Understanding Gaps in Student Engagement and Motivation in Online and Hybrid Mechanical Engineering Courses

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***Abstract*—The continuing growth of engineering courses with fully online or hybrid modalities provide novel opportunities and challenges in engineering education. to fully exploit the online teaching settings, educators should focus on increasing the students' engagement with learning activities as well as the motivation of students to remain connected and follow the pace of the course, especially with the lack of face-to-face interaction. Research in educational psychology shows motivation and engagement are task-specific and interconnected phenomena, therefore assessing gaps in how students' engagement and motivation associate with specific learning activities can lead to contextualized evidence for pedagogical decision making. In this paper we report on development and continuous research-based improvements for two online mechanical engineering courses. the presented analysis is based on a survey instrument and examination of open-ended student feedbacks.**

***Index Terms*—Engagement, Motivation, Mechanical Engineering, Online Education**

Introduction

Online education is today a widely accepted and viable methodology for engineering education in diverse institutional contexts at multiple scales. This broad acceptance and utilization are contingent upon the *quality*, *scale,* and *breadth* of online education as Bourne *et al* point out [1]. The pervasive access to communication technology and connected media enables educators to employ tools such as recorded videos, live streaming of lectures, and live discussion panels in teaching and learning. Bourne *et al*. [1] 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.

Despite the apparent advantages and benefits of online education, there are diverse challenges to ensuring the evidence-based efficacy of online course. 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 [2] however, this might be more challenging in other topics within mechanical engineering. The 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 [3].

A major challenge in determining the quality of online courses is student's engagement and motivation compared to the face-to-face courses. Online courses rely on independent learning habits where students need to manage their own time and effort or develop opportunities for peer interactions. Hence, a research-based tool for evaluating student engagement and motivation in online settings can help educators to close the loop of assessing the instructional 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 [4, 5]. Multi-institutional studies have shown student engagement to be a precursor to persistence and student retainment in engineering [6]. 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 compared to face-to-face settings [7]. Through a meta-synthetic review of the literature on distant learning and online course development, researchers have shown several emergent themes in the literature [8]. 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 targeted feedback to students is also another challenging and demanding aspect of online course instruction [9].

Although engineering labs are commonly identified as a hurdle to the effective delivery of engineering education online [9], we leveraged interactive virtual environments to create Strength of Material laboratory tests for an online course. The use of computational simulations to create virtual lab experiments for online courses has shown promising potential in the previous investigations [10]. 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 of California, Merced. We present our model for defining essential roles and responsibilities to design and manage online courses based on best-practices in literature. Next, we explain the development of a tool to measure students' engagement and motivation followed by our analysis of 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.

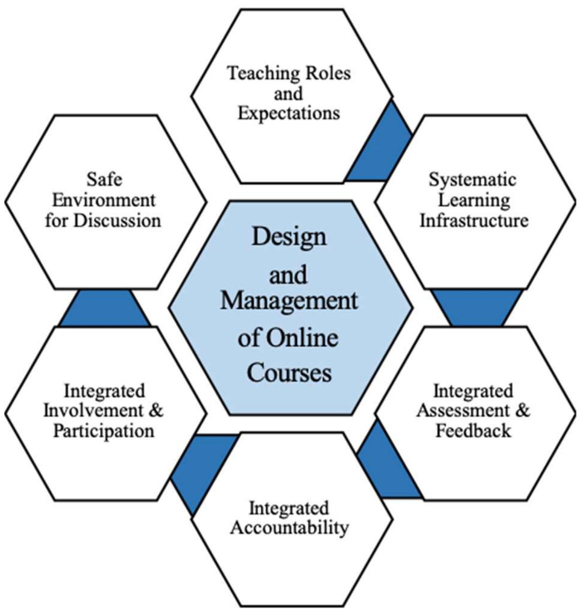

Figure 1. A streamlined framework for the design and management of online courses in engineering.

