Conceptual Learning Gains for Face-to-Face and Asynchronous Online Course Modalities in Introduction to Materials Science

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Abstract
Different educational modalities can affect students in learning challenging engineering concepts. Studies that specifically measure students' conceptual learning gains have been conducted in face-to-face (F2F) and online modalities, but few direct comparisons have been reported. In this study, we collected data from undergraduate students enrolled in introductory materials science courses in a F2F modality (N = 90) and asynchronous online modality (N = 77). Normalized learning gains were reported using a test instrument that combined twenty-six materials science concept questions taken from two concept inventories. Students completed the test at the beginning and end of each course. The average conceptual gain for the F2F modality was found to be higher than the online modality. Statistical analysis revealed a significant difference in the average gains, with a medium effect size. Multiple factors that might lead to this difference in conceptual learning are proposed. The findings in this study can serve as guidance for further educational research and instructional design, focusing on improving students' conceptual learning for both modalities, especially for the asynchronous online learning environment.

Introduction
Engineering courses are generally considered challenging to teach online as they often require mathematical approaches, design tools, and laboratory competency (Bourne et al., 2005). Conceptual understanding undergirds all engineering work; however, explicitly addressing and developing such conceptual understanding in engineering courses is often lacking (Streveler et al., 2008). To address this need, various techniques and tools have been developed to support conceptual learning for college students in various engineering disciplines. In this study, we extend the body of work to address supporting students' developing conceptual understanding of materials science in online modalities.

Distance learning traces back to the 1840s (Kentnor, 2015) and with the development of the internet has evolved into online modalities. While effective online pedagogical practices have been developed, especially in response to the recent global pandemic, studies have investigated student performance and perceptions between different modalities. However, few studies specifically focus on conceptual learning gains. For example, studies in engineering have compared course grades (homework and exams) and demographic data (Bir, 2019; Fischer et al., 2020); participation data, such as attendance for F2F and click activity for online (Bergeler & Read, 2020); and surveys of students' perceptions (Libre, 2021; Sottile et al., 2021). None of these studies have directly measured and compared conceptual learning gains between different learning environments.

In this study, we compared students' conceptual understanding between two course modalities: face-to-face (F2F) and asynchronous online. We were interested in examining how the difference in engineering course modality corresponded to students' conceptual understanding, specifically for challenging materials science concepts.

Conceptual Learning
Differences in student performance by modality are often compared generically as "outcomes." In this work we use Shavelson's et al. (2005) framework to specifically differentiate between different types of engineering knowledge. The framework categorizes knowledge into four types: declarative (knowing that), procedural (knowing how), conceptual (knowing why), and strategic (knowing when, where, and how). Declarative and procedural knowledge can be seen as a foundation to develop conceptual knowledge, which is when students are able to connect what they have learned together to develop conceptual understanding or knowing why. Consequentially, conceptual understanding allows students to solve new problems they have not encountered before

by transferring their knowledge to other contexts (National Research Council, 2000).

Learning challenging concepts in engineering is a complicated process that can be impacted by numerous variables, such as prior robust misconceptions (Yang et al., 2020), lack of broader level conceptual understanding or practical experiences (Sanchez et al., 2022), and anxiety (Phanphech et al., 2022). Misconceptions can stem from students' prior beliefs or from instruction that crams too much content into a short period, which can promote memorization of facts and create incoherent logic (Michor & Koretsky, 2020; Vosniadou et al., 2001). Researchers have rigorously investigated how to identify and repair or replace misconceptions (Krause, et al., 2010). Others argue that instructors can use disjointed prior knowledge as "stepping-stones" to cultivate students' sense making processes (Campbell et al., 2016), such as asking students to share and compare their ideas and experiences for revising explanations and solving problems.

In response, pedagogical techniques have been developed to initiate deeper thinking of concepts in classes (Koretsky et al., 2011). For example, the use of Just-in-Time-Teaching methods with pre-class questions can help students reflect on the course content, reason through common misconceptions, recognize their own learning barriers, and set their focus on the day's lesson (Formica et al., 2010; Kelly et al., 2009; Novak et al., 1999). Similarly, post-class reflection questions such as asking for their muddiest point and the most surprised reflection can help students be more metacognitive (Keeler et al., 2015; Keeler & Koretsky, 2016; Krause et al., 2013, 2014; Mansfield et al., 2018). Other tools such as the use of inquiry-based activities (Gao & Lloyd, 2020) and game-based learning (Shernoff et al., 2020) can promote students' engagement through real-world problem solving.

In this study, we focus on the use of concept-based questions, short qualitative multiple-choice questions that focus on challenging concepts. These questions have been used in a variety of engineering courses, such as: mechanics (Berry & Graham, 1991; Danielson & Mehta, 2000), physics (Beatty et al., 2006; Formica et al., 2010; Wilcox & Pollock, 2014), electrical circuits (Streveler et al., 2008), thermodynamics (Friedrichsen et al., 2017; Streveler et al., 2008; Vigeant et al., 2011), chemistry and materials science (Kitto, 2006; Krause, 2007).

Concept Inventory

Concept Inventories (CI) are psychometrically developed instruments used to measure conceptual learning gains. Initially developed to assess conceptual understanding in mechanics (Hestenes et al., 1992), CIs contain a set of multiple-choice concept questions and are typically delivered at the start and end of a course. Importantly, they contain good distractors (incorrect choices) obtained from empirical data (Alemdar et al., 2017; Koretsky et al., 2011; Krause et al., 2002; Vigeant et al., 2011; Wuttiprom et al., 2009).

