Assessing and Improving Student Engagement and Motivation in Mechanical Engineering Online Courses

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Abstract

Development of online courses in academia has been on the rise and both educators and students have shown interest in possibilities and affordances peculiar to this platform. It offers time flexibility and allows students to better organize their individual learning process. Despite the promising potentials of online courses, they require additional investment both during the course development and in each offering since they rely heavily on instructional design schemes to optimize the content and material for learning outcomes. Previous studies showed that online courses could have lower student engagement and motivation compared to the face-to-face course settings. However, more investigation is required to assess and improve those two factors, specifically for mechanical engineering (ME) online courses. A study is conducted at The University to assess and improve students' engagement and motivation for two mechanical engineering courses offered online at the undergraduate level. The paper will describe the development of courses and the tools designed to assess and improve students' engagement and motivation. The work presents a comparison of two ME online courses and produces actionable results for future improvement of the online courses in a similar context/major. In addition, this work highlights activities such as peer-to-peer interaction and video lectures that students considered beneficial and conducive to their learning experience while mostly reporting online discussion forum and reading assignments as the least helpful. We close the paper by discussing what further strategies could be used to enhance, and leverage student engagement and motivation in online learning settings.

1. Introduction

There is an increasing demand for distance education. The flexibility and convince of learning on demand is an education trend that is constantly evolving. The pervasiveness of communication technology and connected media enables educators to teach via nontraditional tools such as recorded videos, live streaming of lectures, and live discussion panels. Bourne *et al*. (Olin et al. 2005) listed three requirements for effective online engineering education delivery. Those are 1) online courses provide comparable quality to the courses offered traditionally, 2) Students can access the courses anytime and from anywhere, and 3) the online offered topics cover a broad area of engineering disciplines.

The third requirement is still a far reach for engineering education. Despite the apparent benefits of distance or online education, there are many challenges to overcome in that space. In Mechanical Engineering, many traditional courses depend on hands-on laboratories in addition to the face-to-face classes. Some researchers

were able to offer the laboratories as online for appropriate subjects such as control (Duan et al. 2005) however, this might be more challenging in other topics within mechanical engineering. Use of experiential learning, i.e., projects designed with often low-cost kits for physical activity is also found to be beneficial in an online Mechanics course (Dittenber & Ironside 2017).

A major challenge in determining the online course quality is student's engagement and motivation compared to the face-to-face courses. Online courses rely on independent learning where students need to manage their own time and effort assigned to view and engaged with the course material. Hence, a research-based tool for evaluating student engagement and motivation in online settings can help educators to close the loop of assessing course design and to identify opportunities for improvement and re-adjustment of the course material to student needs.

Student engagement in educational activities plays a critical role in the fulfillment of learning objectives and the overall quality of educational experience (Kuh 2001; Qattawi et al. 2014). Multi-institutional studies have shown student engagement to be a precursor to persistence and student retainment in engineering (Ohland et al. 2008). Some studies report that student engagement is the primary challenge of using effective teaching methods in online courses and students appeared to be far more impacted by distractions in comparison to face-to-face sections (Boettner & Bailey 2014). Through a meta-synthetic review of the literature on distant learning and online course development, researchers have shown several emergent themes in the literature (Cherney et al. 2018). First, collaborative online learning environments were more effective in improving the achievement of learning outcomes in comparison to non-collaborative online environments. Second, there are a number of conflicting conclusions in the literature which need to be resolved with further research and data collection. Providing useful feedback to students is also another challenging and demanding aspect of online course instruction (Kinney et al. 2012).

Although engineering labs are commonly identified as a hurdle to effective delivery of engineering education online (Kinney et al. 2012), we leveraged interactive virtual environments to create Strength of Material laboratory tests for an online course. Use of computational simulations to create virtual lab experiments for online courses has shown promising potential in the previous investigations (Uribe et al. 2016). In this study, we developed virtual laboratory experiments for Strength of Material in order to be able to offer the course in a fully online format. On the other hand, we developed a hybrid course on Computer Aided Engineering in which all instructional and learning activities were online except weekly labs.

In this paper, we discuss the overall structure of two online courses offered at the Mechanical Engineering Department at The University. We present our model for defining and developing an online engineering course based on the best-practices in literature. Next, we explain the development of a tool to measure the student engagement and motivation followed by our findings over two academic years. This survey tool is developed with the objective of creating a generic assessment to evaluate student engagement and motivation for both online and face-to-face courses.

2. Mechanical Engineering Online Course Development

The development of online engineering courses relies on collaborative and iterative work. The first step in online course development is the extent to which the desired course will be *online* or *hybrid*. In completely online offerings all course materials and labs are taught via communication technology. This includes previously recorded videos and live (synchronous) online lectures or office hours. The alternative is a hybrid format where the material is taught in both settings, online and face-to-face. Examples of topics that

might suit the hybrid format in mechanical engineering are those with extensive laboratory experiments. The online lectures can be used for introduction and motivation, explanation of concepts and constructs (e.g., fundamental concept required in mechanical design), and derivation of theorems or rules. The instructors, then can use the face-to-face settings to explore applications, solve problems, and offer demonstrations or hands-on activity. In fully online format all instructions need to be delivered in either synchronous (live) asynchronous (pre-recorded) material. However, this allows enrollment without any physical presence on a campus site.

In this work, authors developed two Mechanical Engineering online courses at The University: those are Computer Aided Engineering and Strength of Materials. Both courses have associated labs. In the Computer Aided Engineering the labs are offered face-to-face while in Strength of Materials a virtual laboratory interface is designed for students to conduct the experiments online. The lecture components of the two courses are offered online only. To successfully convert or develop an online course in Mechanical Engineering, we defined six major elements of our design based on the literature of evidence-based best practices in relevant contexts. The elements of our management and instructional design are shown in Figure 1 and will be reviewed briefly here.