I. ONLINE COURSE DESIGN AND MANAGEMENT

The process we used to develop online engineering courses in mechanical engineering was an iterative collaboration between the lead faculty, an instructional advisor, and graduate student assistants. One of the first critical decisions we had to make was regarding the extent to which the desired courses will be *online* or *hybrid*. Based on the requirements of our funding agency and the interest of the faculty to utilize online technologies we transitioned the Strength of Material to a completely online format. This includes pre-recorded videos, a virtual interface for laboratory experiments, online assignments and quizzes, online readings from a "smart textbook", as well as live (synchronous) online lectures, review sessions, and office hours. Alternatively, the course on Computer-Aided Engineering was developed in a hybrid format with interactive opportunities in both online and face-to-face (classroom) settings. To facilitate the coordination during the development stage we defined six major elements of our design process based on the literature on best practices in relevant contexts. The elements of our management and instructional design are shown in Figure 1 and will be reviewed briefly here.

A. *Teaching Roles and Expectations:*

Teaching online engineering courses demands the instructors to have different roles regarding the content choices, students' needs, tracking the development time-line and delivery of the course to name a few examples. Online courses also need to have tailored learning outcomes that may not be the same as that of face-to-face offerings [11] since the nature of the learning experience, i.e. both quality and quantity of student activities, 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 [12]. Explicating the basic aspects of roles and expectations is a critical element of effective collaboration or teamwork efficacy.

B. *Systematic Learning Infrastructure:*

The lack of face-to-face interaction in online courses requires the establishment of a well-defined system to efficiently integrate the course material and deliverables while allowing on-demand modifications throughout the semester. Modularization of the course on a periodic, for example, weekly basis allows to preset the publication timeline of online videos or live streaming, due dates of assignment delivery, and their grading and solution, expected posts 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 result in smoother streamlining of the educational experience. 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 course design relies heavily on the features in the Learning Management System [13] and the level of flexibility they provide vis-a-vis organization of items and conduits of communications.

C. Integrated Assesment & Feedback:

The integration of assessment and feedback tools may take many forms in engineering online courses. It depends on the digitized tools or platforms 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 to enhance 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, strengths, and weaknesses. Thus, it is important to take into account the close connection between the roles of grading and providing targeted feedback.

D. Integrated Accountability:

online education encourages independent learning. It is necessary to integrate an accountability mechanism that enables the students to be fully engaged, oriented, and paced in their learning. Examples of accountability mechanisms are progress indication tools that highlight the percentage of completed tasks for a certain week and checklists that facilitate the pacing of student activities. In the Computer-Aided Engineering online course, students were able to see what percentage of lecture videos they viewed, and in both courses, students received a weekly module overview that made explicit the connection between different items of the module and learning objectives therein. This tool is automatically set to send reminders to students for approaching submission deadlines.

E. Integrated Involvement & Participation:

researchers have investigated the role of student involvement in educationally effective practices as an important proxy for academic achievement [14]. In addition, the rate of faculty-student interaction is also known to have an impact on overall student perception and satisfaction [15]. Richardson *et al* [16] report 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 [17] 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 lecture videos, the use of online 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 and the extent to which they are motivated to do so. On the other hand, regular meetings of the instructional team (faculty, teaching assistants, and instructional designer) allows each member to continuously share, reflect and discuss his or her observations and concerns regarding issues such as performance and learning gaps.

F. Safe Environment for Discussion:

Establishing a safe climate for participation, sharing and discussion is essential to the quality of online courses. Instructors can foster a safe environment by encouraging participation, giving evidence-based reasons to students on its benefits, and creating pathways to students for discussing their challenges and questions throughout their studies. It is the instructor's responsibility to facilitate and encourage participation and communication. Some of the student discussions will be shared among all users (students and instructional team), hence the emphasis on inclusiveness and safe environment is essential in designing a forum where students can post questions and answers and discuss course topics with no inhibition.

II. EVALUATING STUDENT ENGAGEMENT AND MOTIVATION

The immediate impetus of this study is to identify opportunities for educational improvement as we developed two online courses and to gain applicable insights on students' perception of their learning and the extent to which it relates to engagement with course activities. Using students' self-reports, we developed a survey instrument to measure engagement and motivation. We conceptualize engagement as the amount of time that students spend on learning activities of various type, measurable by asking, for example, 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 or usefulness of instructional elements in the course toward their achievement of outcomes.

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, we first exhibit the survey results from two consecutive years addressing the questions 1 and 2 above. In both courses, we first collected data at the end of Fall semester 2017 and then at the mid-semester and final days of Fall 2018. Our net participation rate was around 40% of the total enrolled students. We then discuss the implication of our findings for future action, hence addressing questions 3 and 4.

