

## **Enhancing student experiential learning opportunities in materials science through the development of online virtual laboratories**

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## **EXTENDED ABSTRACT**

Title: Enhancing student experiential learning opportunities in materials science through the development of online virtual laboratories

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### **Abstract**

This paper summarizes an initiative at the Department of Materials Science and Engineering in McMaster University where the instructors are developing a set of virtual laboratories in order to provide experiential learning opportunities and hands-on experiments to students during the lockdown and social restrictions from the global pandemic (COVID19), as well as for future use in virtual learning situations. For the science emulators implemented thus far in the first-year engineering course at McMaster University, the student feedback has been that they are easy to work with and fun to use; overall, the feedback for materials science laboratories was almost unanimously positive.

## 1. Introduction

Science and engineering laboratory activities provide a highly valuable experiential learning opportunity to students, providing them with an intuitive understanding of abstract scientific concepts [1-2]. They also provide opportunities for exploration and discovery, which align closely with the learning process of the scientists and inventors who have driven innovation over the past two centuries [3]. As a result, laboratory activities are one of the most essential components of an engineering education at the undergraduate level. However, traditional laboratory activities tend to involve the teaching assistants performing demonstrations while the students either passively observe or repeat the tasks performed by the TAs. Due to the ever-increasing enrolment levels at universities [4] and the limited resources, equipment, and lab times, there is unfortunately little opportunity to explore “what if” scenarios and to understand the importance/consequences of certain steps in the procedure.

This year, because of the pandemic, McMaster University faced a major challenge, as well as an opportunity to transform the educational experience for over 1200 first-year students who could not attend lectures, labs and design studios in person. To promote student hands-on experiences online virtual laboratory activities were introduced. Many of these activities would provide effective learning opportunities even after the end of the pandemic and the return to in person instruction.

As universities around the world preparing for the post-COVID-19 environment, it is important to leverage lessons learned from the ‘emergency mode delivery’ of digital tools (such as remote and virtual labs, and simulator-based experiments) during the pandemic are applied in the future to ensure high quality teaching, learning and assessment [5]. Virtual and simulator-based laboratories and experimentation can serve a valuable role in developing practical skills and building familiarity with operating procedures, in a cost-effective manner that supports distance-learning. Leading educational institutions have appreciated the potential of remotely accessible real-world laboratory experiments well before the COVID-19 pandemic [5,6].

In this study, we will present two of the ongoing pedagogical developments for our engineering students regarding virtual materials science laboratories: i) Virtual Reality apps and ii) Scientific Emulators. Note that many educational simulations and science emulators have already been implemented in the general science field at the university level (e.g. PhET sims [7] and Wolfram Demonstrations [8]), but less development has been made in the materials science and engineering discipline. Inspired by these emulators [7-8] as well as the Street View navigation feature in Google Maps, the goal of the current study is to remedy the abovementioned problem via the development of a sequence of online virtual laboratories where students can explore and “learn by doing” (i.e. play around with the capabilities!). At the same time, we hope to develop a set of activities that demystify the operating procedures of some engineering equipment, so that students are better equipped for hands-on day-to-day work in an engineering lab.

This virtual laboratory initiative is divided into three stages (see Fig.1), where each phase has a different teaching objective.