Teaching Roles and Expectations: teaching online engineering courses demands the instructors to have different roles not only attending to the content and students' needs, but also managing the development and delivery of the course. Online courses also need tailored learning outcomes that may not be the same as that of face-to-face offerings (Allen & Seaman 2015) since the nature of the learning experience, i.e. both quality and quantity of student activity, and methods of assessment vary in two settings. A careful evaluation of student learning outcomes is necessary to determine the suitability of Mechanical Engineering courses for online education ensuring proper alignment of course outcomes with the instructional medium. Researchers have structured teaching roles in online courses into four categories, namely (i) a managerial or organizational roles concerned with planning, leadership, and monitoring the process, (ii) a social role as the facilitator of discourse and discussion, (iii) an intellectual or pedagogical role sharing scholarly knowledge, and finally (iv) a technical role providing varieties of support with tools and techniques involved in the learning process (Anderson et al. 2001).

Systematic Learning Infrastructure*:* the lack of face-to-face interaction in online courses requires the establishment of a well-defined system that efficiently and effectively integrates the course material and expected deliverables while affording on-demand interventions throughout the semester. Modularization of the course on a periodic, for example, weekly, basis allows to preset the availability timeline for online videos or live streaming, due dates of assignment delivery, and their grading and solution, posting on online discussion board, TA office hours, and on-demand or provisional web conferencing. Consistency and pre-planning for deliverables of both students and instructors results in smoother streamlining of the educational process. It is also necessary to establish well-structured communication methods between students and instructors for general announcements or unpredictable changes in due dates for example. This aspect of our design relies heavily on the features in the Learning Management System (Coates et al. 2005) and its flexibility to provide users with all necessary planning and communication instruments.

Integrated Assessment & Feedback*:* The integration of assessment and feedback tool may take many forms in engineering online courses. It depends on the digitized tool or platform being used. However, the integration should be considered throughout the course design. Desired student outcomes are used as the starting point for the creation of the instructional material (for example video lectures) and assessment is used as a scaffolding opportunity for learning, as well as a direct measure of how students demonstrate the achievement of learning outcomes. Finally, the assessment loop is closed by providing informative feedback to students making explicit their performance, their strengths, and weaknesses.
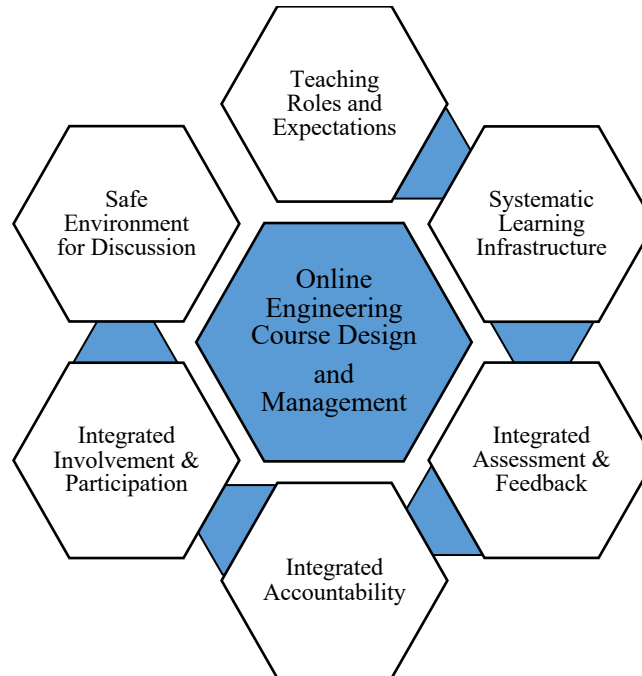
Figure 1 Elements of the instructional approach used in designing and managing online engineering courses.

Integrated Accountability: online education encourages independent learning. It is necessary to integrate an accountability mechanism that enables the students to be fully engaged and pace their learning. Examples of accountability mechanisms are progress indication tool that highlights the percentage of completed tasks for a certain week and checklists that facilitate the pacing of student responsibilities. In the Computer Aided Engineering online course students were able to see the what percentage of lecture videos they viewed and, in both courses, students received a weekly checklist of submitted materials. This tool is automatically set to send reminders to students for approaching submission deadlines.

Integrated Involvement & Participation: researchers have investigated the role of student involvement in educationally effective practices as an important proxy for academic achievement (Chen et al. 2008). In addition, the rate of instructor-student interaction is also known to have an impact on overall student perception and satisfaction (Moore et al. 1996). Richardson et al. (Richardson & Swan 2003) reported that the social presence of both instructors and students are indicators of student satisfaction with the course. More importantly, in online settings, the notion of participation is subject to reinterpretation in comparison to on-ground traditional courses (DeBoer et al. 2014) due to the flexibility afforded to individual students for engaging with the curriculum. Various approaches are adopted to improve student participation, such as integration of quizzes in the instructional lectures, use of discussion boards, and offering synchronous review sessions. One of the aims of our study is to identify the elements of the online course with which students more effectively engage.

Safe Environment for Discussion: the establishment of a safe platform to share and discuss questions is essential to the success of online courses. Instructors can foster a safe environment by encouraging participation and creating pathways for students to discuss their challenges and questions throughout their studies. It is the instructor's responsibility to facilitate and encourage participation and communication. Student discussions will be shared among all users (students and instructional team), hence the emphasis on inclusiveness and safe environment is essential to have a forum where students can post questions, answers and discuss course topics with no hindrance.

3. Student Engagement and Motivation Evaluation Tool

The immediate aim of this research is to identify opportunities for educational improvement as we developed two online courses and to gain some insight on students' perception of their overall experience with the course. In this study, relying on student self-reports, we developed survey instruments to measure engagement and motivation. We conceptualize engagement as the extent or quantity of time that students get involved with the learning experiences of various kind, for example, we ask how often they practice on their own to solve problems, or how often they engage in teamwork. As a proxy for motivation, we evaluate students' satisfaction defined as the perception of helpfulness and/or usefulness of instructional elements or activities in the course.

Focusing on the actionable knowledge gained by evaluating student engagement and motivation, this study is shaped around the following research questions:

1. What are the course elements with which students engage more effectively?
2. What are the course elements students perceive as most effective towards their learning?
3. What changes in instructional and assessment material can be made to leverage course elements with high student engagement and improve elements with low student engagement?
4. What changes can be made to better employ the course elements which students perceive as more helpful in their learning?

In the following section, first the survey results from two consecutive years are exhibited addressing the questions 1 and 2 above. Next, we discuss the implication of the results for future action, hence addressing question 3 and 4.