Conceptual learning gains are often reported from CI data as the average of the ratio of the actual average gain to the maximum possible average gain, known as the average normalized gain, $< g >$, (Hake, 1998). Another approach, when the data is available, is to calculate the conceptual learning gains from each student's scores as the individual normalized gain, g, (Coletta & Steinert, 2020; Hake, 2002):

$$\boldsymbol{g} = \frac{(\boldsymbol{final\ correct}\ \% - \boldsymbol{initial\ correct}\ \%)}{(\mathbf{100} - \boldsymbol{initial\ correct}\ \%)}$$

Larger values of g represent greater conceptual learning (maximum at g = 1). Sometimes negative values are found that might be due to lucky guesses on the initial test or not taking the final test seriously (Coletta & Steinert, 2020; Stewart & Stewart, 2010).

Two CIs are commonly used for introductory materials science courses: the Materials Concept Inventory (MCI) (Corkins et al., 2009; Krause et al., 2002, 2004) and the Material Science Conceptual Evaluation (MSCE) (Rosenblatt & Heckler, 2017; Rosenblatt, 2012). Several studies have reported conceptual gains in F2F courses using the MCI (Krause et al., 2003; Krause, et al., 2010; Zhou et al., 2015) and the MSCE (Sanchez-Mata et al., 2020). These studies investigated the conceptual gains among different pedagogies – such as lecture-based versus active learning – but none have compared different course modalities, such as F2F versus online.

We found just two studies comparing conceptual learning gains in engineering courses between different modalities. Phanphech et al. (2022) compared students' conceptual learning gains of passive electric circuits between synchronous versus asynchronous online physics courses using a test called DIRECT (Sangam & Jesiek, 2012). The reported data for both online modalities showed positive gains, with the gain for the synchronous group (0.222) larger than the asynchronous group (0.105). Wallace and Knudson (2020) used the Biomechanics Concept Inventory to compare the conceptual gains between F2F and hybrid (part in person and part synchronous as well as asynchronous online) modalities. Interestingly, the mean in gain for the hybrid modality (0.26) was slightly higher than the F2F (0.15) with both having medium effect sizes. We have not found any published studies in engineering that directly compare the conceptual learning gains in students between F2F and asynchronous online modalities.

Research Question

In this study, we investigated students' conceptual learning gains in materials science introductory courses in F2F and asynchronous online modalities. Specifically, we were interested in answering the following research question:

Is there a difference between the conceptual learning gains of students in F2F vs. asynchronous online modalities?

Methods

Ethics Statement

This study was conducted following the approved institutional review board IRB-2020-0775 procedure. The choice to participate was purely voluntary and available for all students enrolled in the courses. All data analyzed and reported in this study was gathered only from participants who provided their consent. These data were stored in a secure server that can be accessed only by research team PIs and approved members via the Oregon State University credentials. To protect the identity of the participants, randomly assigned numbers replaced all participant identities for all data processing and the data were aggregated for shared results. To ensure all students were treated equally during their terms, regardless of their choice to participate in the study, the instructors for all courses – which are two of the authors – and all members of the research team did not access the consent forms until the end of each term after final grades were submitted. There was no compensation for students to participate in the study.

Setting

The Introduction to Materials Science (MATS 321) course at Oregon State University is offered in both F2F and asynchronous online modalities every term, except the summer term in which only the online section is offered. The F2F section is a larger lecture-type class with 150 – 190 students per term. The online section usually has 30 – 50 students and is open for on campus students as well as distance students. The course is mandatory for some engineering majors and an elective for others.

Data in this study were collected from a F2F course in Fall 2021 and from the asynchronous online courses over four terms (Winter to Fall 2021). Both course modalities were based on the same textbook and topics covered. The courses were designed by the same instructors, which are two of the authors – one teaches the F2F course and the other the online courses. The structure of both course modalities was similar with the same concise pre-recorded weekly lecture videos, multiple-choice concept question homework assignments on one of the challenging topics, weekly reading comprehension quizzes, end of week topic quizzes, two midterms, and a final exam.

The F2F course was delivered after a COVID-19 pandemic peak when most students were back on campus wearing masks. Around 70% of students participated in the classroom while others participated via a synchronous video conference platform. The concise pre-recorded weekly lecture videos were provided as out-of-classroom resources, but the instructor also lectured during class time. The instructor in the pre-recorded videos was the same as the one teaching the F2F class, thus the topic covered during lecture time were the same but with longer explanations and examples. Concept questions were not assigned as homework, except for the same challenging topic as assigned in the online courses, but were included for in-class activities and discussions. The midterms and final exam were held in class, timed, and proctored. Students were allowed to bring a one-page study note, but these were not open book exams.

The online courses were delivered in four terms from Winter to Fall 2021, one in the same term as the F2F course. For the first two terms, the instructor provided an asynchronous, non-anonymous discussion board. For later terms, the instructor added anonymous discussion boards in addition to the non-anonymous one, based on student requests. The instructor also provided an opportunity for students to join synchronous discussion sessions via video conferences. There were three sessions per term, each on the week before each midterm/final exam, scheduled based on most availability provided by students (an optional anonymous ungraded survey). These meetings were recorded and posted for anyone who could not attend. The three exams (midterms and final) were timed and had flexible starting times in which students could start working on each exam any time within a 48-hour period. To minimize academic misconduct in these online exams, large pools of randomized questions were used and students were unable to see their submitted works until after the exam period ended. Exams were open book, but internet searches and discussion with others were not allowed. A proctoring system was used for two out of four final exams, and other exams only required students to submit a picture of their faces with their IDs.

