BUILDING ENGINEERING FUNDAMENTALS IN AN ACTIVE LEARNING ENVIRONMENT

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Abstract – *Schulich has undergone a dramatic transformation of its first-year engineering cohort from a traditional delivery method to a flipped classroom. That is, course material is delivered online and class time is effectively used for active learning sessions. However, the majority of legacy first-year course content needs adaptation to fit this model, which aims at maximizing student learning and creativity. Active learning engages students and promotes analytical problem solving, critical thinking, and develops an understanding geared towards the application of the material. The necessary scaffolding to achieve this mission is a large undertaking but the added value for students is immense. We provide evidence that supports our goals and describe and reflect on seven practices implemented by our teaching team to over 500 students in 6 sections including one remote block. Active learning represents huge shifts for both instructors and students. This study aims to provide insight to those who are exploring a transition towards an active learning approach that utilizes instructor teaching teams, and more individualized support for students' learning.*

Keywords: Active Learning, Flipped Classroom, Teaching Team, Engineering Education, Equitable Teaching, Learning Tools.

1. INTRODUCTION

For decades, first-year engineering courses have been delivered using traditional methods where instructors introduce the material directly to the students, requiring them to consolidate that knowledge later [1]. The flipped classroom concept [2] aims at pre-class preparation to maximize class time for active learning activities [3]. Active learning (AL) represents Significant shifts for both instructors and students. Students need to be more responsible of their learning, take initiative, be proactive, and develop skills to work in teams. Instructors need to be agile in adapting to the students' needs during the course's transformation: iterating session-to-session on what works and what doesn't is critical.

AL methods are advantageous to students [4] in that they allow them to (a) reflect and express what they have learned, (b) communicate with their classmates on meaningful discussions to strengthen their learning, (c) improve their understanding of course material, (d) develop problem solving and analytical skills, (e) increase their motivation and overall engagement in the course and with the instructor, and (f) perform better on assessment components of the course [5, 6].

The Schulich School of Engineering transformed all its first-year engineering courses to a flipped classroom. That is, students are provided with lecture material before attending class for their first point of interaction to explore and engage with the new content. They are given the opportunity to complete weekly quizzes to solidify their understanding and use class time on active learning worksheets to solve in groups within assigned learning communities. Additionally, they are presented with demos and learning artifacts to support them visualize and further consolidate their understanding. The new organizational structure of the course is summarized in Fig. 1.

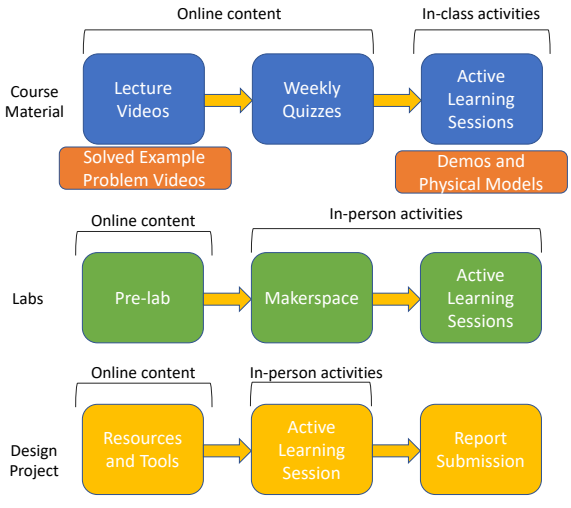


Fig. 1: New "flipped" organizational structure of first year engineering courses.

Cognizant of the importance of available infrastructure, AL session design, demonstrations and tools, and the interplay of technology, our teaching team are sharing their strategies, challenges, and outcomes from this process. The teaching team of 4 instructors consisting of an experienced faculty member, a new faculty member, a post-doctoral associate, and a research associate were tasked to co-create the course content and active learning material and adapt this long-developed content to align with the flipped classroom transition maximizing the student learning experience and creativity. This was an opportunity for all to learn and develop teaching skills from one another and collaborate effectively to make this drastic transition.

During the Fall term of 2021, the new format of AL was introduced. Feedbacks from the instructing team were documented on a weekly basis, while the students' feedbacks were solicited from the First Year Representatives on a biweekly basis. Unfortunately, due to the confidentiality, only qualitative and generalize statements could be given in this paper.