4. Results and Discussion

This section presents and discusses the survey results for the online courses, Strength of Material as well as Computer Aided Engineering. Figure 2 illustrates the results of a question aimed to evaluate student engagement with various activities in Strength of Material. We find that lab and quiz assignments, as well as watching lab or lecture videos are items student spend most of their time engaging with (mean values are highest as reported in Table 1). For activities of reading the textbook, practicing on your own, and exploring the internet on the course topics are also activities reported by around 30% as being engaged with "very often". On the other hand, optional problem sets and answering reflective questions, and the use of online forum, neither of which is graded or assessed in this course, are activities that majority of students report "never" engaging with.
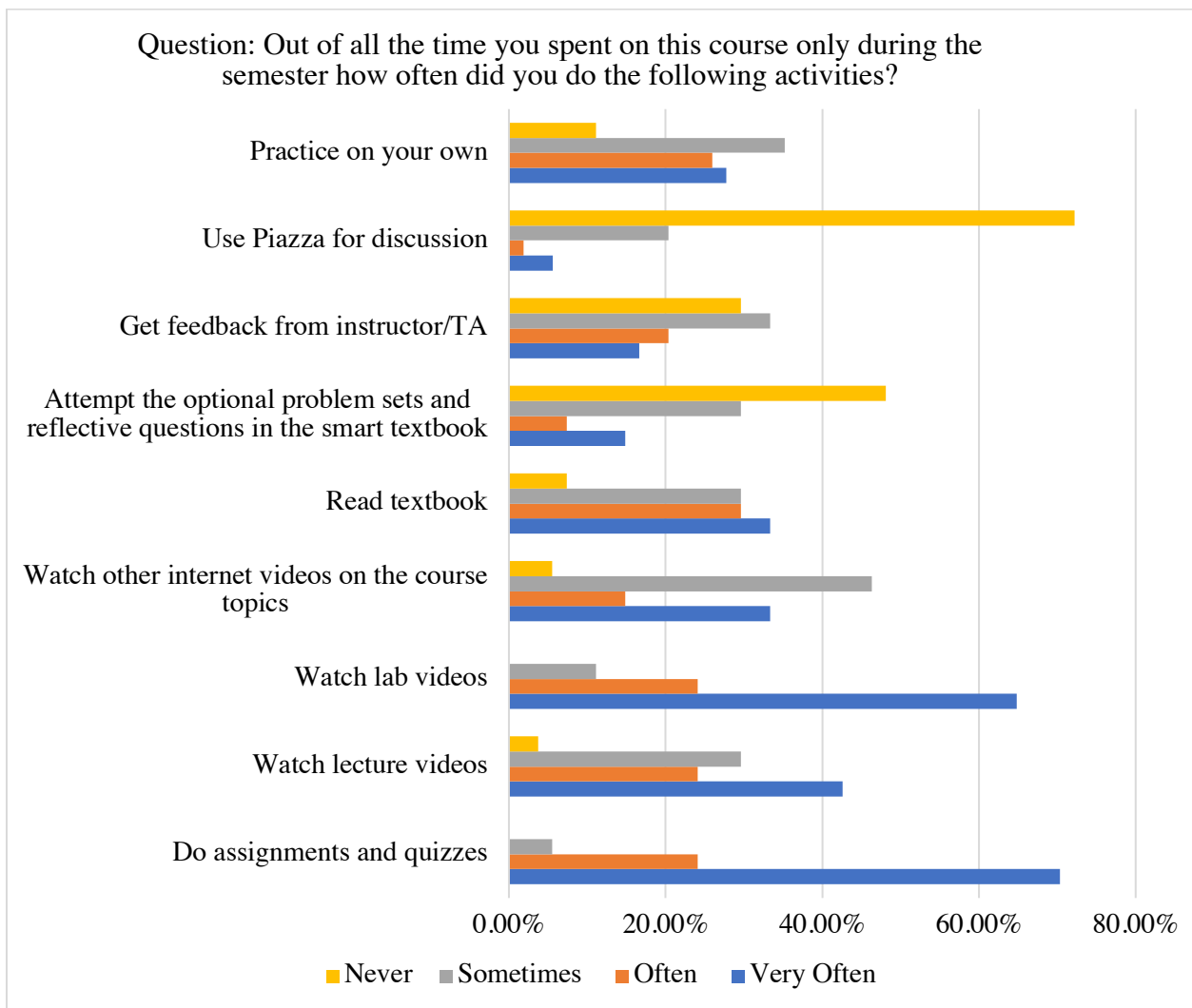

Figure 2 Assessing Student engagement with instructional activities in online Strength of Material course over two academic years (n=54).