III. RESULTS AND DISCUSSION

A. Student Engagement:

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

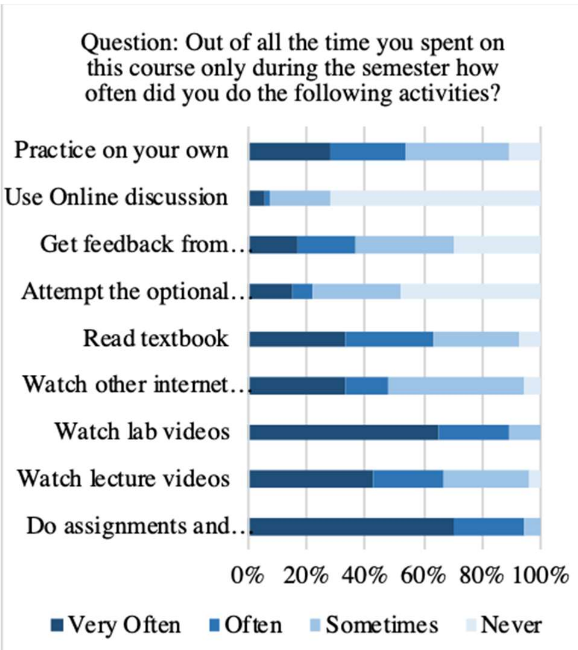

Figure 2. Assessing Student engagement with instructional activities in online Strength of Material course over two academic years (n=54).

In Computer-Aided Engineering the same question yielded similar findings (p-values for t-test comparison of two courses are given in Table 1). While smaller number of students report high engagement ("very often") with the course videos in Computer-Aided Engineering, this difference is statistically insignificant (p-value=0.67) with Strength of Material 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, thus we conclude both data sets to entail similar findings. In both courses, we find that engagement with the online discussion forum to have the smallest mean value.

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

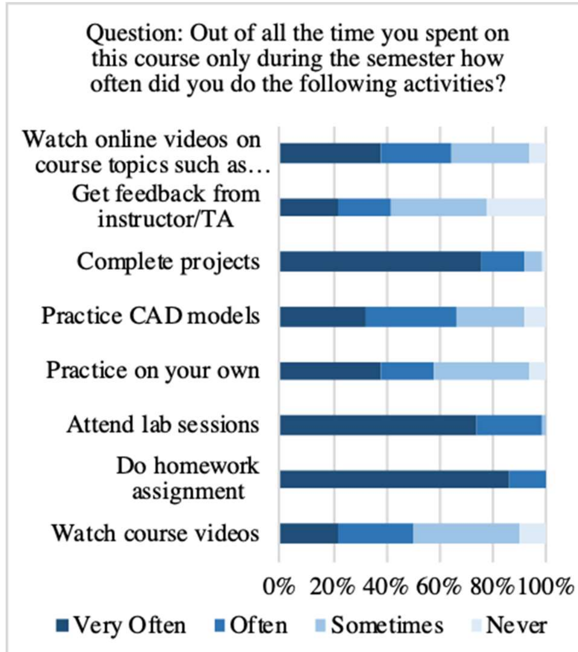

Figure 3. Assessing Student engagement with instructional activities in online Computer Aided Engineering course (n=50).

TABLE I.
MEAN VALUES (μ) FOR ENGAGEMENT IN STRENGTH OF MATERIAL (**SM**) AND COMPUTER-AIDED ENGINEERING (**CAE**) ARE 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 CONFIRM THAT ON AVERAGE BOTH CLASSES YIELD SIMILAR RESULTS.

Activities	μ (SM)	μ (CAE)	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
Practice 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

B. Student Motivation:

Next, we ask students to report on their perception of learning and how they find the course activities contributing to that. We survey them first based on their perception of achieving the 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 both Strength of Material and Computer-Aided Engineering, we find the majority of students to "agree" that taking this course helped them achieve the course learning outcomes. Figures 6 and 7 illustrate clustering of responses in both courses for all learning outcomes that is left skewed.

