SIMULATING AN ENGINEERING WORKPLACE: A NEW APPROACH TO PROTOTYPE-BASED TEAM PROJECT

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ABSTRACT

This paper documents the remote management of a first-year foundations of engineering course with special focus on students' learning by completing a prototype-based project in an online course. The COVID-19 pandemic brought on unprecedented challenges to the teaching and learning communities around the world. Educators made purposeful changes in their teaching approaches, shifting rapidly from in-person to online mode of instruction. This study documents a project-based course that adopted an asynchronous mode of instruction as a part of the general engineering curriculum at a large Southeast university in the United States during the pandemic. This asynchronous course – through implementing necessary changes and adaptations – simulated the experience of a cross-border engineering workplace. The course content focuses on engineering design and problem-solving, physical prototyping, simulated data collection and analysis, contemporary software tools, and professional practices and expectations (e.g., communication, teamwork, and ethics). Learning activities are designed to introduce students to the types of work that engineers do daily and to challenge students' knowledge and abilities as they explore the different elements of engineering by completing an aesthetic wind turbine project.

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Our paper reports on the development of the course site as informed by recent national developments in scholarship and practice for online teaching and learning. The principles of course design alignment as well as instructor presence and learner interaction as suggested by these national standards are discussed. Further, the study records strategies adapted to enable students to complete a successful prototype-based project working in geographically distributed and virtual, international teams.

1 INTRODUCTION

The COVID-19 pandemic presented innumerable challenges for multiple fields, including the education sector. As a result of the implementation of social distancing and isolation measures to mitigate the spread of the contagion, educational institutions in the US, including schools and universities [1] [2], faced sudden nationwide closure for months from March 2020. Classes were abruptly shifted from being conducted in person to being conducted online via video-conferencing applications [3]. Active methodologies for optimal student learning [4], which conventionally focus on direct teacher-student interaction in a classroom, were no longer sufficient [1]. Lecture-based instruction was able to continue, however, coursework requirements became an issue – in particular for engineering courses that typically required hands-on, practical components such as labs and the completion of prototype-based course projects.

It is important to note that most engineering students were not used to online education, thus capturing their attention and encouraging their participation could represent a significant challenge. Some factors that contributed to this were the lack of motivation for online learning and academic stress related to it, for example speaking up in class became more stressful [5]. Although teachers adapted well to the sudden transition from teaching in person to teaching through online video conferencing software [6], students struggled with finding uninterrupted time or a quiet place to attend classes at home [7]. Another hurdle was the prevalence of digital inequalities among students [8], such as limited internet or technological resources as theorised by Beaunoyer et al. from a few factors that determine the efficiency of using technology. The primary factors were the quality of available hardware and software to access the tech resources, help provided by peers, and personal experience [8]. Interestingly, student satisfaction with the new learning methodologies differed from the suppositions initially made. In a study [9] it was established that not only did student satisfaction remain high when adapting to remote learning, but this was also reflected in the higher grades, indicating an overall improvement in the learning outcomes [9].

This paper records the ways in which a course instructor at a large, Southeastern university tackled the unprecedented changes brought about by the COVID-19 pandemic. It contains a detailed description of the modifications to the course format and deliverables, and the methods of student communication and collaboration from different geographical locations. It concludes with an account of how student participation in remote teams resulted in successful achievement of the course goals, including the prototype project, while inculcating ethical awareness. The asynchronous course simulated a global engineering workplace by replicating the typical experience of engineering projects whose success relies heavily on both individual and team-based efforts within the context in which team members are separated by both time and space – through implementing various adaptations. The theoretical framework used in this study mainly integrates active learning [4] and project-based learning (PBL) approaches. Simulating an engineering workplace in an asynchronous setting is challenging for a multitude of reasons. For instance, one of the abilities the students are expected to demonstrate is innovation, which tends to be inadvertently suppressed by students reluctant to venture beyond their earned expertise or skill set [10]. The PBL approach overcomes this by assigning projects that often revolve around solving a real-world problem through consistent and focused teamwork [10], so that students experience a learning curve addressing areas inside as well as outside of their major. Active learning has been established as a highly effective mode of instruction in both modern classroom and online synchronous/asynchronous settings [10]. This paper discusses a course in an asynchronous setting that allowed students to access the course materials at a relatively relaxed pace but still used active learning principles. Through group projects, the course ensured active student-student and student-content interactions.