In the Computer Aided Engineering course, the same question yielded similar findings (p-values given in Table 1). Although a smaller number of students report high engagement ("very often") with the course videos in Computer Aided Engineering compared to the Strength of Material, this difference is statistically insignificant (p-value=0.67) according to a two-tail t-test comparison of the data. Table 1 reports the p-values calculated by a t-test analysis of the survey data regarding student engagement. The null-hypothesis corresponding to the p-values for each question is the assumption that mean values from both classes are equal. In none of the engagement questions this null-hypothesis was rejected, hence we conclude that both data sets entail similar findings. In both courses, we find that engagement with the online forum to have the smallest mean value.
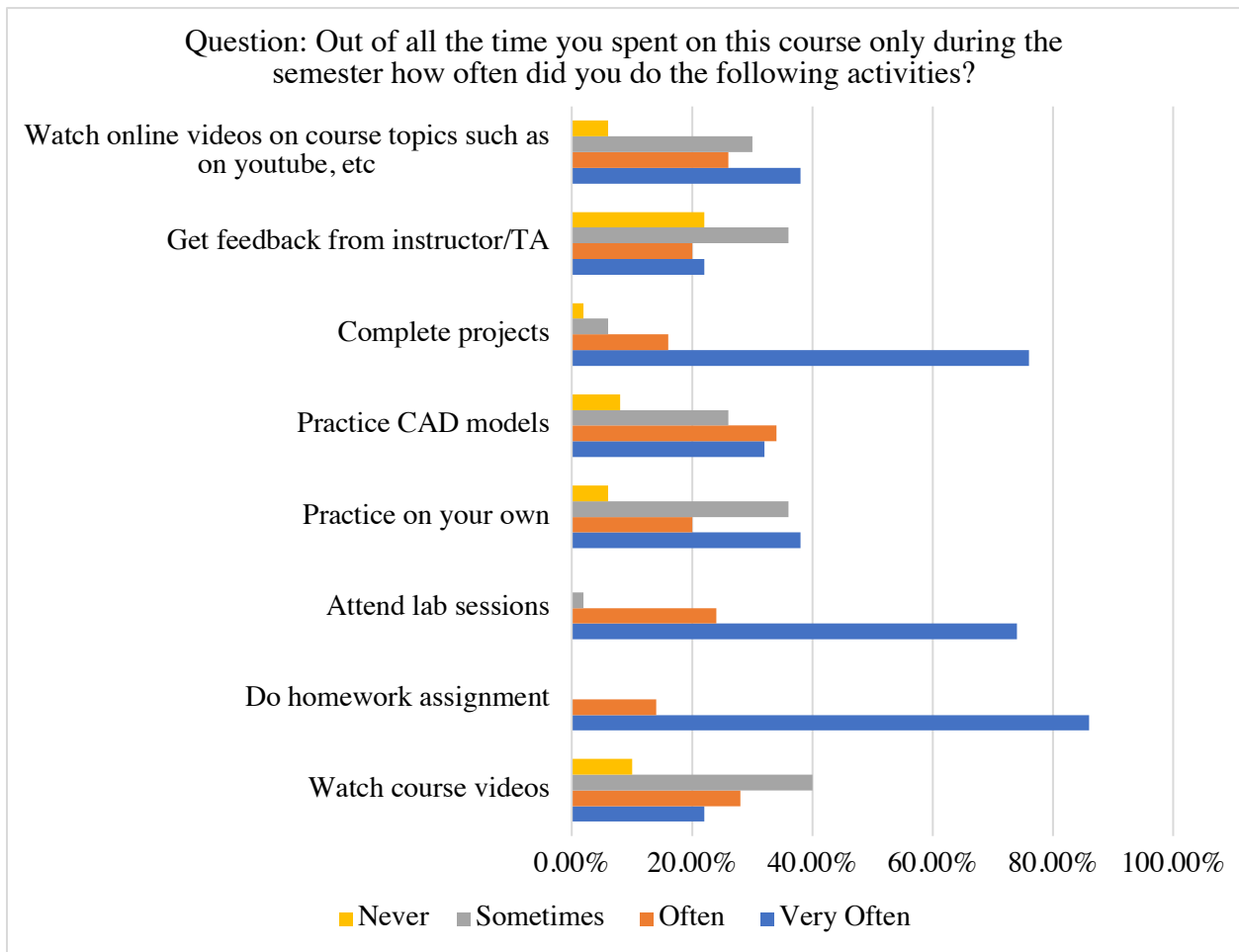

Figure 3 Assessing Student engagement with instructional activities in online Computer Aided Engineering course (n=50).

To further explore practices common to our students' patterns of studying and learning, we asked another question that seeks to illustrate how students engage and interact with peers and instructors. In Strength of Material, as shown in Figure 4, we find that nearly 50 percent of students interact with each other by seeking help from their peers to discuss and explain material to each other either "often" or "very often". In the Computer Aided Engineering Course, findings are similar as shown in Figure 5.
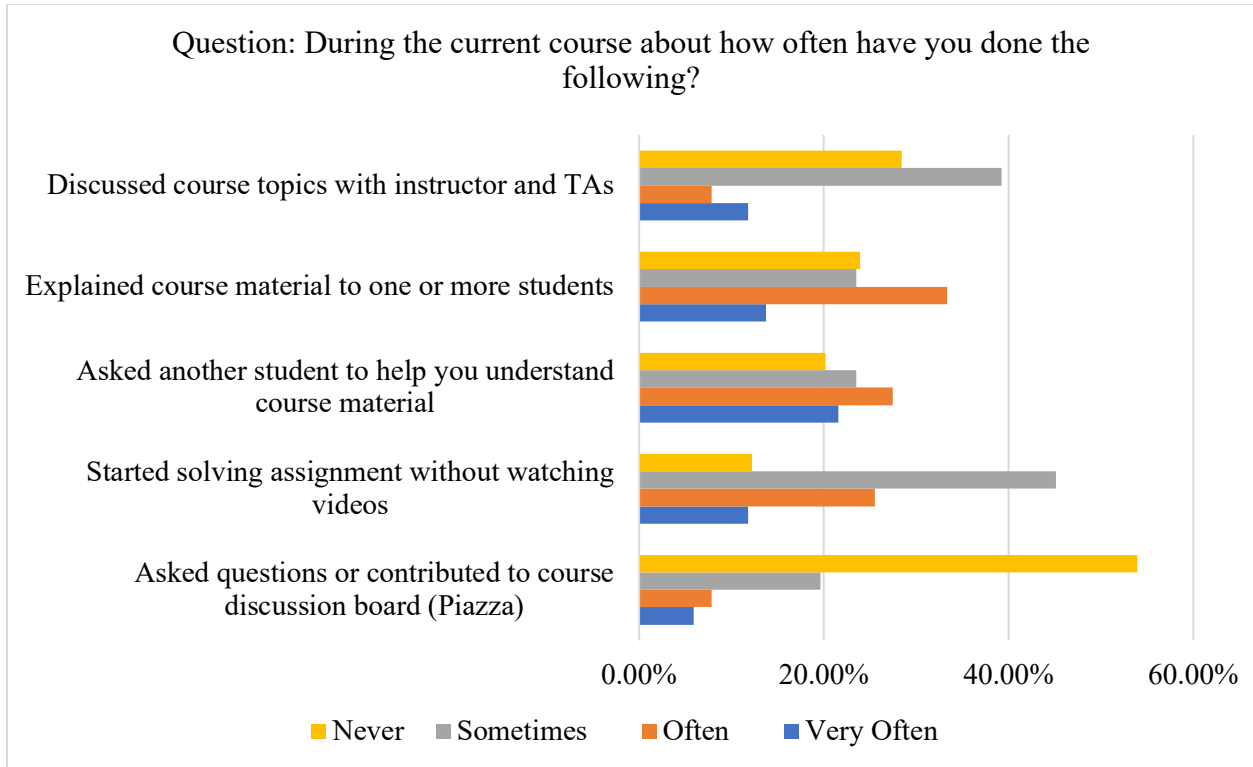

Figure 4 Assessing Student engagement with peers and instructors in online Strength of Material course over two academic years (n=54).