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 appraisal of helpfulness. As Figure 8 illustrates, lab and lecture videos, quizzes, and personal practice time are ranked highest in helpfulness by students in Strength of Material while they report online discussions and reading assignments as least helpful to outcome achievement. Using Pearson Correlation Factor (a measure of linear dependence) between average engagement of activities and their helpfulness in Strength of Material we find these two observations to correlate with a factor of 0.86 and the p-value=0.015. In this case, null-hypothesis refers to the assumption that average engagement of activity and its helpfulness are not correlated. We are able to reject this hypothesis with a significance well below 0.05. To summarize, our data shows that activities that students spend most of their time engaging with are the same as activities they find most helpful towards achievement of outcomes.

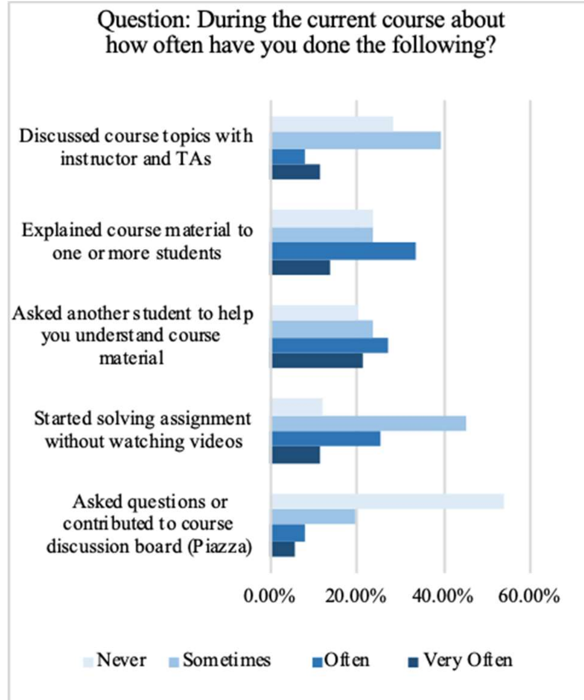

Figure 4. Assessing Student engagement with peers and instructors in online Strength of Material course over two academic years (n=54).

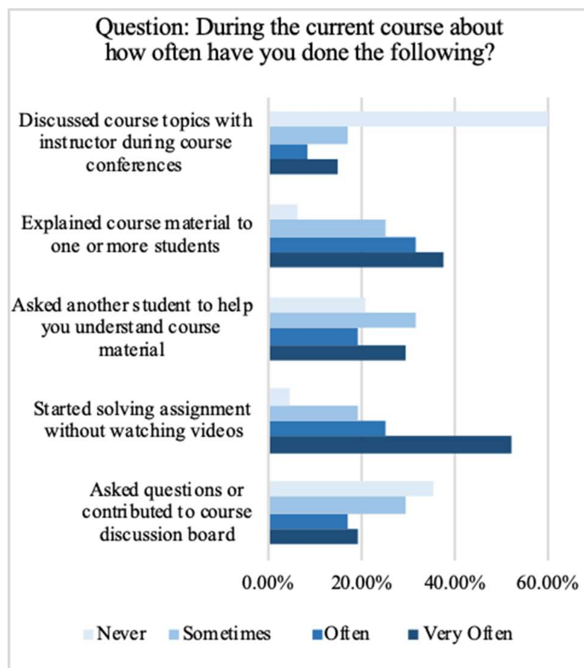

Figure 5. Assessing Student engagement with peers and instructors in online Computer-Aided Design course over two academic years (n=50).

