2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33353

A Blend Flex Engineering Mechanics Course

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A BlendFlex Engineering Mechanics Course

Abstract

The sudden eruption of a global pandemic has conveyed enormous changes to college campuses. Universities had to suddenly switch to virtual teaching and this shift appears to be here for a while. Although different disciplines vary in their degree of ease in adapting quickly to a new mode of teaching, faculty must be innovative in using available technology to successfully switch to remote teaching, while keeping or increasing even further the efficiency of conveying the content of their courses.

Faculty at Florida Gulf Coast University (FGCU) teaching "Engineering Mechanics," a sophomore-level 4-credit hour course covering both engineering statics and dynamics, shifted to a BlendFlex mode of course delivery with a virtual, asynchronous component. The class was split into two cohorts for in-person class meetings. The Learning Management System (Canvas) modules were organized into lesson pages with objectives and materials posted for each lesson. Before attending their assigned sessions, students reviewed the reading assignments and lesson videos. Each face-to-face meeting covered two lessons, as both cohorts interchanged meeting days to accommodate half the registered students and maintain social distancing. Students were asked to come to class prepared with any questions pertaining to the lesson videos and be ready to practice problem solving.

The class was scheduled for three days per week, 100 minutes per session. Cohort A met every Monday, Cohort B met every Friday, and both alternated meeting on Wednesdays. Each cohort had separate quiz days based on their meeting schedule; both cohorts had the same exam days with students spread out in two classrooms to maintain social distancing. Instructors held office hours by appointment, either face-to-face or virtual. A Learning Assistant (LA) was available to help all students with learning course concepts, practice problems, and review for assessments (quizzes and exams). The LA held online office hours in the evenings and weekends as needed.

This study will provide an assessment of students' performance on exams for the sections using BlendFlex mode taught in Fall 2020, compared to previous semesters where students were taught in a traditional Face-to-Face format. A summary of students' perceptions will be provided based on extensive surveys and questionnaires throughout the semester.

Introduction

For the last seven years, the authors have been investigating ways to improve student performance in engineering mechanics (statics and dynamics), a required course for students majoring in bioengineering, civil engineering and environmental engineering at FGCU. Success in this course is critical to success in follow-up mechanics courses and upper-level engineering courses. Data has been collected on students' performance on homework, quizzes and exams, and on the students' thoughts on learning and course delivery. Thus far, it has been concluded that the use of traditional hand-written homework, frequent assessment via quizzes [1], or the Pearson Mastering Engineering [2] software for formative assessment did not have a significant impact on students' performance on exams. It was also observed that neither traditional nor online homework scores correlated well with exam scores; however, in-class quizzes did correlate with final exam scores. More recently, using the Mastering Engineering Online system, specifically the inclusion of the Adaptive Follow-Up modules [3], it was observed that this also lacked any impact on overall student performance. In fact, Adaptive Follow-Up in the Mastering Engineering system was punitive by some of the students rather than as a resource to encourage mastery of the material [4]. Additionally, although Exam Wrappers did not seem to increase exam scores and performance; overall, having students fill out quiz and Exam Wrappers did seem to foster reflection and adjustment in most participants [5]. They encourage students to think about their study habits, the types of errors they tend to make, and the variety of ways that they are or could be engaged in the course [6]. And finally, after a year-long experiment, it was concluded that requiring students to submit homework for a grade did not improve exam performance over students who were not required to submit homework for a grade [7].

The course is a four-credit course taken by students in their second-year. It is taught in a combined lecture/lab environment with three meetings a week for a total of five contact hours. Although the course has been taught by seven different instructors over the years, it is essentially a team-taught course. Instructors use the same textbook and syllabus, they collaborate on writing and grading quizzes and exams, and they use common grading rubrics. Over the years, assessments have remained similar in level of difficulty, which allows for comparison of student performance across semesters. The course instruction closely follows the ExCEEd Teaching Model with the use of common board notes among the instructors. Prior to the onset of the COVID-19 pandemic during the spring 2020 semester, there was ample time and opportunity for active, hands-on learning during the lecture/lab period. Students spent a good portion of class time working in small groups to solve problems under the supervision of the instructor. All instructors require attendance, take roll, and for students who have an excessive number of unexcused absences, there is a grade reduction outlined in the syllabus. The prerequisites for the course are Calculus 1 and Physics 1, and students are expected to be proficient in these areas. Grades are based on a weighted average of two statics exams (40%), one dynamics exam (26%), six quizzes (18%), and two projects (16%). Students must earn a minimum grade of C in the course and at least a 70% exam average to move on to follow-up courses that require Engineering Mechanics as a prerequisite. Over the past

four years, the overall passing rate for this course is 72%. The average passing rate was 70%, 78%, 70%, and 68%, respectively, from 2017 to 2020.