2 METHODOLOGY

2.1 Overview of Course Designs

Foundations of Engineering is the second course in a two-course sequence taught to first-year general engineering students at a large Southeast university. This project-based course serves as an introduction to engineering for students through various skill development tasks. According to the curriculum, this is accomplished by engaging students in coursework that focuses on engineering design, problem-solving, physical prototyping, simulated data collection and analysis, contemporary software, as well as project management skills and standard professional practices in communication, teamwork, and ethics. Students are to design and build a 'backyard' wind turbine that operates as a kinetic sculpture kit that can be sold to homeowners, as an aesthetically-pleasing lawn ornament that generates some electricity. They are expected to be able to demonstrate competencies in using various engineering skills and tools to solve design problems. Students are reminded to implement engineering design processes while evaluating the potential ethical implications of their proposed solutions.

Using SolidWorks as a tool for computer-aided design (CAD), students learn to create physical analogs of virtual geometric solids in preparation for their project drawings. They first individually learn to design simple solids with step-by-step instructions and video tutorials provided. Their learning is then tested through SolidWorks assignments asking students to design the flange, tool block, and shaft.

Students are also introduced to the concept of stakeholders with different objectives. One of the course goals is to train students to not only develop engineering expertise but also interpersonal skills that will enable them to communicate engineering decisions to technical managers in an effective manner. To facilitate the acculturation of learning and working in a project-based environment, students are introduced to various aspects of day-to-day engineering tasks as they familiarise themselves with the different elements of the engineering design process.

2.2 Project Management and Professional Skill Development

Even though the course had to switch to remote instruction for this particular cohort, expectations on course outcomes were upheld. Students were expected to be able to define the project specifications as communicated to them through the Client's Project Description Letter. They were also to know the project timeline, to become familiar with project management tools, and to understand the uses of Comprehensive Assessment of Team Member Effectiveness (CATME). When discussing project management, the importance of early planning in relation to cost and influence was emphasised, highlighting the need to complete the project and deliverables in an efficient manner. Teamwork and issues with roles, responsibilities, and communication were thoroughly explored along with task management and the use of project scheduling tools such as Gantt Chart. Students were also briefed on details on project deliverables with milestones and important due dates throughout the semester.

Students were first given a Project and Team Start-up Package assignment to complete that contained: (a) the context and background of the design problem, (b) statement of given specifications, (c) major stakeholders, (d) questions that they may have about the project, (e) an initial project schedule, (f) identification of the major roles of team members, and (g) a team contract (agreement among team members). This assignment provided them with crucial guidance on resource management and planning throughout all major phases of the conception and design of a modified solution. Students were instructed to develop the scope for what needed to be done, identify all necessary tasks, and define the milestones and deadlines that would allow them to track their progress towards completion.

An essential first step was for students to demonstrate their comprehension of the design problem and their awareness of its technical implications to the project client. After identifying specifications, describing major and minor tasks, and providing the background in their project plan, students were asked to specify: (1) the stakeholders, (2) project management logistics (team roles and team contract documents, software tools being used for remote communication, file repository, and task management), and (3) individual questions for the client from each team member. Within team contracts, students were prompted to identify team goals and strategy, schedule and location of team meetings, team reporting and communication details.

With the help of first-quarter project and team status update reports (similar process was in place for the third quarter), the importance of periodic reports was emphasised - ensuring adequate project progress on time, within scope, and under budget. All teams were expected to have completed the design and construction of a first set of prototypes before the report was due. Hence, the main purpose of this report was for the teams to discuss the progress they had made and to present summaries of their early designs. In addition, the students were also required to reflect on what they had accomplished to date, examine their plans going forward, and make the necessary corrections to keep the project on track.