Participants

Students who took MATS 321 courses in either modality were mostly in their junior or senior years pursuing undergraduate degrees in mechanical engineering. Participant data are reported in

Table 1. Only complete data sets from students who did not drop or withdraw from the course, provided their consent, and completed both initial and final “MCI + MSCE” test instruments (described in the next section), were used in the analysis reported here (see

Table 1). The number of participants represented a sample of slightly over half of the total students enrolled.

Table 1. Number of participants based on modalities.

	F2F	Online [a]
Students enrolled in courses	175	147
Students who provided consent	147 (84%)	126 (86%)
Students with complete data	90 (51%)	77 (52%)

[a] Four asynchronous online courses combined

Learning Measures

We developed the "MCI + MSCE" test instrument based on a combination of questions taken from the two CIs, the MCI and MSCE, to compare the conceptual learning gain from the beginning of the term to the end. A total of 26 multiple-choice concept questions (8 from MCI and 18 from MSCE) were chosen based on their alignment with topics covered in the course. There were three to five answer choices per question. Questions were provided via the Concept Warehouse online platform (Friedrichsen et al., 2017; Koretsky et al., 2014). The test instrument – the initial (pre) test at the beginning of each term and the final (post) test at the end of each term – was available for a 7-day period and students could complete them at their own pace with no time limit. Students who completed both tests received participation points for completion as a bonus score on top of their final grade, regardless of their participation in the research study. Students were encouraged to answer based on their current knowledge without researching for the correct answers. No answer key was provided, and the exact questions were not discussed in either course modalities; however, similar concepts were discussed during the term. All correct percentages from each student's initial and final of the test instrument were collected and calculated as normalized gain, g, using the equation shown on page 3.

Analysis

We used RStudio (RStudio Team, 2022) for the statistical analysis. Preliminary analyses using a Kruskal-Wallis test indicated that there was no statistically significant difference in average normalized learning gains among the four online courses, $p = .65$; therefore, data from all four online courses were combined to represent the online modality (See

Table 1 for participants in both modalities). We investigated if the averages (population means) of the students' conceptual learning gains for F2F and online modalities were different. We based our test on a significance level of $\alpha = 0.05$. We used a two-tailed Welch's t-test to test the difference in means of individual normalized gains between the two groups, assuming a normal distribution due to the large sample sizes. We chose the two-tailed, instead of one-tailed test because one group can have a higher or lower mean gain. Each modality data set was independent within groups as well as between groups since students would not take two MATS 321 courses the same term. For any students who reenrolled in the course in later terms to get a better grade, they were included as different and independent data, as their performances would have changed when they went through the course the second (or third) time. During the analysis, we removed one outlier ($g = -0.82$) in the F2F group as it is reasonable that the student was not engaged in their final CI, based on their response. We quantified the magnitude of the difference using the effect size Cohen's d (Cohen, 2013) with the weighted average pooled variance due to the non-uniform sample sizes. To compare the respective variances of two samples, we used a Fisher's F test, also known as F-test of equality of variances.

Results

Conceptual Learning Gains in F2F versus Online Modalities

Table 2 shows the results of conceptual learning gains for the "MCI + MSCE" test instrument. The number of students with complete data sets (N) and the mean (M) and standard deviation (SD) of the initial-final differences are reported. A two-tailed Welch's t-test revealed a statistically significant difference between the mean gain for F2F ($M = 0.36$, SD 0.26) and online ($M = 0.21$, SD 0.21) modalities. Using Cohen's d, the effect size of 0.61 indicated a medium effect (Sawilowsky, 2009). This result indicates that modalities can affect conceptual learning gains in an introductory to materials science course. However, note that the average normalized gains of both modalities are lower than 0.5, indicating an opportunity for improving conceptual learning in both modalities, especially the asynchronous online modality.

Table 2. Average normalized conceptual learning gains from the "MCI + MSCE" test instrument for F2F and online modalities.

	N	*M*	*SD*	*t*(163)	*p*	Cohen's *d*
F2F	89	0.36	0.26	3.95	<.001	0.61
Online	77	0.21	0.21			

Note. Fisher's F test indicated there is no significant difference in variances ($F = 1.54$; $p = .053$).

The distributions for both modalities are shown in the box plot in Figure 1 and the histogram in Figure 2. The interquartile ranges for both modalities overlapped (Figure 1) and the distributions were approximately normal (Figure 2).

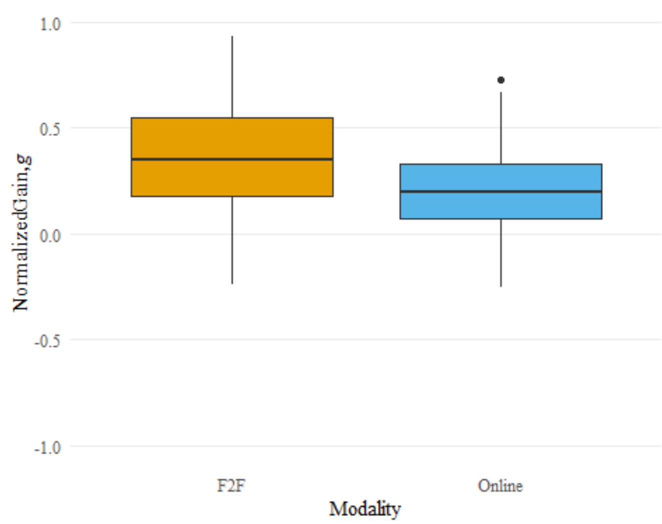

Figure 1. Box plot of conceptual learning gains for F2F and online modalities.