Table 1 Mean values for engagement questions in both Strength of Material (μ_{sm}) and Computer Aided Engineering (μ_{cae}) calculated by assigning the following weights: Never=0, Sometime=1, Often=2, and Very Often=3. The p-values corresponding to a two-sided t-test confirms that on average both classes yield similar results.

| Activities	μsm	μcae	p-value
Doing homework assignments	1.30	1.20	0.99
Watching lecture videos	1.26	1.24	0.67
Getting instructor feedbacks	0.96	1.04	0.91
Practicing on your own	1.20	1.20	0.96
Watching online videos (e.g., Youtube)	1.15	1.26	0.97
Explaining material to other students	1.10	1.31	0.62
Asking another student for help	1.06	1.04	0.97
Contributing to online discussion board	0.47	0.87	0.28
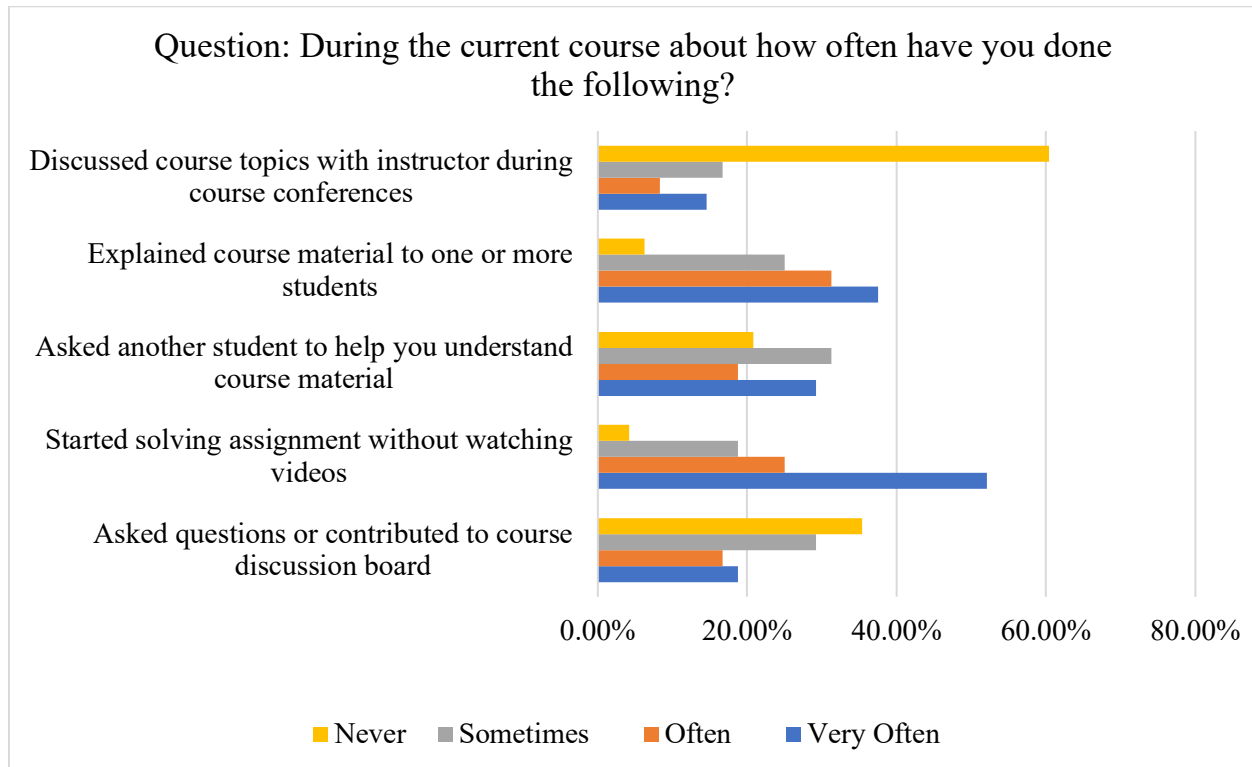
Figure 5 Assessing Student engagement with peers and instructors in online Computer Aided Engineering course (n=50).

Next, we ask students to report on their perception of their learning. We survey them, first based on the achievement of course learning outcomes which in Strength of Material are

1. analyzing internal forces and moments in beams or structural members under different types of loading (axial, torsion, bending),
2. analyze axial or torsional deflections in beams or structural members,
3. determine shear and normal stress distributions along a cross-section of a beam or a structural member under axial, torsional, or bending loads,
4. determine the maximum normal and shear stresses at a material point and the planes at which they occur using stress transformation/Mohr's circle analysis,
5. design structural members for allowable stresses or perform their failure analysis.

and in Computer Aided Engineering are

1. analyze, verify, and interpret Finite Element Analysis (FEA) results,
2. follow design procedures including problem identification, data collection, problem formulation, approaches, methodology, and solution,
3. use industry-standard software packages and analytical tools,
4. construct 3D solid models, 2D drawings, and assembly and sub-assembly structures.