Based on our practices and experiences, we have categorized the implemented changes into seven pedagogical practices:
1. Dividing course-content development based on expertise and technical backgrounds.
2. Ensuring consistency and equitable experience for all students in different sections.
3.Promoting collaboration, teamwork, and peer mentoring.
4. Recruiting and training senior undergraduate students along with teaching assistants to achieve one-on-one interactions with students and delivering meaningful input and feedback.
5. Creating learning artifacts to help students visualize complex concepts.
6. Transforming traditional labs into makerspace student experiences and course-based undergraduate research experience (CURE) projects; relating course content and theory to real life applications.
7. Accounting for virtual students in teaching effectiveness and inclusivity.

This study provides insights to those exploring a transition towards an active learning approach that utilizes instructor teaching team.

2. EXPLORATION OF TEACHING PRACTICES

In this section, the specific methods that were employed to achieve our seven pedagogical practices are described and were selected based on existing best practices and prior experience [7]. The benefits as perceived by the instructors are then discussed. Finally, the limitations of our methods are examined, and recommendations are made.

2.1. Division of Course Content Creation Based on Instructor Expertise

2.1.1. Methods. Creation of course content was assigned to instructors based on individual expertise. By course content, we mean the creation of lecture videos, the writing of active learning worksheets, the building of classroom demos, etc. The course had one scheduled active learning session per week. This means the material for twelve active learning sessions needed to be developed. The course coordinator was responsible for creating all the lecture videos. Each of the other instructors was responsible for developing the material for four active learning sessions. All instructors delivered all course content to their respective lecture sections. This allowed for instructors to utilize their strong understanding to create robust and engaging material for students. Specifically, the instructor whose background was in fluid mechanics created tutorials and demonstrations for sessions whose focus was on fluid flow, whereas the other instructors with backgrounds in chemical engineering created content and demonstrations on phase equilibria, equations of state for gas systems, solid lattices, and heat conduction.

2.1.2. Benefits. This division of labour ultimately resulted in improved tutorial material for students. Traditionally, the quality of material delivery directly correlated with an instructor's background, while sections of the course less in line with the instructor's background suffered. By dividing tutorials based on expertise, instructors were able to lean on the specialized understandings of their fellow instructors when delivering content out of step with their background. This division of labour allowed for expert instructors to recommend pedagogical approaches that were both clear and engaging for students, given an instructor's nuanced and well-rounded understanding of said material. For example, based on the recommendations of the fluid-mechanics instructor, the delivery of the Bernoulli equation expanded from a simple presentation of the equation to an exploration of its implications in several simple but thought-provoking experiments. Similarly, the in-tutorial discussion of laminar and turbulent flow was improved through several flow visualizations recommended by the fluid-mechanics instructor. Live demonstrations also benefited, since specialized instructors could quickly recommend, and design demonstrations based on their experience.

2.1.3. Recommendations. Although multi-disciplinary courses such as this one benefit from the strategic division of labour based on the expertise of each instructor, it is also important to ensure that instructors do not recommend material beyond the course's scope. It is unavoidable that the enthusiastic instructors will be inherently biased towards their own backgrounds and will want to share as much as possible with the students. However, it is

important that instructors are reminded of the key learning objectives of the course and that material remains focused on those objectives. This is where a coordinating instructor is important: the coordinating instructor can review tutorial material created by the instructing team and ensure that it remains focused on the course's learning objectives, extracting any superfluous content and recentering a tutorial's focus. In this course, the coordinating instructor made key recommendations to the tutorial focused on pipe flow that removed extraneous material but provided more time to focus on pipe flow problems and reading the Moody chart, both of which are key learning objectives of the course.

2.2. Ensuring Consistency and Equity Across Sections.

2.2.1. Methods. The instruction team wanted to ensure that students received a consistent experience regardless of what tutorial and lab section they were assigned to. This was achieved in various ways. On a weekly basis, students were all given access to the videos of lectures as well as solved problems that were related to topics covered that week. Furthermore, for tutorials, instructors worked through the same worksheet and presented the same slide stack to ensure that consistent content was being relayed to students. Instructors also met at the beginning of each week to discuss strategies for that week's tutorial and lab session to further ensure that students received the same experience across all sections.

To ensure an equitable delivery of the course material for all students, including those online, the instruction team recognized the importance of facilitating different learning styles amongst the students. For that reason, several delivery methods were facilitated by the instruction team: The use of videos allowed students to work individually and at their own pace; tutorials blended instructor-led learning with team-based learning; tutorials also provided various pathways to learning including traditional approaches such as lecturing and solving problems, as well as more contemporary methods including visual aids, videos, games, surveys, and team-based competitions.