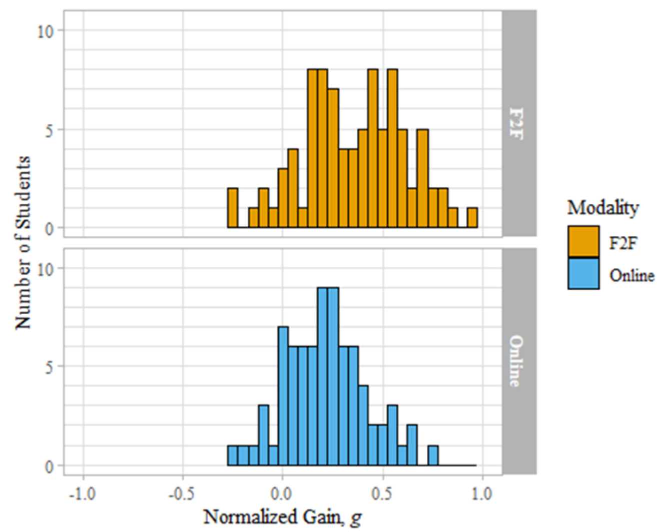

Figure 2. Histogram of conceptual learning gains for F2F and online modalities.

As shown in the figures, there were some negative gains. Rather than concluding students knew less at the end of the term, this result could be from lucky guesses during the initial test (Coletta & Steinert, 2020). Although Stewart and Stewart (2010) suggested that a "guessing" effect correction should be reported since blind guessing can result an average score of 20% for five answer choices, they also concluded that the average of the gain may be unchanged, so it is reasonable to report the results without the correction. As we did not plan to incorporate reporting the guessing effect correction in this study, we did not collect associate question ("I'm guessing") and thus unable to report a correction.

Discussion

Although the F2F and online courses were developed in coordination and as similarly as possible, we found a statistically significant difference in conceptual learning gains between them. Little is reported in the literature comparing conceptual learning gains between modalities, but previous research has shown developing conceptual knowledge in students is more challenging than developing declarative or procedural knowledge (Streveler et al., 2008). As there can be multiple parameters in play, next we provide some conjectures on the difference in learning gains between modes based on other findings in the literature.

Self-Regulation

The most common explanation for why students perform worse with online learning than F2F is the need for self-regulation (Broadbent, 2017; Parkes et al., 2015), which can affect not only conceptual learning process but learning other types of knowledge as well. Although there are benefits of online education, such as the flexibility, both instructors and students must understand that this is not a solitary, non-structured, nor self-paced activity (Bourne et al., 2005). As students in online or remote modalities are often working full time and taking care of others (for instance, married and have children) while studying (Venable, 2022b), they might struggle more with time and energy management. Over a thousand nationwide self-reported survey data, the biggest concern reported about online/remote learning experience in college and graduate students is balancing their education with work, family, and household obligations (Venable, 2022a). These students might also take longer to complete their degree, resulting in not retaining their prerequisite knowledge as well as students who have just taken a course in the previous term.

Moreover, the resources provided in the online modality such as textbooks, lecture slides, and pre-recorded videos that students can access anytime, require students' discipline to engage more than attending a scheduled lecture time. In addition, difference in the exam setting – proctored and in-person with a non-opened book midterms/final exams in the F2F course in this study – might have influenced students' study habits and methods throughout the term, resulting in higher conceptual gains.

Social Presence

Another challenge in the online learning environment is the lack of human interactions or "social presence" (Wei et al., 2012), which has significant effects on learning interaction and performance. In this study, after all quantitative data were collected, the two instructors for both modalities (authors) were asked to recall their observations of the class. They were asked to recall how the discussion environments related to the development of conceptual understanding, as well as other details that might affect students' conceptual learning. Although these observations were not conducted using a rigorous conventional method, the instructors were aware of their class dynamics. Their perceptions are explained next.

During the F2F in-person lecture class time, the instructor recalled frequent student interactions including questions and active discussion around some ungraded concept questions. Although the online modality also provided three synchronous recorded office hours per term via a video conference, the instructor recalled that there were very few students who joined each session, with the same students attending multiple sessions per term. The conversations from students who joined these sessions were usually focused on the procedural-type questions that the students got wrong and other general questions about the upcoming midterm or final exams. Concept questions were rarely discussed for this modality during these synchronous sessions.

For the asynchronous discussion boards in the online classes, there were some discussions that focused on concept questions in the assigned homework, recalled by the instructor. There were some participations by students asking questions related to homework problems before the due date and some participations after they received their homework results (no answer key was provided). Again, participation in these asynchronous discussion boards usually came from the same students that participated in the synchronous video conference sessions each term. As the participation in these discussion spaces were optional and not graded, regardless of the effort of the instructor to encourage students to participate, the instructor recalled that hardly any students tended to initiate the conversation nor provided responses to their peers on these discussion boards. Moreover, almost none of the discussions were continuous. The questions from a student usually ended with one guidance hint or further questions provided by the instructor, and the questions rarely elicited response from their peers. Similar levels of participation occurred with the anonymous discussion boards that were provided in the online classes on later terms (requested by students). However, it is important to note that, the instructor also recalled that there were students who reported in anonymous course evaluation surveys that they have never posted on the asynchronous discussion boards, but they still read and learned from the limited conversations in these spaces.

To promote positive communication and learning, which can strengthen conceptual development through rigorous discussions in the online modality, Thompson (2006) has gathered practical advice from researchers and instructors along with student feedback on how to better set up and facilitate online discussions. This advice includes structuring the activity, communicating expectations, having interesting open-ended questions with topics that serve course objectives, encouraging peer assessment, and monitoring but not dominating (nor be absent from) the discussion. In addition, incorporate the use of multimedia such as video recordings instead of text only in the discussion boards and encourage students to share their videos when joining the synchronous video conference sessions can also help strengthen human aspect between instructor and student and among students themselves. Another idea to enhance instructor presence in the asynchronous environment is to incorporate a casual recorded video as an announcement as suggested by Tanski (2022).

