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A large integrated online hardware design course

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Belinda B. Wang received the B. A. Sc. degree (with honors) in 1986 and subsequently the M. Eng. degree in 1990 in Electrical Engineering from the University of Toronto. She joined the Electrical and Computer Engineering Department at the University of Toronto as a Tutor in 1986 teaching/coordinating tutorials and laboratories. She also held the position of Manager, PC network from 1988 to 1991 managing the departmental undergraduate computer networks. She was promoted to Senior Tutor in 1992 and then to the rank of Senior Lecturer in 1999. Since then she has been primarily teaching first and second year undergraduate courses such as digital systems, introductory electronics, electric and magnetic fields, circuit analysis, electrical fundamentals, computer fundamentals and calculus. She also serves as the P. Eng. Czar in the ECE Department since 2007 engaged in the promotion of the Professional Engineer designation amongst faculty members. She was promoted to Associate Professor, Teaching Stream in July 2015. Professor Wang, in collaboration with University of Waterloo has produced a set of new online learning modules that support the teaching of foundational level electromagnetics and circuits in engineering programs. She is actively engaged in activities involving teaching pedagogy, technology and innovation.

A Large Integrated Online Hardware Design Course

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Growing up, we have all experienced the educational system at various levels. In kindergarten, teachers taught us by reading stories to us, drawing colourful pictures on paper, and holding our hands to trace letters. Teaching and learning took place in close physical proximity. In middle school, kids sat around tables and teachers walked from table to table to teach and observe. The teacher's physical presence and personal attention to students were vital parts of the learning environment. In high school, as class sizes grew and teachers spent more time in front of the class than with individuals, students still had plenty of interactions with their teachers in classrooms, hallways, gyms – even outside on the field. For many of us, university education stretched the distance between students and teachers ten-fold compared to high schools. Lessons took place in lecture halls with hundreds or even thousands of students. Professors would lecture from the podium; students would listen to the professor's voice and follow the writing on the board or screen. Yet even in these cases, there was still a tangible physical presence of the professor in the room. Students could ask questions during a lecture and get instant feedback. In early 2020, the COVID-19 pandemic smashed through the traditional educational model that we have known since 1635 – the creation of the first public school in America. The physical distancing requirement erected an unimaginable barrier between the educators and the learners overnight. Educators had to rethink and make huge adjustments to adapt to teaching in a virtual environment. In this paper, I share my personal experience developing an integrated online course from inception to implementation, and reflect on online education for the future.

Mode of Delivery

First and foremost, when building an online course, the mode of delivery needs to be determined – whether to give lectures synchronously or asynchronously. The course coordinator and I chose the asynchronous model for our 2nd year Digital Systems course. The biggest motivating factor was the geographical spread of our cohort across different time zones. Asynchronous lectures allowed all students equal access to the materials, allowing them to consume the content in their own time, at their convenience. A traditional semester course consists of 39 lectures; however, instead of pre-recording 39 hour-long lectures we divided the course into 27 modules. In each module we had an introduction video highlighting the content and its connections with other modules, followed by several short (5-15 minute) videos, each covering a single concept. In total, we made 140 videos for the course. The short video format was effective given the limited attention span of online learners. It also improved the efficiency of our lectures and the clarity of presentation. As professors who are accustomed to giving in-person lectures, we missed seeing our students' facial expressions and body language, which gave us clues about their understanding of the material. Stepping into the shoes of a student, we could imagine the obstacles to learning through videos – there would be no opportunities for immediate clarification or further explanation from the professor when trying to understand the material. We considered those issues carefully when making the lecture videos. We deliberately slowed down the pace by pretending to have a live audience, posing and answering questions, and we ended each video with a summary of the topics covered. We posted lecture notes from the videos and suggested problems for students to solve after watching the videos to help them digest and absorb the content. We linked the interactive discussion board to each study module so that discussions around a concept became extra resources for students to gain a deeper understanding. We ran three office hours weekly to accommodate students in different time zones and to increase interpersonal interaction. To provide further guidance to students who had to juggle five courses, we batch released the study modules and solutions to problems to help set expectations for the pace of learning.

Virtualizing a Practical Laboratory

For a hardware design course, a crucial hurdle to overcome was translating the experience of a hands-on practical laboratory (lab) into an online platform. The labs in the original course required the use of a field programmable-gated array chip (FPGA) on a physical board called the DE1-SoC. Before the pandemic, students learned hardware design by programming the FPGA chip, interacting with their designs using keys and switches on the DE1-SoC board, and observing LED lights, digital displays, and images on VGA monitors in laboratories. Before creating a virtual lab experience, we considered the use of a hardware kit at home by each student. However, the cost of the at-home kit would be over $300 per person, which the university could neither impose on the students nor support. Instead, we virtualized this experience by building a virtual graphical user interface (GUI) to mimic the hands-on experience. Students could see and interact with a virtual image of the LED lights, HEX displays, keys, switches, and VGA display on their computer screen. Many students commented on how satisfying it was for them to see the LEDs light up when they clicked on the switches. To enhance students' practical learning experience, we posted lab preparation videos to guide them through the lab exercises and teaching assistants conducted small group video conferencing sessions to offer individual assistance, as was provided in physical labs in the past. The need to be flexible, adaptable, and mindful of challenges faced by students became ever more important in a virtual learning environment. We responded to students' feedback quickly; when students missed a lab session or two for personal or technical issues, we promptly scheduled extra sessions so that students would not miss valuable learning opportunities. Labs in a design course are vital for students to truly grasp the concepts and gain practical experience.