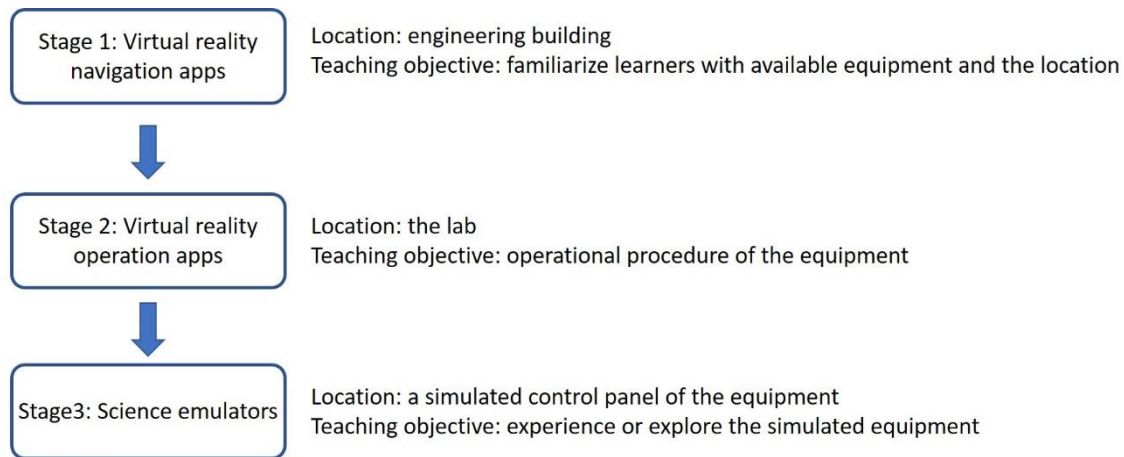


Fig. 1 Conceptual flow chart of the online virtual laboratories experience

For the first-year learners who are currently studying virtually and have never stepped onto the university campus, there are a few factors that can be intimidating and can negatively impact their educational experience. First, they would not be aware of what engineering testing equipment is available (e.g. cold rolling machine, universal tensile machine, optical microscopy, and electron microscopy) and where the equipment is located. Second, they would not be aware of operating procedures of these machines. Finally, they may have less hands-on operating time compared to the experience in traditional labs. Therefore, the teaching objectives of the laboratory activities should focus on addressing these drawbacks of remote learning by familiarizing students with available equipment, operational procedures, and hands-on operating experience to build technical expertise.

As a result, Stages 1 and 2 of this project focus on the development of low-cost **Virtual Reality Apps** that allow learners to navigate the building, locate the equipment, and familiarize themselves with their operating procedures. The user interface will be rather similar to the “street view” function of Google Maps. Stage 3 of this project focuses on the development of a sequence of materials science-related **Scientific Emulators** that are specifically designed to align with the learning objectives and technical content of a specific engineering course. In this collaborative project, different co-authors were responsible for different stages of the virtual laboratory development. The remainder of this extended abstract will provide more technical details and snapshots of the ongoing progress of the i) virtual reality apps and the ii) science emulators.

## 2. Stages 1 & 2: Virtual Reality Apps (Navigation and Operation)

We are currently developing a virtual reality app that will serve as a navigation tool to show where and what kind of engineering equipment is available at McMaster University. This navigation tool provides a sense of scale of the equipment to the learners and thereby demystifies the equipment and helps learners to feel less intimidated for the next two stages of the lab (equipment operation and analysis). Fig. 2 showcases a working prototype of the Stage 1 **navigation tool** (the navigation tool was developed in Java and the GUI will be available in a simple web browser). Embedded in the navigation tool will be tabs with additional information so that learners can obtain general information and introduction to the engineering equipment.



Fig. 2 Screen shots of the virtual reality navigation tool

Once the learner becomes familiar with the general function of the equipment, they are then asked to move to Stage 2: the *operation tool* of the virtual lab, where they will be learning the operating procedure as well as the safety precautions of both the sample preparation process and the standard testing procedure using the machine. Fig. 3 shows some machines that will be virtualized to develop the operation tool (we are currently in the process of filming the scanning electron microscope). The same virtual reality technology as seen above will be employed again, with the focus shifting now to the undergraduate laboratory. Furthermore, a more detailed 3D environment will be provided in front of the control platform (e.g. keyboard control bar) as well as within the machine chamber. Multiple information tabs will be placed clearly in the virtual environment to explain the operating procedure and provide additional information.