2.2.2. Benefits. A major benefit was consistent tutorial attendance across different sections. In other courses with multiple instructors, oftentimes students will sort themselves based on their preferred instructor. This has the dual consequence of both overburdening some instructors, while underutilizing and not developing others. Consistent attendance allowed for all instructors to be equally utilized by the students, while developing all instructors professionally.

2.2.3. Recommendations. The methods employed by the instruction team effectively achieved a consistent delivery of the course content to students across sections. However, further steps could be taken to improve learning equity across students. As structured, the delivery of the course is biased towards a more individualized learning approach, and many students have expressed a desire for more instructor-led experiences. There is a possibility of facilitating this request since there is sufficient classroom time contingency.

Steps could be taken to provide more cultural equity with regards to the delivery of the course. Instructors could highlight contributions made by scientists outside of the west that are typically discussed. The relevancy of class concepts to countries beyond the west, as well as to minority and marginalized groups could also be explored.

2.3. Promoting Collaboration, Teamwork & Mentoring Among Peers: for Students and Instructors

2.3.1. Methods. Peer interactions were seen by the instruction team as an effective additional mode of learning for students beside the instructor or the provided learning materials. As such, these interactions were heavily promoted. A very simple and traditional method was through assigning group work. All assignments in this course, which included three lab write ups, an undergraduate research project, and a final research project, were made into group assignments with the groups for the lab write ups assigned at the beginning of the semester. Furthermore, lab sessions and tutorial sessions were heavily group oriented. Students were required to sit with preassigned groups and were strongly encouraged to exchange contact information and to support each other. Each session began with an ice breaker to foster relationships between students. Several sessions had a competitive aspect where groups were pitted against each other to solve problems and answer questions. For example, one tutorial tasked groups with estimating the minimum height within a tube such that the outlet stream would strike a target within a tank, with the team closest to the correct distance getting to write their team's name on the tank. In another tutorial, groups were tasked with identifying the correct viscosity model for specific fluids, winning prizes for the correct response.

2.3.2. Benefits. The primary benefit to fostering peer interactions was that it helped students construct support networks among their peers. Through their classroom interactions, students quickly built networks of four or five of their other peers whom they could rely on for support. This was evident with regards to this course, where students would ask each other for assistance when faced with material that was unclear to them. This collaboration extended to other courses as well. The game-like aspect of team learning also seemed to foster deeper learning. Students often commented how they thoroughly enjoyed the various competitive activities throughout the course,

and how they felt like they retained and understood the concepts better in these settings.

2.3.3. Recommendations. Although the methods used here did well at facilitating the desired peer interactions, the interactions were atomized and disjointed. If the various competitions were tracked week-to-week and tallied, then this sense of team sport would be more greatly fostered, and the students would be further encouraged to have their team succeed. This sense of true teamwork through a sport-like setting would further encourage collaboration, teamwork and mentoring between peers, as well as drive attendance as students will actively wish to participate in weekly competitions.

2.4. Recruiting and Training of Senior Undergraduate Students and Teaching Assistants

2.4.1. Methods. Traditionally, undergraduate students were not a part of the teaching team. For this year, three undergraduate students were recruited to support the teaching team, consisting of instructors and graduate students. These students have recently completed their third-year program and are from different disciplines. The students were hired through the faculty as full-time interns to support all engineering courses in first year. In this particular course, the instructors encouraged the undergraduate students to review the materials prepared by the instructors and to provide feedback from a student's perspective. Once per week the teaching team met virtually to plan for the upcoming week's teaching activities, including tutorials and labs. During this meeting the format and the teaching content were reviewed, clarified, revised, and improved upon based on the recommendations provided by the entire teaching team. In cases where demonstrations were utilized, additional training time was scheduled to perfect the execution prior to the sessions with the students.

2.4.2. Benefits. The integration of the undergraduate students into the teaching has yielded many positive results. These senior students have recently completed these courses themselves, thus, they generally have a good understanding of the course's concepts. Being closer to the age group of the students themselves, the senior undergraduate students were able to build connections with other students, whereas the students may be intimidated to approach instructors. Additionally, the senior undergraduate students were able to provide the instructors with valuable insights based on their own recent experience of taking the same course. Overall, the teaching team was able to accomplish various objectives with the integration of instructors, teaching assistants, and senior undergraduate students. The instructors have the role of preparing useful material that further clarifies and emphasize important concepts, with the teaching assistants and undergraduate students providing support with demonstrations and assistance with practice problems.