In Strength of Material, we find the majority of students to agree that taking this course helped them achieve the course learning outcomes. Findings in Computer Aided Engineering is similar for this question as well.
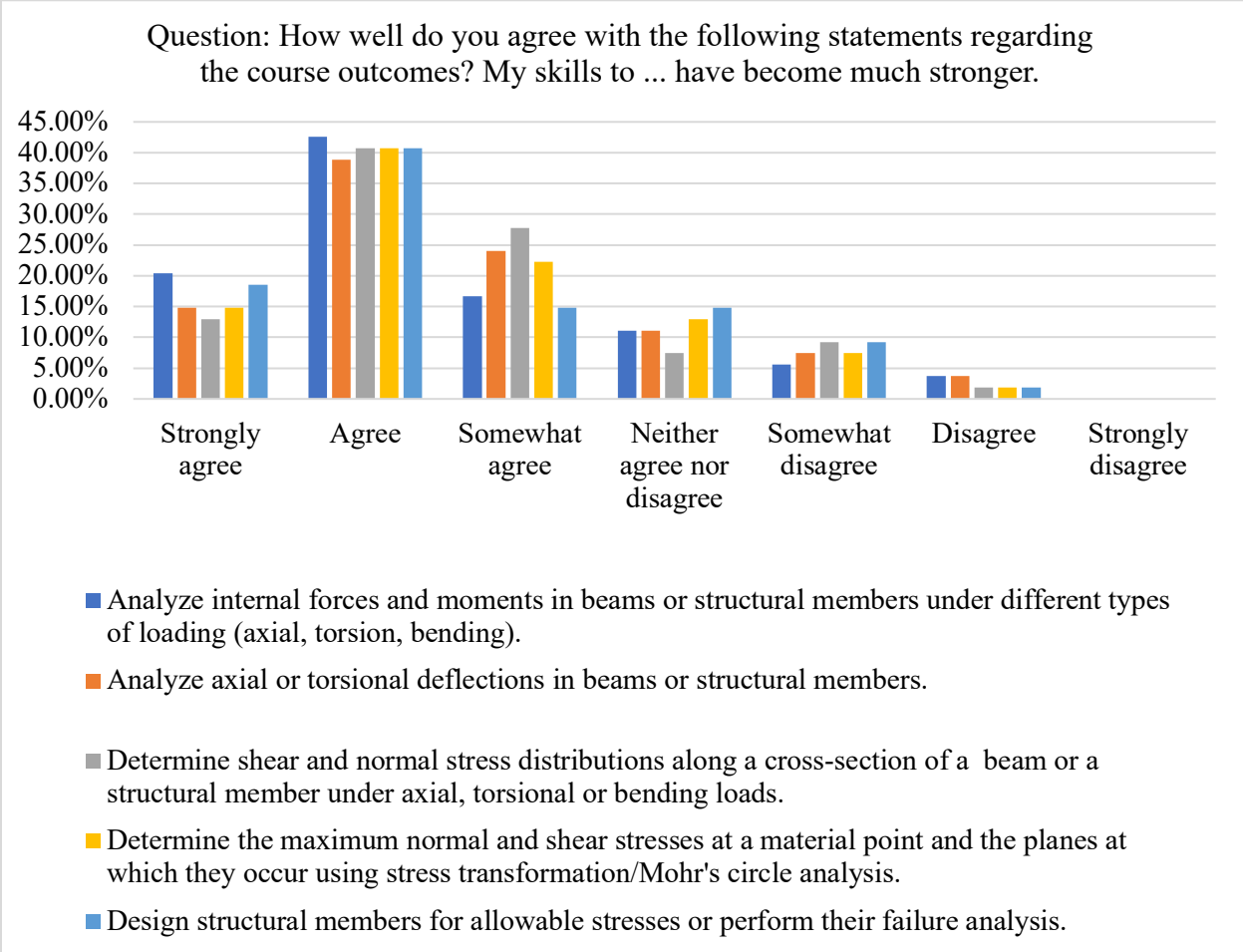
Figure 6 Assessing student perception of learning as a proxy for satisfaction with the online Strength of Material course (n=54).
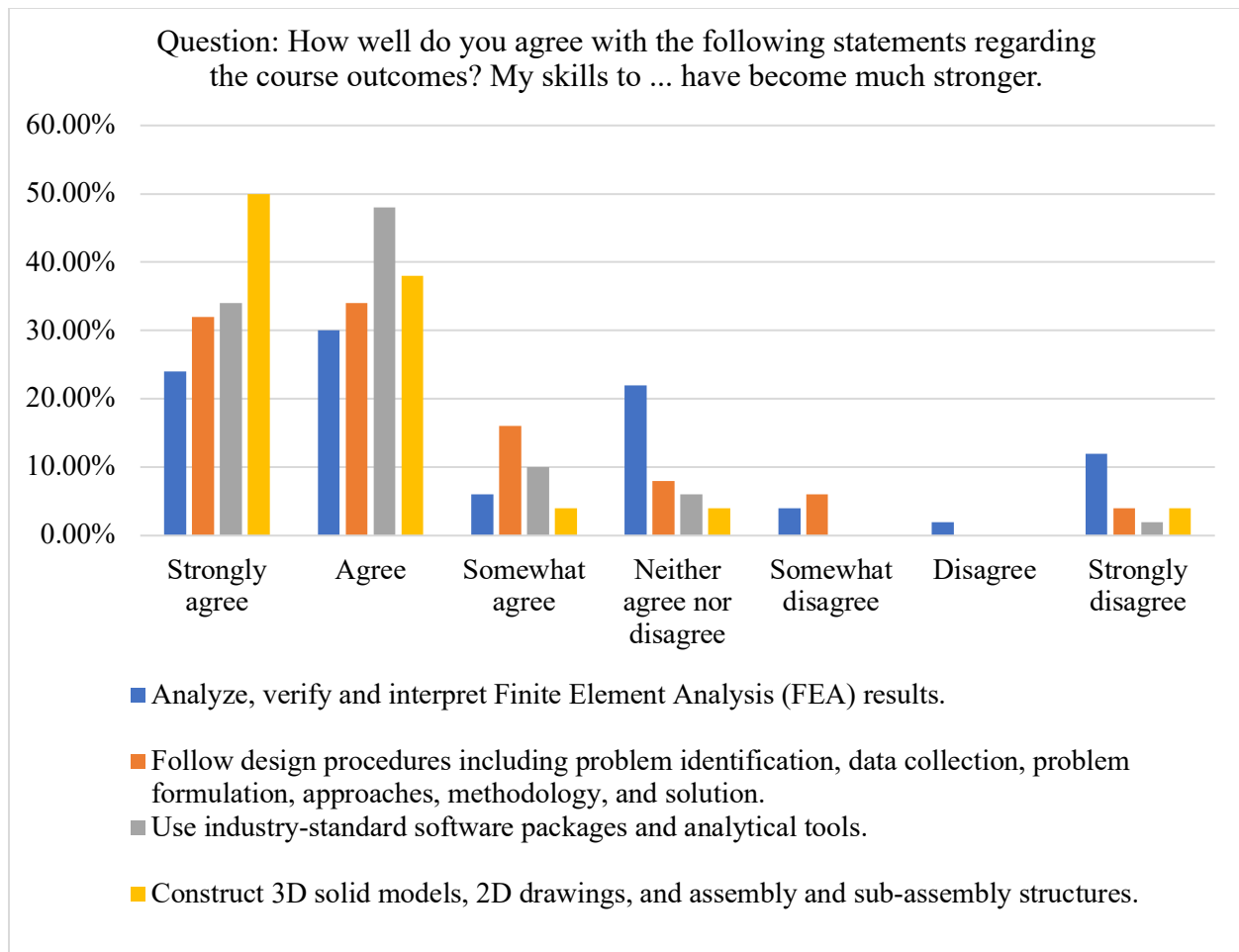
Question: How well do you agree with the following statements regarding the course outcomes? My skills to ... have become much stronger.