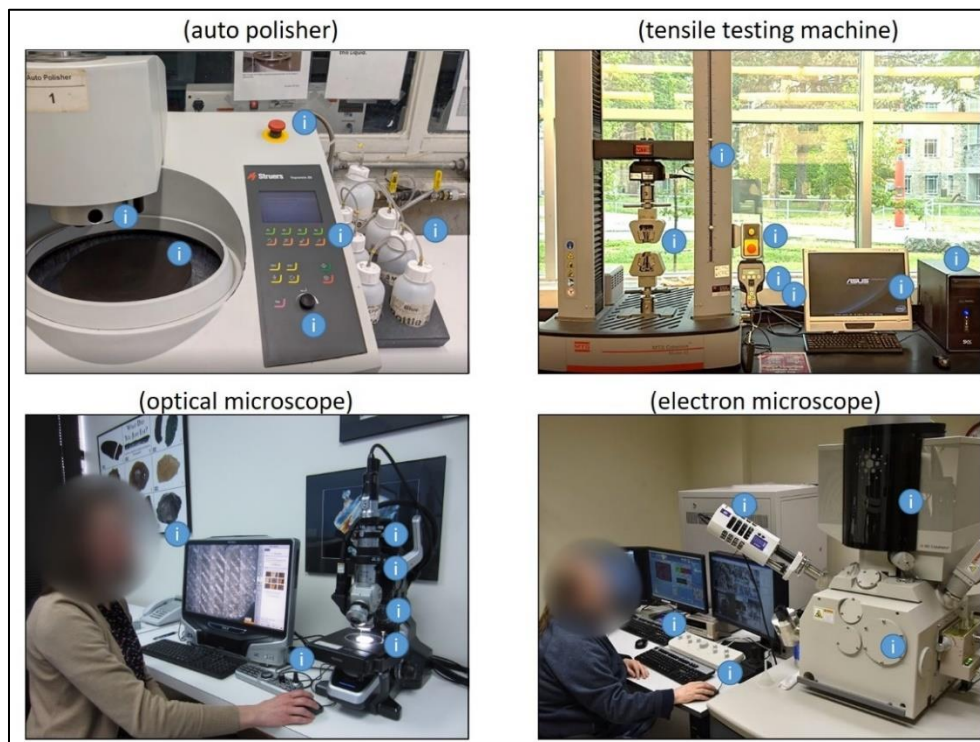


Fig. 3 Conceptual flow chart of the online virtual laboratories experience

### 3. Stage 3: Science Emulators (Analysis)

After the learners have familiarized themselves with the equipment from Stages 1 & 2 of the virtual labs, they will then be asked to operate an interactive educational game using a science emulator for experimental analysis. The emulator allows students to explore different options to solve engineering problems given in the lab manual and thereby gain a solid understanding of the scientific principles involved (learning-by-doing).

Several emulators have been developed concurrently. Currently, four emulators have been developed, and three of them have already been implemented in the course this year. The four developed emulators are shown in Fig. 4. The virtual cold rolling, tensile test, and thermocouple emulators were developed in Python and the built-in Tkinter library to create an interactive GUI. The virtual optical microscope emulator was developed in C# with the .NET framework.

A sample experiential lab question using both the cold rolling and tensile test is shown in Fig. A1 in the Appendix. In this mechanical lab, students were asked to use an iterative process of cold rolling and tensile testing to design an aluminum sheet with specific dimensions (i.e. final thickness) and mechanical properties. To generate realistic animations of the process, for each time-step that the tensile test is being performed, the state of the tensile test is calculated and used to update the aluminum specimen image on screen as well as to draw a portion of the stress-strain curve. This calculation is based on a formula used to simulate a stress-strain curve with variable material property values from the literature.

For the virtual microscope, hundreds of high magnification images were stitched together to create virtual specimens that can be loaded into the digital microscope. The user can then move the microscope to explore the specimen and zoom in on any features of interest.