Recommendations. Although there were many successes associated with this integration, further improvements can be achieved. As with any newly developed program, additional timing is required to convey the ideas, training, and perfecting execution. Despite the fact that the content of the tutorials and labs were prepared a few months in advance, the integration of the teaching assistants and the senior undergraduate students did not occur until the beginning of the semester. This has occasionally created the issues of not having sufficient time for training. The size of the teaching team, consisting of instructors, tutorial teaching assistants, laboratory teaching assistances, and interns, also created the same issue due to schedule conflicts.

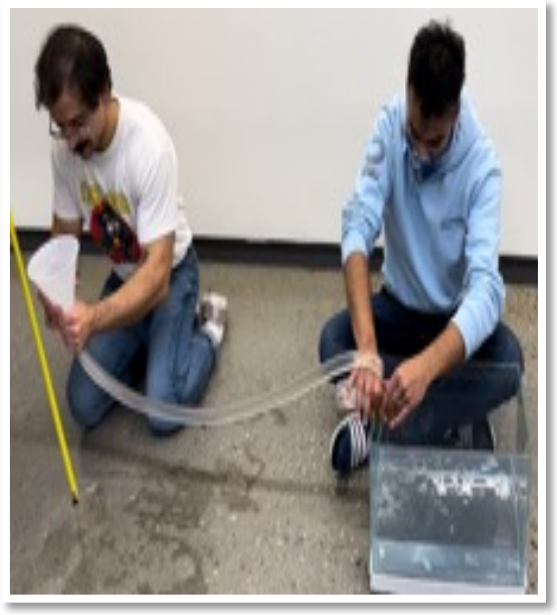


Fig. 2. Senior undergraduate student support with a class demo.

2.5. Creating Classroom Demos and Physical Models to Help Students Visualize Complex Concepts

2.5.1. Methods. To aid with concepts delivery, various teaching tools were employed. This ranged from videos to a variety of physical artifacts. For each specific theme, the artifacts were carefully chosen to convey key concepts. Examples are shown in Fig. 3, for the chapters focusing on the phase behaviour of matter, students were provided with 3-D phase diagrams to help them visualize the relationship between pressure, volume and temperature. When turbulence was introduced to the students, a large oil-water instability tube was prepared to show students how turbulence can initiate in flows without solid boundaries.

For the solid's topics, the students were provided with sphere-connector kits to allow them to explore the solids lattice structures.

2.5.2. Benefits. In general, these creative activities were well received. The students were excited to be able to carefully view the multifaceted nature of the learning artifacts. In some of the demonstrations, students were encouraged to participate with teaching assistants. In other activities, students were involved in competitions with prizes being awarded. The timing of these hands-on activities may also have helped with student reception. Generally, activities alternated between traditional problem-solving focus to learning artifacts and demonstrations.



Fig. 3. Learning artifacts created for AL sessions. (a) A three-dimensionally printed Pressure-Volume-Temperature (PVT) diagram with phase regions denoted. (b) Oil-water flow instability tube demonstrating the onset of turbulence without solid boundaries.

2.5.3. Recommendations. There were challenges experienced with these learning activities. As there were multiple learning sessions for these learning artifacts and demonstrations, storage and logistics quickly became an issue. Wear and tear of the artifacts proved to be an even larger issue. Superior quality materials could have been used to lengthen the lifespan of the learning artifacts. However, time and resources restricted the available options. Another challenge was sanitizing between learning sessions during a pandemic. In retrospect, these challenges are minor and easily amenable.

2.6. Transforming Traditional Labs Into Makerspace Student Experiences and Course-Based Undergraduate Research Experience (CURE) Projects

2.6.1. Methods. The lab component for this course remained the same for decades. It included a scripted manual providing students step-by-step instructions on how to perform the experiments and required them to submit a written report for each lab. Students spent on average 10-15 hours writing the report with many of them plagiarizing "road maps" they inherited from previous students of the course. Scripted labs do not result in deep learning based on students' feedback and even though the design of the experiments was truly exceptional, the learning experience was not. To provide meaningful experiential learning, the labs transitioned into a framework that combines problem-based approaches and active learning. With the shift, students were required to complete prelab work by scheduling a time in the lab room to conduct the experiments and collect data, followed by attending a 3-hour active learning session to use the collected data towards solving an engineering application problem.