Legend:
- ■ Analyze, verify and interpret Finite Element Analysis (FEA) results.
- ■ Follow design procedures including problem identification, data collection, problem formulation, approaches, methodology, and solution.
- ■ Use industry-standard software packages and analytical tools.
- ■ Construct 3D solid models, 2D drawings, and assembly and sub-assembly structures.

Figure 7 Assessing student perception of learning as a proxy for satisfaction with the online Computer Aided Engineering course (n=50).

Next, we ask students to report how helpful they found each instructional element of the course. In both courses, we observe a substantial match between areas of high student engagement and high student satisfaction. As Figure 8 illustrates, lab and lecture videos, quizzes, and personal practice time are ranked highest in helpfulness by students in Strength of Material. Online discussions and reading assignments are identified by students as activities least helpful to outcome achievement. We find that Pearson Correlation Factor (a measure of linear dependence) between average engagement of activity and it's helpfulness to be 0.86 and the p-value=0.015. In this case, null-hypothesis refers to the assumption that average engagement of activity and it's helpfulness are not correlated. We are able to reject this hypothesis within the significance well below 0.05.

In Computer Aided Engineering, students report homework assignments and individual practice as well as attending weekly labs as the most helpful elements of the course. We observe that on both courses "practicing on your own" is characterized as helpful in more than 75 percent of cases, however, when students asked how much time they spend on that activity (shown in Figures 2 and 3) in both courses, around 40 percent report "never" or "sometimes". In Computer Aided Engineering course, however, we find a weaker correlation between average engagement of activity and it's helpfulness with Pearson Correlation Factor of 0.45, thus unable to reject the null-hypothesis (p-value is 0.4391).
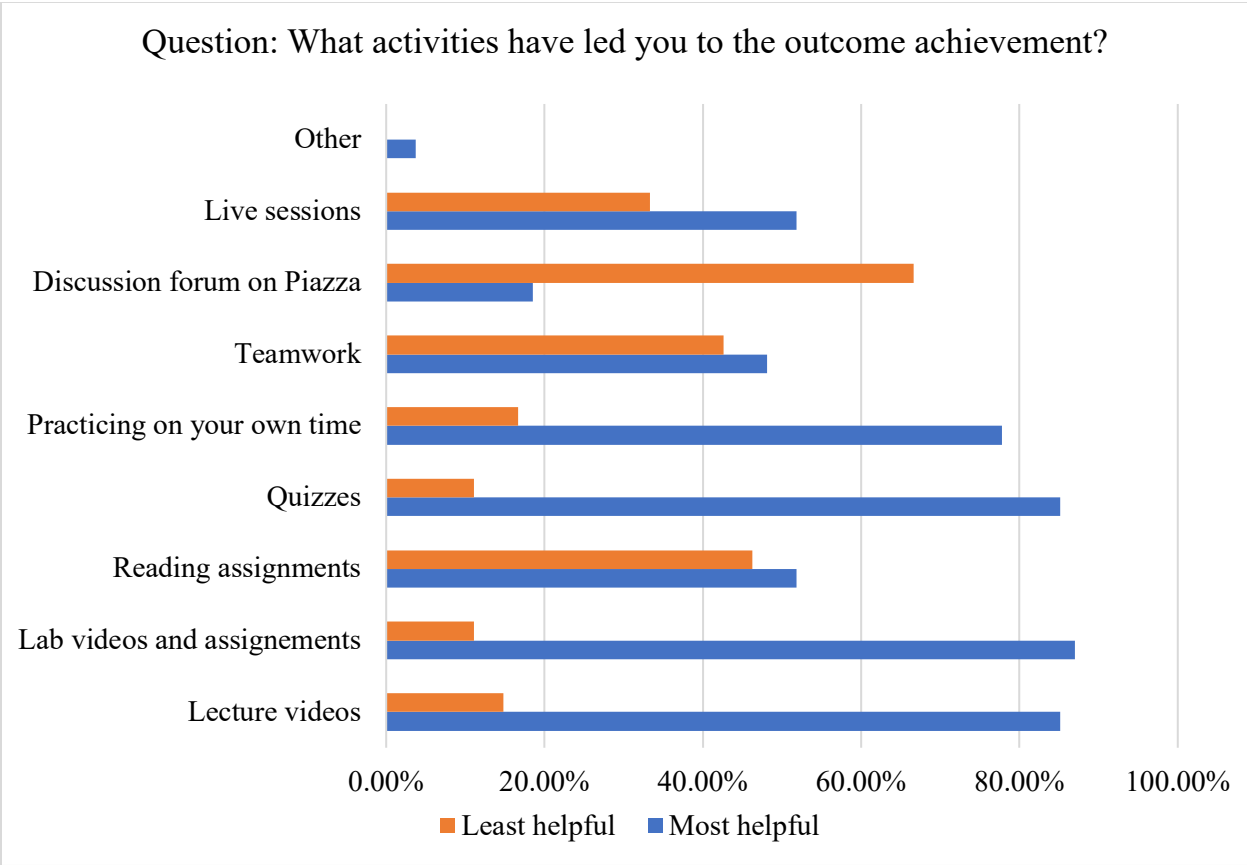
Figure 8 Assessing the course element that students perceive as helpful to their learning.
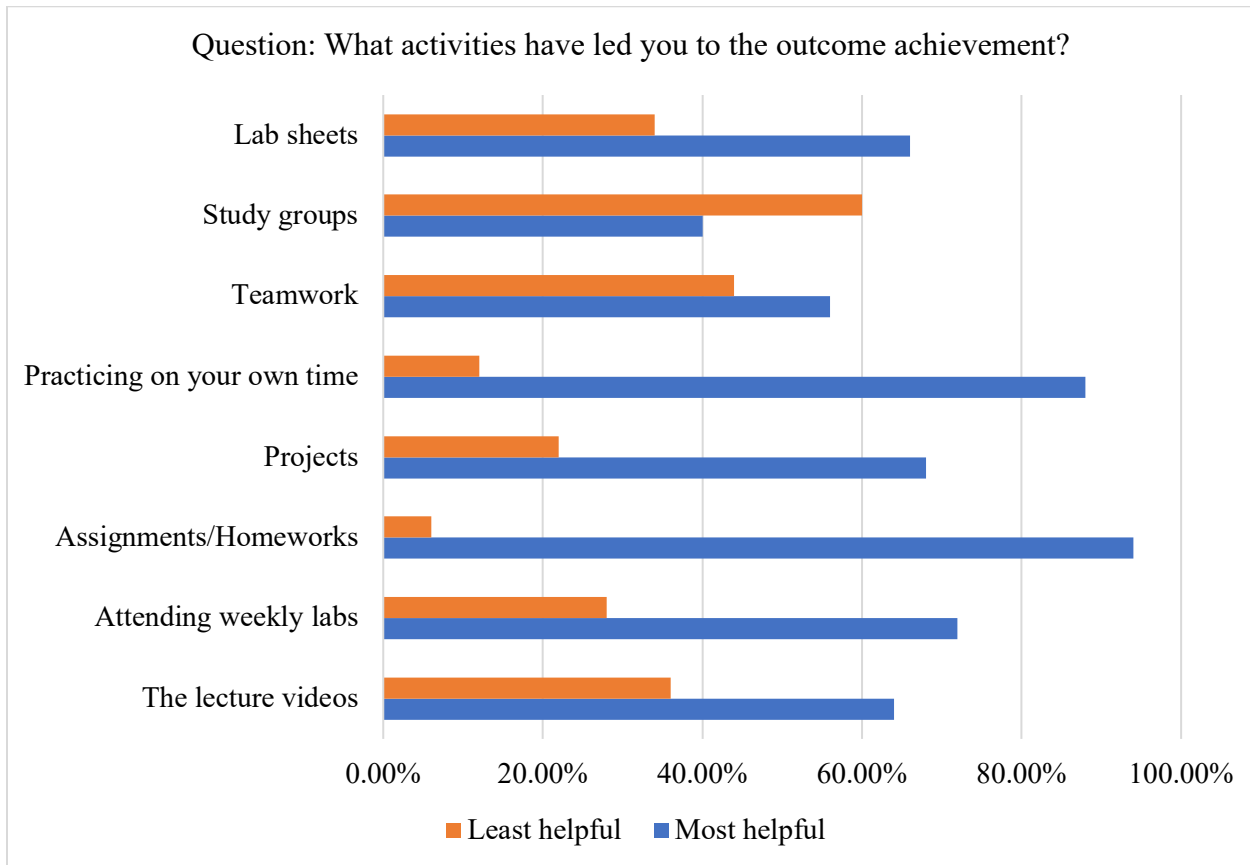
Figure 9 Assessing the course element that students perceive as helpful to their learning.