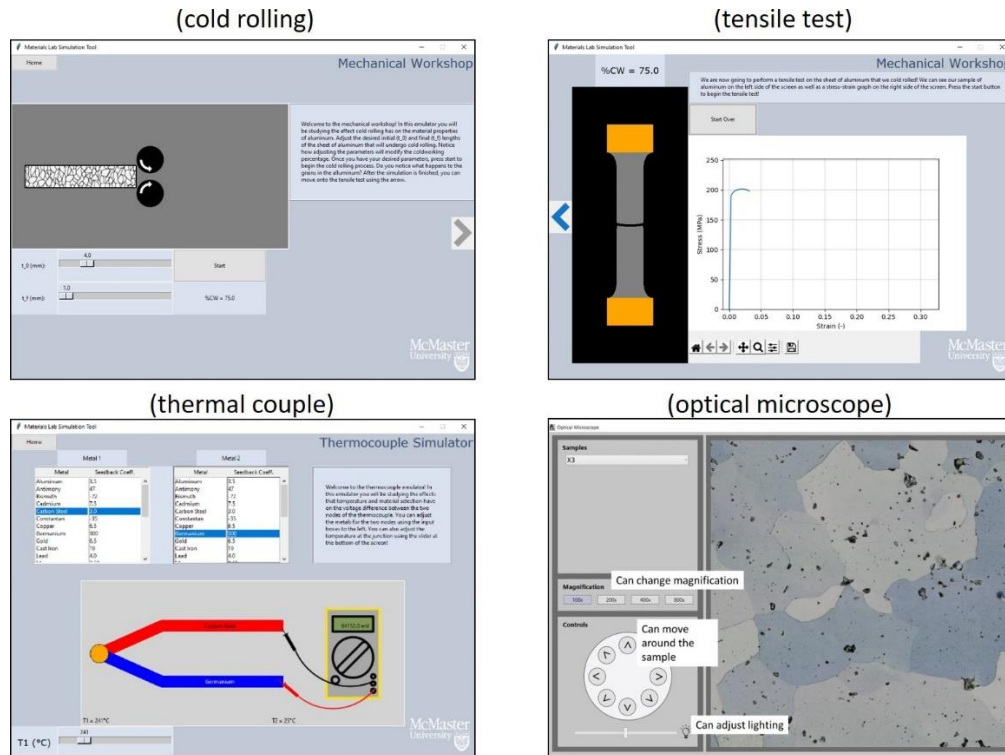


Fig. 4 GUI of the currently developed science emulators at McMaster University

## Conclusion

Our proposed 3-stage virtual online laboratory activities will provide learners with an opportunity to gain direct and interactive experience with these different engineering experimental equipment, offering a more hands-on component to online-only courses or acting as a useful supplement to activities in highly crowded in-person laboratories. For the science emulators implemented thus far in the first-year engineering course at McMaster University, the student feedback has been that they are easy to work with and fun to use; overall, the feedback for materials science laboratories was almost unanimously positive.

We believe that the development of virtual science laboratories will benefit students even after the pandemic. In the future, student evaluations on the effectiveness of these virtual laboratory activities will be conducted to provide insightful feedback to ensure that the experience of using these virtual devices aligns with the teaching objective for the course.

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## Appendix

### Experiential Learning Questions

[Hint: please use virtual tensile testing emulator and work on the following question together as a group]

**Question 4a:** Imagine you are a team of engineers working in an aluminum foil manufacturing company. Your company has previously developed various types of aluminum foils with different processing routes, foil thickness, and mechanical properties for various applications such as floor panels and beverage containers. A new potential client, KF Aerospace, has recently announced a \$30-million expansion of its facility for airplane repair and restoration at Hamilton International Airport. They have reached out to your supervisor and would like your company to design a new aluminum air foil for an airplane wing (see Fig. 7) out of annealed AA3015 alloy plate with the following design requirements: yield strength  $\sigma_y > 180$  MPa, final thickness of the aluminum plate = 3 mm and elongation to fracture should  $\epsilon_f > 3.5\%$  (i.e. the strain at the final point of failure) – otherwise, the material would be too brittle for future repairs.

Your supervisor has given you permission to take advantage of the existing (virtual) cold rolling mill and tensile testing facility to develop this new material. Please propose an original aluminum plate thickness that your company should purchase before the cold rolling process, as well as the percent of cold working required.

[Hint: yield strength is the stress after the elastic region, not the ultimate tensile strength]

**[For this question, please take proportional limit as  $\sigma_y$ , instead of 0.2% off set stress]**

- A) original thickness = 3 mm with 0% percent cold work
- B) original thickness = 5 mm with 40% percent cold work
- C) original thickness = 6 mm with 50% percent cold work
- D) original thickness = 9 mm with 66.7% percent cold work
- E) original thickness = 12 mm with 75% percent cold work
- F) original thickness = 15 mm with 80% percent cold work

**Question 4b:** Export the tensile curve of your chosen processed material. Which of the following describe your coldworked material the closest?

[Note: it is difficult to get the exact values, so choose whichever is closest]

- A)  $E = 70$  GPa,  $\sigma_{UTS} = 175$  MPa
- B)  $E = 200$  GPa,  $\sigma_{UTS} = 175$  MPa
- C)  $E = 70$  GPa,  $\sigma_{UTS} = 200$  MPa
- D)  $E = 200$  GPa,  $\sigma_{UTS} = 200$  MPa

Fig. A1 Sample experiential learning question related to the use of virtual cold rolling and tensile test emulators.