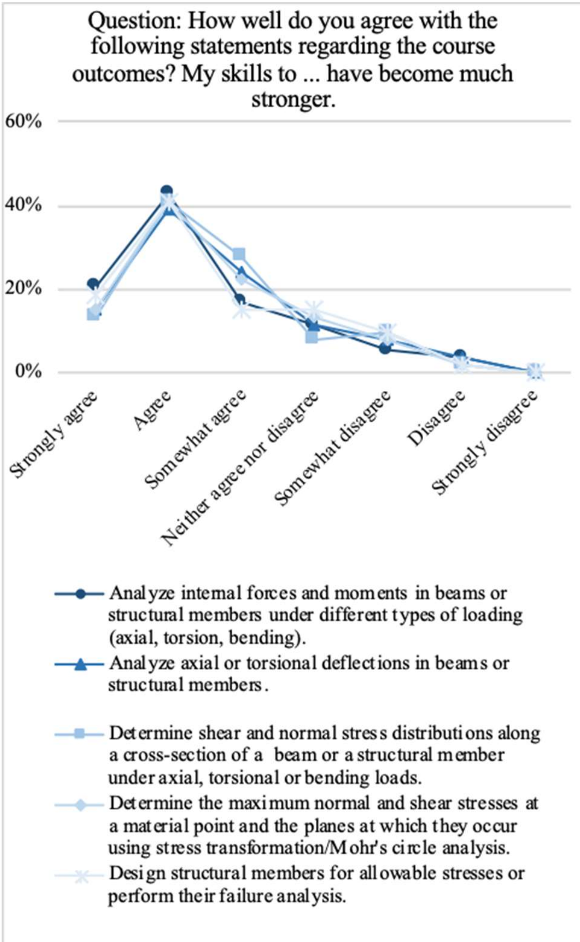

Figure 6. Assessing student perception of learning as a proxy for satisfaction with the online Strength of Material course (n=54).

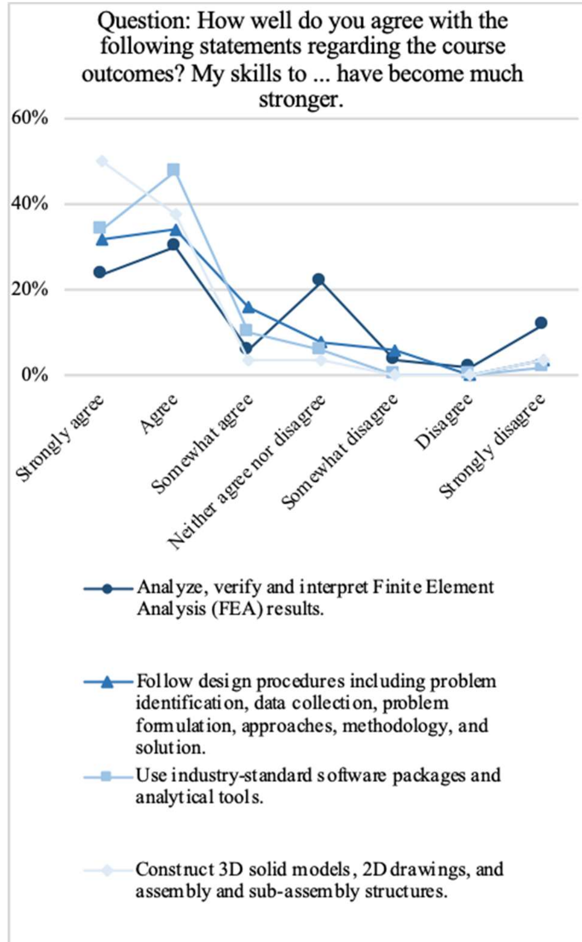

Figure 7. Assessing student perception of learning as a proxy for satisfaction with the online Computer Aided Engineering course (n=50).

In Computer-Aided Engineering, students report homework assignments, individual practice, and 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% 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 we find a weaker correlation between average engagement and its perception of helpfulness. In this case Pearson Correlation Factor is found to be 0.45 and p-value is 0.4391 thus data do not corroborate the same conclusion in this case. We can explain this difference by lower rate of helpfulness that students report for time taking activities such lecture videos and assignments, while the project activity that they find very helpful to their learning took a much smaller amount of time over the entire span of the course. Hence, we would point out that our correlational analysis is best suited for comparison of activates that are expected to repeat with equal frequency, for example weekly.

C. Open-Ended Student Feedbacks:

Using thematic analysis of student comments regarding their learning experience in our online and hybrid courses we were able to identify two categories that students addressed in their comments. First, they explicitly point out the impactful role of *individual independence* towards success in online settings by using terms such as "this is more on the students than anything" or "students should not expect the Instructor or TAs to hold their hand". Their comments suggest that student decision making, time management, and personal discipline are crucial factors in learning efficacy. Second, students express some concerns regarding the reading assignments using phrases such as "I would add weekly lectures restating what was said in the textbook" or "I would add … checkpoint questions throughout the reading to ensure the important concepts are understood". These comments provide further support that increasing intra-module alignment can help students better appreciate the connection and gradual scaffolding of learning activities in each week.