For the fall semester of 2020, the enrollment in the two sections of the course were 45 and 33. Due to social distancing requirements as determined by the Centers for Disease Control and Prevention (CDC) during the COVID-19 pandemic, based on total enrollment in this course, and limited classroom seating, the faculty had to decide to either teach the course totally virtual online or shift to a BlendFlex mode of course delivery with a virtual, asynchronous component. After experiencing the total virtual mode that was required by the university at the start of pandemic during the second half of the 2020 spring semester, the faculty decided that in the best interests of student learning they would adopt the BlendFlex mode for as long as the university would let them meet face-to-face with their students. The idea for the BlendFlex model originated in 2013 and was pioneered at the two-year Central Georgia Technical College, where students had the option to attend face-to-face or synchronously online with asynchronous experiences [8]. In response to COVID-19 health and safety needs, FGCU adopted this BlendFlex format among several other alternative instructional formats such as online, synchronous online, and hybrid.

This course was scheduled to meet three days a week, 100 minutes per session. For social distancing reasons, the classroom for this course could only accommodate 23 students. So, each section was divided into two cohorts for each face-to-face meeting; Cohort A met every Monday and Cohort B met every Friday, with both alternating on Wednesday. Each in-person meeting covered two lessons, such that each cohort had three in-person meetings, covering the same amount of material every two weeks. Cohorts had separate quiz days based on their meeting schedule, but identical exam days using two classrooms to accommodate social distancing guidelines. Course content was organized into modules on the Canvas learning management system. Lesson pages contained objectives, reading assignments, lesson videos, worksheets, additional problems, and students had access to homework solutions. Students were expected to review the lesson videos prior to attending their assigned problem-solving sessions. Some lesson videos had been prepared for the dynamics portion of the course during the spring 2020 semester when the university went all virtual. For the fall 2020 semester, all new lesson videos had to be created for the statics portion of the course, which comprised two-thirds of the semester; original dynamics videos were reposted for the last one-third. Overall, four faculty shared in the responsibility for making the lesson videos. One faculty member recorded voice-over presentation slides, another recorded themselves presenting on a whiteboard, and the other two recorded hand-written notes in a document using a stylus pen. In the BlendFlex mode, in-class time was spent on a very brief review of the lesson and then students worked in small groups on the whiteboards to solve worksheet problems under the supervision of the instructor. Thus, in terms of in-class agenda, the difference between the traditional course format and this BlendFlex format, was the shift to asynchronous delivery of lesson content to videos that students were expected to watch before coming to class, while problem-solving remained at core of all face-to-face class meetings.

The current study examines the performance of students in two sections of the course, assessment of students' performance on exams for the sections using BlendFlex mode taught in Fall 2020, compared to previous semesters where students were taught in a traditional Face-to-Face format. A similar study was conducted at the University of Central Florida (UCF) for the same course and concluded that "students from a class, where mixed-mode approach is used, perform better compared to students from a class, where only face-to-face method is used" [9]. Section sizes at UCF are over one hundred students, whereas all sections in this study are no larger than 48, and face-to-face time in the combined lecture/lab format is mostly problem-solving rather than lectures in the BlendFlex mode, which in essence is a "flipped classroom" design.

As an added resource, a Learning Assistant (LA) was available to help students with problem-solving in class for one section (due to class schedule conflict), held online office hours, posted review materials, and conducted exam review sessions open to all students in both sections. Although the LA Program started at FGCU in the fall of 2016 following the Generalized Program Elements (GPEs) of the Learning Assistant Model [10], this was the first time an LA was utilized in Engineering Mechanics. Most LAs work in introductory STEM classes such as math; however, the program has grown significantly with LAs working in other areas, such as business, history, composition, language, and now engineering. Learning Assistants are undergraduate students who have been or are undergoing training in pedagogy and, through the guidance of faculty, facilitate student learning by encouraging active engagement in and out of the classroom. LAs are not Teaching Assistants (TAs) who are involved in grading; the focus of the LA is on assisting students throughout the learning process, as a peer mentor who has recently taken the course, which enables them to provide guidance and insight from the student perspective. Thus, while shifting to the BlendFlex instructional model, with asynchronous online video lessons and in-class face-to-face problem-solving sessions, hoping that having a LA would be beneficial to facilitate student learning. Especially outside of class, since total face-to-face contact hours were reduced for cohorts to accommodate social distancing.

Previous work [7] demonstrated that, whether or not students were required to submit homework for a grade, exam performance did not improve. Again, in this study optional homework assignments were provided in the BlendFlex course. However, the previous study examined the effect of homework in one semester between two sections, here the analysis was expanded to include historical data in order to build a statistical model to investigate the impact of homework with BlendFlex and LA on exam performance. Also, student perception of the BlendFlex model of instruction with LA support is reported.