2.3 Decision Matrix and Prototyping

Students were encouraged to engage in individual design ideation and freely generate ideas and sketches (Figure 1) for the wind turbine’s design. Then, they had to use the qualitative approach for the evaluation of alternative designs of fellow team members (Figure 2). This approach involved the use of decision matrices in the identification of the relative importance of the features/criteria through a set of systematic comparisons by using a pairwise comparison chart, followed by the assigning of weightage to features based upon the rank order of importance, scoring their alternative designs, and eventually narrowing down one final design to prototype (Figure 3). Using the specifications list as their guide, students were first instructed to submit five decision criteria for testing their team’s wind turbine designs. Once a final design was selected, teams were instructed to build the model wind turbine with accessible materials and test it with a fan or hair dryer to observe whether a pattern was created when it spun (Figure 4). MATLAB was used to calculate the power and the torque generated by the specific wind turbine. As a team, students then virtually tested their prototype using Computational Fluid Dynamics (CFD), which analyses fluid flows using numerical solution methods. A video of their working turbine model was required to be submitted for grading.

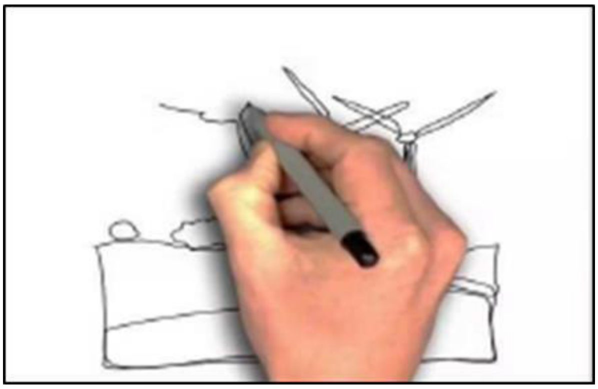

Figure 1. Freehand sketching of a student's online design ideation

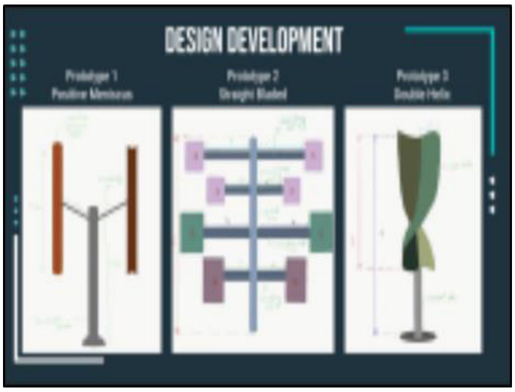

Figure 2. Design development with competing alternatives

Figure 3. An example showing the use of Decision Matrix

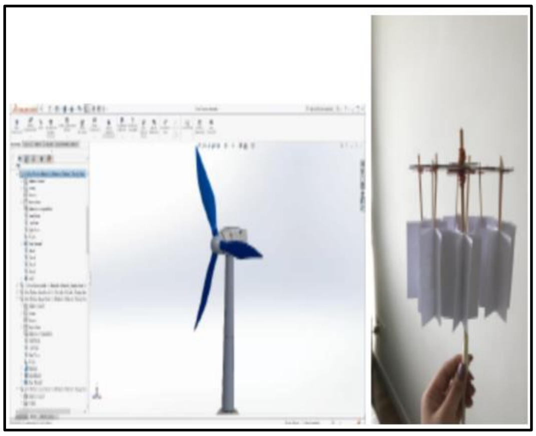

Figure 4. Virtual and physical prototyping examples

3 IMPLEMENTATION AND ADAPTATION

A cohort of 61 students was divided into 11 virtual teams of 5 students and 1 team of 6. Considering the asynchronous mode of instruction, the Canvas (a learning platform available for use by the university) site setup of the course was informed by recent developments in scholarship and practice for online teaching and learning (https://www.qualitymatters.org/rubric) with a particular emphasis on the purposeful planning of the online space alongside its structure and delivery. Table 1 summarises the primary changes and adaptations that occurred in the online format.