Anxiety

Anxiety is another factor that can affect students' conceptual learning gains in the online learning modality, according to Phanphech et al. (2022). Particularly, they reported that students in an asynchronous online modality suffered more with psychological anxiety (had a fear of failing, had low self-esteem, etc.) and online anxiety (lacked enough computer knowledge, insufficient social interaction with other students or communication with instructors, etc.) They recommend online classes incorporate both synchronous and asynchronous elements. This approach can reduce anxieties that can impede learning in general. For example, an asynchronous online course could include more frequent synchronous discussion opportunities such as more frequent office hours scheduled around student availability as well as recordings for those who cannot attend.

Feedback Mechanism

Another important factor to promote conceptual learning in students is the type and time of the feedback. To promote conceptual change, students need to be helped to increase their metaconceptual awareness – become aware of their existing presuppositions and beliefs – through group discussion and verbal expression of ideas (Vosniadou et al., 2001). Based on the conceptual leaning gains data in this study, the lack of immediate feedback in the asynchronous discussion boards resulted in discontinuous discussion and may have hindered richer conversations, compared to the more interactive, in person with prompt feedback discussions in the F2F environment. Therefore, asynchronous discussions may be associated with the lower conceptual knowledge gains. Thus, when covering each concept, especially for asynchronous online large engineering classes, instructors should structure the course to include adequate time and opportunities for rigorous class discussion (Wallace & Knudson, 2020) and include a systematic approach to provide timely feedback, which may promote further conceptual thinking. We recommend more research focused on how to best incorporate assessments that can automatically and adaptively provide specific feedback to individual learners. For instance, computer technologies or artificial intelligence (Conejo et al., 2004; Keeler et al., 2016; Wilson &

Scott, 2017; Zhai et al., 2021) can be used as tools for grouping similar misconceptions and providing repetitive feedback. This approach can help to free up time and energy for instructors in online classes to devote themselves to other richer tasks.

In this study, students in the F2F modality had access to both in-person lectures as well as the concise pre-recorded weekly lecture videos. Students who watched these short videos before the lecture times could bring their questions to class. On the other hand, the online modality did not have a longer synchronous lecture time nor weekly synchronous office hours that students could ask and receive prompt responses to their questions. Thus, being at the same time (synchronously for timely feedback) in the same room (in person, social present) can enhance students' engagement and a deeper conceptual understanding on topics found in this study. We suggest online classes include informal human-like prompt feedback mechanism on tasks as well as promote deepen discussion environments to help students achieve conceptual understanding of complex engineering concepts. In addition, Vosniadou et al. (2001) recommended that instructors analyze classroom discourse and group discussions to better understand how knowledge construction occurs.

Limitations and Future Recommendations

This research was conducted in real classroom environments, which makes it difficult to maintain consistency between groups. Students from similar disciplines who enrolled in the MATS 321 course in different terms or academic year came from diverse backgrounds, e.g., taken different other related courses. The recent global pandemic also led to unexpected circumstances that fundamentally disrupted instructors' and students' lives. For example, people who lacked space, equipment, and strong internet to work from home struggled to keep up with this change – this includes not only students but also instructors and teaching assistants (Koretsky, 2022; Sottile et al., 2021).

Due to the instructors' desire to improve their courses over time and in this study, the asynchronous online course underwent small changes as previously described, which may have affected students' performance, positively or negatively. The structure of the course also played an important role. Students in F2F course were able to access the pre-recorded weekly lecture as well as the in-person lecture while the online modality had only asynchronous resources. The difference between assessments in the course modalities (e.g., bringing a study note sheet or an open book exam) might affect students' approach to studying, resulting in different learning gains. In some terms, especially during the summer, the online course lacked a teaching assistant, and thus we assume less support and prompt feedback was given to students. The study also did not collect discussion and engagement data in a systematic way. Further studies to closely investigate these differences in modalities that can affect students' conceptual gains are recommended. The data for the F2F modality in this study came from a single term, which might not accurately represent the norm of this modality. More data from the same course modality could confirm the result. Furthermore, demographics of the participants should further be investigated, as this is not the main focus reported in this paper. Lastly, it is recommended to perform replications of this study for other topics and disciplines.

Although the scope in this study is limited, specifically focused on an introductory materials science course from one university, the findings reported here will help not just researchers but also course instructors to improve their instructional design to support students' conceptual learning. The results from this study show that there are opportunities to improve students' conceptual understanding for both the F2F modality and even more for the asynchronous online modality. The suggestions of techniques and tools discussed here should further be studied and used in ways that can help students to better develop their conceptual understanding. The challenges reported here are also helpful to consider for educational researchers. Future research can adapt and use the idea and approach from this study to investigate and compare the effectiveness of teaching challenging concepts for any discipline across different course modalities.

Conclusion

Although online learning has become more prevalent, there is still limited research in comparing engineering students' conceptual understanding between course modalities. The reported difference in conceptual learning gains between the two modalities from this study – higher in F2F – supports the idea that modality can affect students' developing conceptual understanding. As various factors that could possibly contribute to the difference observed were discussed; from a constructivist perspective, classroom discussion is one of the critical tools to support students in processing challenging conceptual concepts. We suggest the F2F might have been better able to provide appropriate formative feedback i.e., through in-person class discussions on challenging concepts, and we recommend online courses focus on stimulating more continuous discussion around concept questions to enhance students' developing conceptual understanding.

