hours* is greatly appreciated.

Fig. A7 Student feedback on the new ENG-1P13 first-year engineering course at McMaster University.