3.1 Highlights of Course Organization

First, an introductory video was included on Canvas to depict the instructor's passion for teaching. Adhering to the guidelines of quality assurance and management of online courses, the course homepage was strategically formatted for easy accessibility. The Modules page was also set up to contain one module per week, making it easy for students to find resources and lectures. The weekly class activity, learning materials, and weekly objectives were all linked thematically. In addition, the grading criteria were made clear for the graded discussion board.

Table 1. Summary of the primary differences between the two formats of the course.

Regular In-person	Post-COVID-19 Asynchronous Online
Mandatory **attendance** of class sessions and active in-class participation are expected.	Geographically dispersed students worked through course/project materials on Canvas in different time zones at their own convenience.
Team members are given class time to engage in **team-building activities** at the start.	Team-building exercises could not be executed due to the asynchronous nature of the course.
Team members regularly **meet in person** during scheduled class times to check in and to schedule group meetings outside of class.	Heavy reliance on online applications (e.g. Zoom and WhatsApp) for communication, and for completing project-related group tasks in general.
Materials typically required for team project prototyping are readily available throughout the course duration.	Students were expected to use their creativity in sourcing and securing suitable materials from their immediate surroundings.
Access to the well-equipped Frith **engineering design lab** on campus.	Students did not have access to special tools and lab equipment or lab assistants.
Live **CAD instruction sessions** are given to provide individualised help during class.	Students were given access to a set of pre-recorded CAD demo videos on CANVAS.
The use of **Computational Fluid Dynamics (CFD)** for testing prototypes is optional.	All teams used CFD as a means to virtually test their prototypes.
In-class **final project presentations** that showcase the teams' final physical prototypes.	Recorded online presentations were the only feasible option.

3.2 Feedback on Outcomes: Support, Accessibility, and Usability

All in all, feedback collected from students as part of the course surveys per IRB guidelines was overwhelmingly positive, such as "*the Sunday night email containing links with helpful resources helped a lot and the instructor was always welcoming and approachable*," giving much needed confirmations that students were able to benefit amply from this course delivery format.

The requirements for learner interaction were clearly stated on the discussion board. The instructor sent weekly emails that introduced the topics for that week, which allowed a more personalised approach generally uncommon with asynchronous teaching. This helped establish rapport with students, who lauded the instructor for being "*really friendly and understanding…helps the students in both course materials and mental health*." There were other comments and positive feedback from this cohort of students directed at how the instructor was handling the course, such as the instructor was "*always available for students, and … responds to emails very quickly*", "*helped me learn how to clearly use SolidWorks…was very helpful whenever I had any questions*", "*very helpful during her office hours and also a great person to talk to… understands the situations us students go through, and helps us accordingly*", and "*always provided instructions clearly and used recordings to explain content*.". Another student shared in the end-of-semester teaching evaluations that "*(instructor) is one of the best instructors I've had so far in my university. She always delivers the course material very clearly and effectively. The course is always engaging and I've never felt bored at all. The assignment feedback makes me improve always, and the weekly announcements help me stay on track and not fall behind.*"

An evaluation of the course from a faculty who provided a teaching evaluation review states: "*The instructor provides thoughtful learning experiences and resources that support her students at every step. For example, the instructor introduces conflicts of interest in an effective way and provides scaffolding through examples and an* *exercise to help students practise what they learned. The instructor managed to effectively teach, not only virtually, but also in a fully asynchronous mode*."