5. Conclusion

Development of hybrid or fully online courses has gained momentum within the engineering education community, in part, to increase accessibility and offering more flexibility or individual customizability of learning to students. However, developing effective instructional material while leveraging unique features of online platforms, and collecting evidence of student performance to inform and improve the instructional design of online courses is a practical challenge requiring research and scholarly attention. This paper reports the process of developing two online courses in Mechanical Engineering, one is Strength of Material offered in a fully online format, the other is Computer Aided Engineering offered in hybrid format. First, we developed a framework informed by the extant literature to streamline the process of course development addressing the roles and responsibilities of both instructors and students. Next, to identify (1) elements of the online courses requiring future improvement, and (2) opportunities to enhance learning by surveying student experiences, we focused on evaluating student engagement and satisfaction.

We find that learning experiences that students perceive as effective or helpful correlate with activities they mostly engage with such as lecture videos, homework assignment, and quizzes in Strength of Material. In the hybrid format, students also perceive weekly face-to-face sessions as helpful towards their learning, while in a fully online format around 30 percent of students find live sessions as "least helpful". In both courses, we observe high peer-to-peer interactions, as well as low engagement with an online discussion forum. Two potential strategies to encourage further participation in online discussion forum are (i) attributing grade points as an incentive, or (ii) providing directives, examples, and structures for initiating various types of discussions in such an environment. In addition, our study demonstrates that students invest

significant time on lecture videos, homeworks, quizzes, and projects. For educators, this is a warrant to regard these elements as critical to online instruction demanding effective design and full alignment with desirable course outcomes. To further scaffold student learning during the activities with high rates of student engagement, in particular, the lecture videos and the subsequent homework assignments, we intend to consistently implement the following redesign. All lecture videos, as of now, cover foundational concepts and theories supplemented with a number of applied model-problems. The homework assignments or quizzes can be built directly upon the model-problems covered in the lecture videos by adding further layers of details and/or components. This approach can enhance the integrity of each module and we expect to encourage students in paying closer attention to these activities.

This study provides limited insight to be able to conclusively respond to our motivating research questions. For example, to obtain a more nuanced account of how students interact with the course material, their peers, and instructors a qualitative and/or a mixed research framework can be used. Such an approach will be better suited for identifying the gaps in the activities students highly engage with and/or those they deem beneficial to their learning. This study and its future developments not only provide evidence for our own future offerings, but also can be shared with students to provide meta-cognitive information on how in previous cycles participants engaged with and perceived the learning opportunities in online and hybrid courses.

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