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References

Alemdar, M., Lingle, J., Wind, S. A., & Moore, R. (2017). Developing an engineering design process assessment using think-aloud interviews. *International Journal Of Engineering Education*, *33*(1), 441–452.

Beatty, I. D., Gerace, W. J., Leonard, W. J., & Dufresne, R. J. (2006). Designing effective questions for classroom response system teaching. *American Journal of Physics*, *74*(1), 31–39. https://doi.org/10.1119/1.2121753

Bergeler, E., & Read, M. F. (2020). Comparing learning outcomes and satisfaction of an online algebra-based physics course with a face-to-face course. *Journal of Science Education and Technology*, *30*(1), 97–111. https://doi.org/10.1007/s10956-020-09878-w

Berry, J., & Graham, T. (1991). Using concept questions in teaching mechanics. *International Journal of Mathematical Education in Science and Technology*, *22*(5), 157–749. https://doi.org/10.1080/0020739910220506

Bir, D. D. (2019). Comparison of academic performance of students in online vs traditional engineering course. *European Journal of Open, Distance and E-Learning*, *22*(1), 1–13. https://doi.org/10.2478/eurodl-2019-0001

Bourne, J., Harris, D., & Mayadas, F. (2005). Online engineering education: Learning anywhere, anytime. *Journal of Engineering Education (Washington, D.C.)*, *94*(1), 131–146. https://doi.org/10.1002/j.2168-9830.2005.tb00834.x

Broadbent, J. (2017). Comparing online and blended learner's self-regulated learning strategies and academic performance. *The Internet and Higher Education*, *33*, 24–32. https://doi.org/10.1016/j.iheduc.2017.01.004

Campbell, T., Schwarz, C., & Windschitl, M. (2016). What we call misconceptions may be necessary stepping-stones toward making sense of the world. *The Science Teacher*, *83*, 69–74. https://doi.org/10.2505/4/sc16_053_07_28

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. Academic Press.

Coletta, V. P., & Steinert, J. J. (2020). Why normalized gain should continue to be used in analyzing preinstruction and postinstruction scores on concept inventories. *Physical Review. Physics Education Research*, *16*(1), 10108. https://doi.org/10.1103/PhysRevPhysEducRes.16.010108

Conejo, R., Guzmán, E., Millán, E., Trella, M., Pérez-de-la-Cruz, J.-L., & Ríos, A. (2004). SIETTE: a Web-based tool for adaptive testing. *I. J. Artificial Intelligence in Education*, *14*, 29–61.

Corkins, J., Kelly, J., Baker, D., Kurpius-Robinson, S., Tasooji, A., & Krause, S. J. (2009). Determining the factor structure of the materials concept inventory. *2009 ASEE Annual Conference and Exposition, Conference Proceedings*. https://www.scopus.com/record/display.uri?eid=2-s2.0-85029088835&origin=inward&txGid=f050c6f268db9f9c88efac1fc8b264fb

Danielson, S., & Mehta, S. I. (2000). *Statics Concept Questions For Enhancing Learning*. 5.554.1.

Fischer, C., Xu, D., Rodriguez, F., Denaro, K., & Warschauer, M. (2020). Effects of course modality in summer session: Enrollment patterns and student performance in face-to-face and online classes. *The Internet and Higher Education*, *45*, 100710. https://doi.org/10.1016/j.iheduc.2019.100710

Formica, S. P., Easley, J. L., & Spraker, M. C. (2010). Transforming common-sense beliefs into Newtonian thinking through just-in-time teaching. *Physical Review Special Topics. Physics Education Research*, *6*(2), 20106. https://doi.org/10.1103/PhysRevSTPER.6.020106

Friedrichsen, D., Smith, C., & Koretsky, M. (2017). Propagation from the start: The spread of a concept-based instructional tool. *Educational Technology Research and Development*, *65*(1), 177–202. https://doi.org/10.1007/s11423-016-9473-2

Gao, R., & Lloyd, J. (2020). Precision and accuracy: knowledge transformation through conceptual learning and inquiry-based practices in introductory and advanced chemistry laboratories. *Journal of Chemical Education*, *97*(2), 368–373. https://doi.org/10.1021/acs.jchemed.9b00563

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Hake, R. R. (2002). Relationship of individual student normalized learning gains in mechanics with gender, high-school physics, and pretest scores on mathematics and spatial visualization. *Physics Education Research Conference*, *8*(August 2002), 1–14. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=10EI2q8AAAAJ&citation_for_view=10EI2q8AAAAJ:IjCSPb-OGe4C

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. (testing students' understanding of force concepts in physics). *The Physics Teacher*, *30*(3), 141. https://doi.org/10.1119/1.2343497

Keeler, J. M., Brooks, B. J., Gilbuena, D. M., Nason, J. A., & Koretsky, M. D. (2015). What's muddy vs. what's surprising? Comparing student reflections about class. *2015 American Society for Engineering Education Annual Conference & Exposition*, 26.1731.1-26.1731.14. https://doi.org/10.18260/p.25067

Keeler, J. M., Ekstedt, T. W., Cao, Y., & Koretsky, M. D. (2016). Data analytics for interactive virtual laboratories. *2016 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/p.26638

Keeler, J. M., & Koretsky, M. D. (2016). Surprises in the muddy waters of high-enrollment courses. *Journal of Chemical Education*, *93*(11), 1830–1838.

Kelly, J., Corkins, J., Baker, D., Tasooji, A., & Krause, S. J. (2009). Using concept building context modules with technology and 5 E pedagogy to promote conceptual change in materials science. *Association for Engineering Education - Engineering Library Division Papers*, 14.1317.1–14.1317.15. http://search.proquest.com/docview/2317927069/

Kentnor, H. E. (2015). Distance education and the evolution of online learning in the United States. *Curriculum and Teaching Dialogue*, *17*(1–2), 21.