The instruction team also implemented a course-based undergraduate research experience (CURE) project to prompt students to use their problem-solving and analytical-thinking skills [8]. Students were given a real-life engineering problem related to some of the challenges facing our world today and were asked to use their course knowledge to solve it with the use of a simulation tool to provide theoretical results. This motivated students to reflect on the simulated results and compare them to reported experimental data identifying the differences.

2.6.2. Benefits. This transition from a scripted experiment followed by an unguided lab writeup to a more supervised engagement with the data is that students were given the opportunity to appreciate both meaning and utility of the data, and its application to real-world problems. Completing the prelab work helped students better understand the concepts before attending at the makerspace to conduct the experiments and collect data. One great path that was beneficial in the execution of the labs was to run with an active learning model instead of a take home assignment. This gave the student groups an opportunity to connect and work together, which promoted collaboration, teamwork, and effective discussions in class. Additionally, student could complete their work while receiving one-on-one support from the instructor and

teaching assistants. Originally, labs writeups represented cumbersome assignments with little benefits that detracted from the students' ability to work in groups due to their conflicting schedules.

Implementing undergraduate research projects in a first-year engineering course has tremendous benefits in developing a student researcher's skill suite, which includes finding course-related information/data, evaluating and reflecting on its source and credibility, managing and organizing data, analyzing the data, and finally communicating the results [8, 9]. This is a skillset that is necessary for all students and can be applied throughout their engineering education and career.

2.6.3. Recommendations. The execution of the prelab was not as effective as could be. There needs to be clear communication on the need and importance to complete the prelab prior to the session. Further, a mechanism should be implemented to check the completion of the prelab before going through this experience.

2.7. Accounting for Virtual Students in Teaching Effectiveness and Inclusivity

2.7.1. Methods. The teaching team wanted to create an effective collaborative environment with diverse students to enrich every group member's experience. A pilot session was designed to form mixed groups of in-person and online students with the hope that it would provide online students access to the campus student ecosystem and get them more involved with students on campus. The instructor team quickly realized this was not possible. Virtual students were instead eager to ask the in-person students questions that were related to their first-year experiences, their courses, campus life, and other topics not necessarily related to the course. This, in turn, distracted in-person groups and did not facilitate teamwork and cooperation with regards to the task at hand.

In response to these challenges, inclusion strategies were developed to accommodate online learning. The instructor team adjusted their approach to boost the students' learning retention through various multimedia material that was created for the virtual block in lieu of the class physical models and demos presented in class. A recap slide deck was also included at the beginning of each AL session to provide support, answer questions, and clarify any confusion students may have experienced when engaging with the content. For the lab component, virtual students utilized the simulation tool to understand concepts and collect data from running the experiments in the lab by their peers for analysis and comparison. Additionally, instructors increased their dialogue with students and ensured consistency between the different sessions.

2.7.2. Benefits. The recent COVID19 pandemic required instructors to offer a rich and consistent delivery of the course despite the lack of in-person interactions. The actions taken by the instructor team facilitated this need.

2.7.3. Recommendations. The virtual block required additional support so that these students can adapt to their unique individual learning styles and reach their full potential. The virtual block was scheduled at the same time of the regular class session which was difficult for the instructor to manage. The instructor was occupied with students online in some instances spending more time with them than the ones in class. TAs and senior undergraduate students supported this process and were very helpful to students. We recommend scheduling online classes at different times than the in-person ones.

3. Conclusions

Active learning strives to have students learn through reflection and expression; peer-to-peer conversation and class dialogue; deeper understanding of material; strengthening their problem solving and analytical skills; richer engagement with the instructor; and more purposeful assessment components. This paper presented an exemplary case study of this teaching methodology in action. Particularly, it described AL teaching as applied to a first-year engineering fundamentals course. Seven actions were taken by the instructor team meant to facilitate this learning methodology. The benefits of the actions taken were outlined in the paper. In general, the actions adopted by the instruction team provided students with a richer understanding of the course content, a more consistent experience between sessions and planted enthusiasm within students that hopefully perseveres throughout their careers. Recommendations were provided throughout the paper as well.

In general, the recommendations were meant to better foster consistency between sections, improve the learning experience and ease logistical challenges when delivering a course to such a large student group. The recommendations are easily implementable and are not seen as a barrier to improving the course's delivery. The instructor team are pleased with the results of their first attempt at AL teaching and look forward to making further improvements to the course.

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