Navigating the entire course through the modules on Canvas was easy. Each week's resources could be located both on the overview page and the specific resources page. The PowerPoint files with audio were made easily accessible (yellow matter on Canvas). A testimonial from a student supports the above criteria of the course quality management guidelines: "*I really liked the course. It was engaging and interesting. … we had to collaborate on the interesting topic of the wind turbine. I really liked the part when we had to come up with our individual designs. Each team assignment, we had the time to socialise and talk which was really fun too. Overall, this class helped me awaken my creative sign with a mix of my academic side.*"

Not being able to meet in person encouraged students to switch to alternative methods of communication for completing group tasks. Zoom, Discord, and WhatsApp turned out to be popular and effective applications for direct student communications. Tools like Canvas, Google Docs, and Google Drive were used for shared storage and editing assignments. A student testimonial (edited for brevity) reads: "*While the course may not be as fun in an asynchronous setting, the course was most definitely productive … functionalities like screen share, and posting links in the chat were very convenient and reliable ... This made us more efficient and made our work even more valuable as everyone did their best work in their own style*."

Positive feedback apropos to the connection of the taught course with an actual engineering workplace was recorded by a student whose testimonial (edited for conciseness) reads: *"Taking the class online has made learning harder .... However, real-world engineering problems often deal with incomplete information and uncertainty. I believe that the uncertainty pushed the students to work by themselves and not count on anyone. In this way, we learnt basic engineering skills. In fact, engineers usually do experimentations with software, models, or prototypes in order to deal with uncertainty. Experimentations are one the first steps in engineering design. In fact, each engineer has his own plan to solve problems..."*

4 DISCUSSION AND LIMITATIONS

This study covers the various aspects of an engineering course forced to abruptly transition online due to the Covid-19 pandemic. The paper also reports the technical details of the course as well as the course outcomes that were achieved through the inculcation of communication, teamwork, and understanding of ethics in students. The course format was asynchronous, i.e., the minimum attendance course policy was suspended, to accommodate international students who resided in different time zones. Further, to reduce workload for students, the weekly assignments had been reduced to biweekly. Prompt steps, as highlighted above, were taken by the course instructor to fulfil the remote pedagogy requirement after the pandemic began.

The essence of the course was delivered through simulating the experience of remotely-connected global engineering teams. While working asynchronously, completion of the course project – a final design analysis and critique of a physical prototype made from a CAD model – remained a primary course requirement. Ethics in the engineering workplace was also a required consideration in the final assessment; how well students complied with stakeholders' interests was evaluated. Special consideration was given to ensure that students were provided with an immersive experience of how engineers work, remotely, on a regular basis: following industrial standards, collaborating in teams, complying with the customer design requirements, and completing projects with ethical considerations. The widely distributed geographical locations of international students, collaborating in an organised way and coming up with creative ways to procure the required materials, was a significant challenge. Working remotely, each group needed to spend time planning the project, organising the work, identifying action items for each person, and following up to ensure the work was completed on time as well as accurately.

The unavailability of hardware lab equipment and wind turbine kits for international students led towards devising creative solutions driven by conceptual clarity. Students used whatever resources that were available to build the project from scratch, such as cardboard pieces, tapes, straws, canes, etc. For the final prototype submission, the constraints of the previous version were solved to build a better working model. Data for the torque generated by the wind turbine as proportional to the wind speed and other factors was recorded and analysed for proficiency calculations and error estimations. Where this project showed positive results for the instructor's implemented methodologies of online pedagogy, it also exemplified the students' (a) keenness to learn, (b) remarkable adaptability to remote learning, (c) versatility to handle responsibilities in remote teams, and (d) resourcefulness and ability to reproduce results comparable to an actual engineering workshop.

However, some of our findings may not be entirely generalizable; for example, the scope of this study does not necessarily extend to non-STEM project-based courses taught online during the pandemic that may require different skill sets. In addition, the personal quality and previous online teaching experience of the instructor, as well as the availability of additional support could potentially have significant impacts on students' experiences. Further, the course introduced here was at the undergraduate level; findings of current study may not be replicable at other levels of education such as high school and lower, or in different educational settings. Lastly, future research is needed to help us more fully understand the challenges and opportunities in this specifically under-explored modality of online prototype-based learning, while possibly looking to integrate the best practices of using information and communications technology (ICT) in e-learning of courses specifically involving PBL.