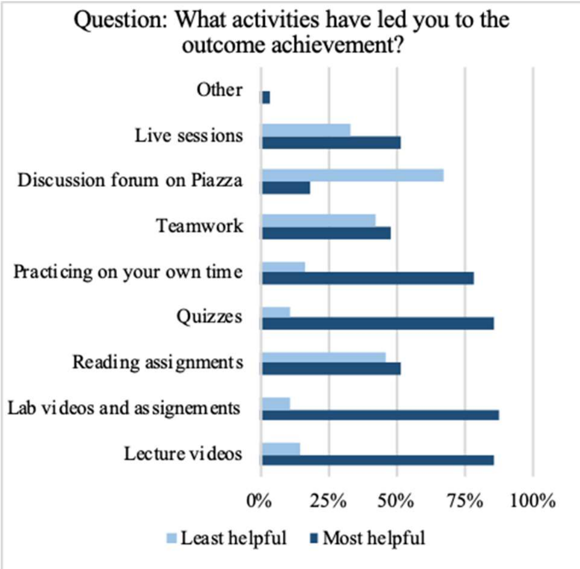

Figure 8. Assessing student perception of how various activities are helpful to their learning achievement.

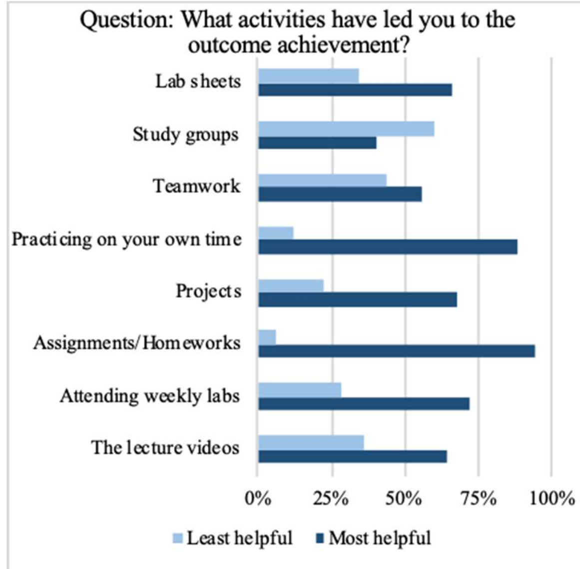

Figure 9. Assessing student perception of how various activities are helpful to their learning achievement.

IV. CONCLUSION

The development of hybrid or fully online courses has gained momentum within the engineering education community, in part to enhance accessibility and individual customizability of learning opportunities of diverse students. However, developing effective instructional material while leveraging unique features of online platform 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 fully online, the other is Computer-Aided Engineering offered in a hybrid format. First, we developed a framework informed by the extant literature to streamline the process of course development addressing the basic roles and responsibilities for instructional teams and students. Next, to identify (1) elements of the online courses requiring continuous improvement, and (2) opportunities to enhance learning by surveying student experiences, we focused on evaluating student engagement and motivation.

We find that learning experiences that students perceive as effective or helpful correlate with activities they mostly engage with such as lecture videos, homework assignments, and quizzes in Strength of Material. In the hybrid format, more than 70% of students perceive weekly face-to-face sessions as helpful towards their learning, while in a fully online format around 50% of students find live (synchronous) sessions as "Most helpful". In both courses, we observe high rates of peer-to-peer interactions, as well as low engagement with an online discussion forum. Two potential strategies to encourage further participation in online discussion forums are (i) allocating grade points as an incentive, or (ii) providing templates, directives, and structures for engaging in various types of discussions in such an environment. In addition, our study demonstrates that students invest significant time in lecture videos, homework, quizzes, and projects. For educators, this provides a warrant to regard these elements as crucial 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 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 several 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 complexity. This approach can enhance the intra-module integration and further incentivize students towards closer attention to all elements in a module.

This study not only provides insights to answer our motivating research questions, but also informs our ongoing and future efforts to expand the techniques of assessing engagement and motivation in online engineering courses. For example, to obtain a more nuanced account of how students interact with the course material, their peers, and faculty a qualitative or a mixed-method research framework can be used to more closely track the diversity of individualized approaches and motives students use for learning in an online environment. The results we report in this study and the survey instrument developed therein are applicable in diverse educational settings for design and development of online, hybrid, or on-ground engineering courses subject to common and necessary discretion of educators.

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