Assessment

After overcoming the major obstacle of online content delivery, we tackled one of the most contentious issues for online courses – assessment. Many institutions have adopted proctoring software such as Examity and ProctorU. Our faculty however, has strongly discouraged the use of proctoring systems for several key reasons. 1) Proctoring software does not guarantee academic integrity; 2) excessive monitoring increases student stress levels; 3) the hardware setup (e.g., camera and microphone/speaker) introduces equity and accessibility issues for some students with physical challenges and medical conditions; 4) there are economic and technical challenges in setting up all required components for proctoring services. Instead of adopting the proctoring software, we developed a two-stage assessment process that comprised of a timed written test, followed by a short video interview. We believe that the interview served as a strong deterrent for cheating. Out of 342 students, we flagged six as potential cases of academic misconduct after three assessments. At the end of the semester, we achieved a grade distribution (Figure 1) similar to that of last year (Figure 2), demonstrated on the following page.

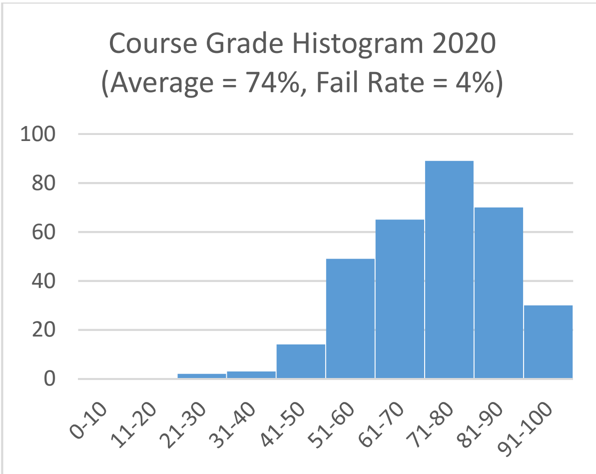

Figure 1 Course grade for 2020

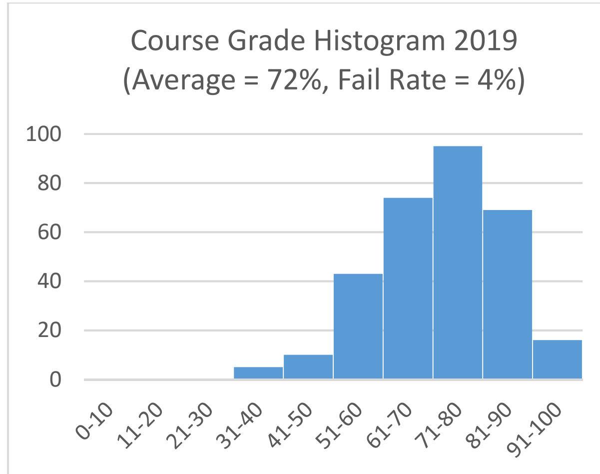

Figure 2 Course grade for 2019

Technical Requirements

We started the planning process for the course in the summer of 2020. The decision to develop more than one hundred lecture videos meant that we needed technical support to implement our plan. We reached out to the faculty's IT team and received strong support that allowed us to effectively create, edit and deliver the content. We created a naming mechanism to organize the videos, notes and suggested problems. By the end of the summer, we built the course shell on the learning management system (Canvas LMS), created the virtual graphical user interface for the lab component, and finished recording more than half of the videos. We received continued IT support during the delivery phase of the course from September through to November as we added more elements to the course shell. One week after the start of the semester, we received feedback from students in Bangladesh that they were having trouble viewing our videos. Our technical support team quickly resolved the issue by uploading the videos to another streaming service. Technical support played an invaluable role in our online course development from inception to delivery, and it is an indispensable part of any virtual educational system.

Conclusion

The pandemic has brought new challenges to traditional educational systems. We answered that challenge by offering this fully integrated online course to a class of 342 students successfully. Our unique integrated approach of combining asynchronous content delivery with synchronous practical experience created a better learning environment for this design-oriented course. The asynchronous lectures offered students flexibility and improved accessibility, while the synchronous practical sessions gave students an effective virtual lab experience and interactions with teaching assistants. Throughout the term, the departmental student-staff committee consisting of the associate chair, faculty members, student counsellors and student representatives met once a month to address student concerns as they had done each year previously. Class representatives from each of 2nd, 3rd and 4th year conveyed the feedback from their respective classes. The 2nd year class appraised our course as the best run second year course and the 4th year representatives named their favourite course of the fall semester. There were 32 total undergraduate courses in the fall semester. Following this news, the chair of the department invited us to speak at the faculty meeting on the theme of "Embracing Online

Teaching”. Our talk had raised interest from a few faculty members who decided to adopt some of our strategies into their courses for the winter semester. Our experience has taught us that early and thorough planning, efficient continuous technical support, and time investment are essential for building effective online courses. Looking ahead, there is a strong shift towards online education at universities and colleges for reasons of accessibility, as well as economies of scale. The post-pandemic landscape for educational systems will be different from the traditional model, and the lessons learned through this experience will give us a great advantage in future higher education.