5 CONCLUSION

This study presents findings from a first-year engineering PBL course that was taught online asynchronously during university closures due to the COVID-19 pandemic. Through various adaptations, the course simulated the global engineering workplace by imitating the experience of engineering projects within the context in which team members are being separated by both time and space. The essence of this paper is to provide fruitful insights into the prompt steps taken by the instructor for effective implementation of online learning methodologies for the course. It also shed light on how students living in different parts of the world communicated with the instructor, learned through asynchronous instructions, collaborated in teams, made ethically informed decisions, and timely completed the course project according to the stakeholders' requirements. The outcomes from this course add to the various methodologies being used in online learning. Highly favourable student feedback represents additional affirmation that the sudden pivoting to online learning had been a much welcome success in this setting. This experience of conducting a PBL course remotely, with further adaptations, can serve as a useful template to help guide colleges of engineering in similar courses if such need arises in the future.

References

[1] A. Akour *et al.*, "The impact of the COVID-19 pandemic and emergency distance teaching on the psychological status of university teachers: A cross-sectional study in Jordan," *American Journal of Tropical Medicine and Hygiene*, vol. 103, no. 6, pp. 2391–2399, Dec. 2020, doi: 10.4269/ajtmh.20-0877.

[2] C. Rapanta, L. Botturi, P. Goodyear, L. Guàrdia, and M. Koole, "Online University Teaching During and After the Covid-19 Crisis: Refocusing Teacher Presence and Learning Activity," *Postdigital Science and Education*, vol. 2, no. 3, pp. 923–945, Oct. 2020, doi: 10.1007/s42438-020-00155-y.

[3] J. J. Park, M. Park, K. Jackson, and G. Vanhoy, "Remote Engineering Education Under COVID-19 Pandemic Environment," *International Journal of Multidisciplinary Perspectives in Higher Education*, vol. 5, no. 1, pp. 160–166, 2020.

[4] M. Prince, "Does active learning work? A review of the research," *Journal of Engineering Education*, vol. 93, no. 3. Wiley-Blackwell Publishing Ltd, pp. 223–231, 2004. doi: 10.1002/j.2168-9830.2004.tb00809.x.

[5] J. C. Heo and S. Han, "Effects of motivation, academic stress and age in predicting self-directed learning readiness (SDLR): Focused on online college students," *Education and Information Technologies*, vol. 23, no. 1, pp. 61–71, Jan. 2018, doi: 10.1007/s10639-017-9585-2.

[6] N. Saputra, N. Hikmah, V. Yustitia, M. Saputra, A. Wahab, and J. Junaedi, "Implementation of Online Learning Using Online Media, During the Covid 19 Pandemic," *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, vol. 4, no. 2, pp. 1802–1808, Apr. 2021, doi: 10.33258/birci.v4i2.1857.

[7] J. S. Barrot, I. I. Llenares, and L. S. del Rosario, "Students' online learning challenges during the pandemic and how they cope with them: The case of the Philippines," *Education and Information Technologies*, vol. 26, no. 6, pp. 7321–7338, Nov. 2021, doi: 10.1007/s10639-021-10589-x.

[8] E. Beaunoyer, S. Dupéré, and M. J. Guitton, "COVID-19 and digital inequalities: Reciprocal impacts and mitigation strategies," *Computers in Human Behavior*, vol. 111, Oct. 2020, doi: 10.1016/j.chb.2020.106424.

[9] F. J. García-Peñalvo, A. García-Holgado, A. Vázquez-Ingelmo, and J. C. Sánchez-Prieto, "Planning, communication and active methodologies: Online assessment of the software engineering subject during the COVID-19 crisis," *RIED-Revista Iberoamericana de Educacion a Distancia*, vol. 24, no. 2, pp. 41–66, Feb. 2021, doi: 10.5944/ried.24.2.27689.

[10] M. Prince, R. Felder, and R. Brent, "Advances in Engineering Education Active Student Engagement in Online STEM Classes: Approaches and Recommendations Active Student Engagement in Online STEM Classes: Approaches and Recommendations."