Kitto, K. L. (2006). Perspectives from the classroom - Developing effective concept questions and collaborative learning for an introductory materials engineering course. *36th ASEE/IEEE Frontiers in Education Conference*, 1–5. https://doi.org/10.1109/FIE.2006.322327

Koretsky, M. D. (2022). Student perspectives of remote teaching during the COVID-19 pandemic. *Chemical Engineering Education*, *56*(1), 47–56. https://doi.org/https://doi.org/10.18260/2-1-370.660-128227

Koretsky, M. D., Falconer, J. L., Brooks, B. J., Gilbuena, D. M., Silverstein, D. L., Smith, C., & Miletic, M. (2014). The AIChE "concept warehouse": A web-based tool to promote concept-based instruction. *Advances in Engineering Education*, *4*(1).

Koretsky, M. D., Miller, R. L., Falconer, J. L., Prince, M. J., Vigeant, M. A., Krause, S. J., & Silverstein, D. L. (2011). *SPECIAL SESSION: Educational methods and tools to encourage conceptual learning*. https://doi.org/182601/1-2--18366

Krause, S. J. (2007, March). Assessing conceptual transfer of phase behavior from the domain of chemistry to the domain of materials engineering. *Proceedings of the Inaugural International Conference on Research in Engineering Education, ICREE*.

Krause, S. J., Baker, D. R., Carberry, A. R., Alford, T. L., Ankeny, C. J., Koretsky, M. D., Brooks, B. J., Waters, C., Gibbons, B. J., Maass, S., & Chan, C. K. (2014). Characterizing and addressing student learning issues and misconceptions (SLIM) with muddiest point reflections and fast formative feedback. *2014 ASEE Annual Conference & Exposition*, 24.273.1-24.273.18. https://peer.asee.org/20164

Krause, S. J., Baker, D. R., Carberry, A. R., Koretsky, M. D., Brooks, B. J., Gilbuena, D. M., Waters, C., & Ankeny, C. J. (2013). Muddiest point formative feedback in core materials classes with YouTube, Blackboard, class warm-ups and word clouds. *2013 ASEE Annual Conference & Exposition*, 23.916.1-23.916.18. https://peer.asee.org/22301

Krause, S. J., Birk, J., Bauer, R., Jenkins, B., & Pavelich, M. J. (2004). Development, testing, and application of a chemistry concept inventory. *FIE*, T1G-1. https://doi.org/10.1109/FIE.2004.1408473

Krause, S.J., Decker, J. C., & Griffin, R. (2003). Using a materials concept inventory to assess conceptual gain in introductory materials engineering courses. *33rd Annual Frontiers in Education, 2003. FIE 2003*, *1*, T3D–7.

Krause, S. J., Decker, J. C., Niska, J., & Alford, T. (2002). A materials concept inventory for introductory materials engineering courses. *National Educators' Workshop: Update 2002*, 413–424.

Krause, S. J., Kelly, J., Baker, D., & Kurpius-Robinson, S. (2010). Effect Of pedagogy on conceptual change in repairing misconceptions of differing origins in an introductory materials course. *Association for Engineering Education - Engineering Library Division Papers*, 15.439.1–15.439.12. http://search.proquest.com/docview/2318134634/

Krause, S. J., Kelly, J., Tasooji, A., Corkins, J., Baker, D., & Purzer, S. (2010). Effect of pedagogy on conceptual change in an introductory materials science course. *International Journal Of Engineering Education*, *26*(4), 869–879. https://doi.org/10.182601/1-2--16355

Libre, N. A. (2021). Activating and engaging students in online asynchronous classes. *2021 ASEE Virtual Annual Conference Content Access*. https://doi.org/10.18260/1-2--36643

Mansfield, J., Alford, T. L., & Theodore, N. D. (2018). Misconception clarification in online graduate courses. *2018 ASEE Annual Conference & Exposition*. https://peer.asee.org/30810

Michor, E., & Koretsky, M. (2020). Students' approaches to studying through a situative lens. *Studies in Engineering Education (Blacksburg, Va.)*, *1*(1), 38. https://doi.org/10.21061/see.3

National Research Council. (2000). *How people learn: Brain, Mind, Experience, and School.* (Expanded edition). National Academy Press. https://doi.org/10.17226/9853

Novak, G. M., Gavrin, A., Wolfgang, C., & Patterson, E. (1999). *Just-in-time teaching : blending active learning with web technology* . Prentice Hall.

Parkes, M., Stein, S., & Reading, C. (2015). Student preparedness for university e-learning environments. *The Internet and Higher Education*, *25*, 1–10. https://doi.org/10.1016/j.iheduc.2014.10.002

Phanphech, P., Tanitteerapan, T., Mungkung, N., Arunrungrusmi, S., Chunkul, C., Songruk, A., Yuji, T., & Kinoshita, H. (2022). An analysis of student anxiety affecting on online learning on conceptual applications in physics: Synchronous vs. asynchronous learning. *Education Sciences*, *12*(4), 278. https://doi.org/10.3390/educsci12040278

Rosenblatt, R., & Heckler, A. F. (2017). *The development process for a new materials science conceptual evaluation*. 1–9.

Rosenblatt, R.J. (2012). *Identifying and addressing student difficulties and misconceptions: examples from physics and from materials science and engineering*. http://rave.ohiolink.edu/etdc/view?acc_num=osu1336658092

RStudio Team (2022). *RStudio: Integrated Development Environment for R* (2022.7.1.554). RStudio, PBC. http://www.rstudio.com/

Sanchez, D., Barner, M., & Brown, S. (2022). Comparing engineering student and practitioner performance on the strength of materials concept inventory: Results and implications. *Journal of Civil Engineering Education*, *148*(3). https://doi.org/10.1061/(ASCE)EI.2643-9115.0000061

Sanchez-Mata, O., Brochu, M., & Zavala, G. (2020). Engineering students' comprehension of phase diagram concepts: An international sample. *2020 ASEE Virtual Annual Conference*. https://monolith.asee.org/public/conferences/172/papers/30506/view

Sangam, D., & Jesiek, B. K. (2012). *Conceptual Understanding of Resistive Electric Circuits Among First-year Engineering Students*. 25.339.1.

Sawilowsky, S. S. (2009). New effect size rules of thumb. *Journal of Modern Applied Statistical Methods*, *8*(2), 597–599. https://doi.org/10.22237/jmasm/1257035100

Shavelson, R., Ruiz-Primo, M., & Wiley, E. (2005). Windows into the mind. *Higher Education*, *49*(4), 413–430.

Shernoff, D. J., Ryu, J.-C., Ruzek, E., Coller, B., & Prantil, V. (2020). The transportability of a game-based learning approach to undergraduate mechanical engineering education: Effects on student conceptual understanding, engagement, and experience. *Sustainability (Basel, Switzerland)*, *12*(17), 6986. https://doi.org/10.3390/su12176986

Sottile, B. J., Cruz, L. E., Burleson, Y.-A. lo, & McLain, K. (2021). It’s about time: An analysis of student activities under remote learning. *2021 ASEE Virtual Annual Conference Content Access*. https://peer.asee.org/37412

Stewart, J., & Stewart, G. (2010). Correcting the normalized gain for guessing. *The Physics Teacher*, *48*(3), 194–196. https://doi.org/10.1119/1.3317458

Streveler, R. A., Litzinger, T. A., Miller, R. L., & Steif, P. S. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education*, *97*(3), 279–294. https://doi.org/10.1002/j.2168-9830.2008.tb00979.x

Tanski, K. (2022). *The Ghost in the Course Shell*. Ecampus course development & training: Tips & tricks. https://blogs.oregonstate.edu/inspire/2022/12/16/the-ghost-in-the-course-shell/

Thompson, J. T. (2006). Best practices in asynchronous online course discussions. *Journal of College Teaching and Learning*, *3*(7). 1*Trends Report*. https://www.bestcolleges.com/research/annual-trends-in-online-education/

Venable, M. A. (2022b). *2022 Trends in Online Student Demographics*. https://www.bestcolleges.com/research/online-student-demographics

Vigeant, M., Prince, M., & Nottis, K. (2011). Fundamental research in engineering education. development of concept questions and inquiry-based activities in thermodynamics and heat transfer: An example for equilibrium vs. steady-state. *Chemical Engineering Education*, *45*(3), 211.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*(4), 381–419. https://doi.org/10.1016/S0959-4752(00)00038-4

Wallace, B., & Knudson, D. (2020). The effect of course format on student learning in introductory biomechanics courses that utilize low-tech active learning exercises. *Sports Biomechanics*, *ahead-of-p*(ahead-of-print), 1–10. https://doi.org/10.1080/14763141.2020.1830163

Wei, C.-W., Chen, N.-S., & Kinshuk. (2012). A model for social presence in online classrooms. *Educational Technology Research and Development*, *60*(3), 529–545. https://doi.org/10.1007/s11423-012-9234-9

Wilcox, B. R., & Pollock, S. J. (2014). Coupled multiple-response versus free-response conceptual assessment: An example from upper-division physics. *Physical Review Special Topics - Physics Education Research*, *10*(2), 20124. https://doi.org/10.1103/PhysRevSTPER.10.020124

Wilson, C., & Scott, B. (2017). Adaptive systems in education: a review and conceptual unification. *The International Journal of Information and Learning Technology*, *34*(1), 2–19. https://doi.org/10.1108/IJILT-09-2016-0040

Wuttiprom, S., Sharma, M. D., Johnston, I. D., Chitaree, R., & Soankwan, C. (2009). Development and use of a conceptual survey in introductory quantum physics. *International Journal of Science Education*, *31*(5), 631–654. https://doi.org/10.1080/09500690701747226

Yang, D., Streveler, R., Miller, R. L., Senocak, I., & Slotta, J. (2020). Using schema training to facilitate students’ understanding of challenging engineering concepts in heat transfer and thermodynamics. *Journal of Engineering Education (Washington, D.C.)*, *109*(4), 743–759. https://doi.org/10.1002/jee.20360

Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., Liu, J.-B., Yuan, J., & Li, Y. (2021). A review of Artificial Intelligence (AI) in education from 2010 to 2020. *Complexity (New York, N.Y.)*, *2021*. https://doi.org/10.1155/2021/8812542

Zhou, Y., Jung, E., Arroyave, R., Radovic, M., & Shamberger, P. (2015). Incorporating research experiences into an introductory materials science course. *International Journal Of Engineering Education*, *31*(6), 1491–1503. https://www.researchgate.net/publication/287222089_Incorporating_Research_Experiences_into_an_Introductory_Materials_Science_Course

About the Research Unit at Oregon State Ecampus

Vision

The Ecampus Research Unit strives to be leaders in the field of online higher education research through contributing new knowledge to the field, advancing research literacy, building researcher communities and guiding national conversations around actionable research in online teaching and learning.

Mission

The Ecampus Research Unit responds to and forecasts the needs and challenges of the online education field through conducting original research; fostering strategic collaborations; and creating evidence-based resources and tools that contribute to effective online teaching, learning and program administration.

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