This study was reviewed and approved by the University's Institutional Review Board.

Methods

Subjects and Surveys

After each exam, students were given an Exam Wrapper to reflect on their preparation and performance in terms of foundation, course involvement, study habit and activities, and sources of error (see Appendix, Table A1 and A2). The purpose of the reflection activity is to highlight habits that are helpful to continue and reveal some areas that could be adjusted. This reflection helps students plan what to do differently and better to prepare for the next exam and asks students what instructors or assistants can do to support their learning. Exam Wrappers have been used to gain insight into major factors impacting student performance. They have been collected for several years to target interventions and address major instructional design factors. With each Exam Wrapper, a survey was included to gauge student perception of the BlendFlex instructional model, their involvement/completion of optional homework assignments that were not required for a grade, and the effectiveness of the Learning Assistant (LA). At the end of the semester, students' reflection/perception of factors influencing/impacting their performance was collected as part of the Student Perception of Instruction (SPoI) questionnaire administered for all courses at FGCU.

Data Sets

Two data sets were compiled for this study:

1. historical data based on students that *completed* the Engineering Mechanics course in a fall semester from 2017 to 2020 and
2. responses obtained from exam wrapper surveys during the fall 2020 term.

An investigation of the effect of homework (required versus optional), a BlendFlex design (versus Face-to-Face), and having a LA was conducted using the historical data (see Table 1). The LA was used for both sections during the fall 2020 semester; however, they were only physically present in one of the sections. A variable, *student caliber*, was created which classified students into bottom-, middle-, or top-third of their class based on the average of their first two exams as all included students completed at least Exams 1 and 2.

Table 1. Course Design Attributes by Semester Year and Section

Term	Section	Class Size (n)	BlendFlex	HW Required	LA Assigned	LA Present
Fall 2017	1	41	N	Y	N	N
	2	33	N	Y	N	N
Fall 2018	1	41	N	Y	N	N
	2	36	N	Y	N	N
Fall 2019	1	29	N	Y	N	N
	2	25	N	N	N	N
Fall 2020	1	39	Y	N	Y	N
	2	24	Y	N	Y	Y

Class size (n) indicates the number of students that completed the course.

The second data set consists of student responses to survey questions on exam wrappers given after Exams 1 and 2 in Engineering Mechanics during the fall 2020 semester. Sixty-seven students completed the Exam 1 wrapper survey. Fifty-three of them also completed the Exam 2 wrapper survey.

Statistical Analysis

Data analysis was conducted using R statistical software [11]. The historical data set was analyzed using a permutation multivariate analysis of variance. Pairwise Wilcoxon Rank Sum post-hoc tests with Bonferroni-adjusted p-values were determined. Data obtained from exam wrapper surveys were analyzed using a z-test for the difference of proportions and Fisher's exact tests. All tests were conducted at the 5% level of significance.

Results

Effect of Homework and BlendFlex Design

Table 2 shows exam performance on all exams. Median scores did not differ much for Exams 1 and 3; however, pairwise Wilcoxon Rank Sum tests confirmed that, when homework is optional, traditional face-to-face instruction (median = 90.00) yields significantly better results than BlendFlex (median = 78.50) on Exam 2 (p=0.0005). Surprisingly, with a face-to-face format, the optional homework model (median = 90.00) produced marginally significant improvement on Exam 2 compared to the required homework model (median = 84.33) (p=0.0456).

Table 2. Median Exam Performance by Instructional Design and Homework

Design	Homework	Class Size (n)	Exam 1	Exam 2	Exam 3
BFLX	Optional	58	88.33	78.50	81.50
F2F	Optional	29	88.00	90.00	83.00
F2F	Required	174	87.50	84.33	84.25

BlendFlex (BFLX) or Face-to-Face (F2F) with optional or required homework.
Class size (n) indicates the number of students that completed all three exams;
counts differ from Table 1 due to exclusion of students that did not attempt Exam 3.

A permutation multivariate analysis of variance revealed a significant main effect of a BlendFlex design ($F[1,249]=7.63$, $p=0.002$), but not required versus optional homework assignments ($F[1,249]=1.55$, $p=0.2004$). Specifically, BlendFlex had a significant, detrimental impact on Exam 2 performance with students achieving scores, on average, 6.5 points lower than Face-to-Face sections ($p=0.0023$). While BlendFlex did not seem to affect Exam 1 performance ($p=0.79$), the impact was barely insignificant ($p=0.064$) for Exam 3 with scores about 3.7 points lower for students in BlendFlex sections.

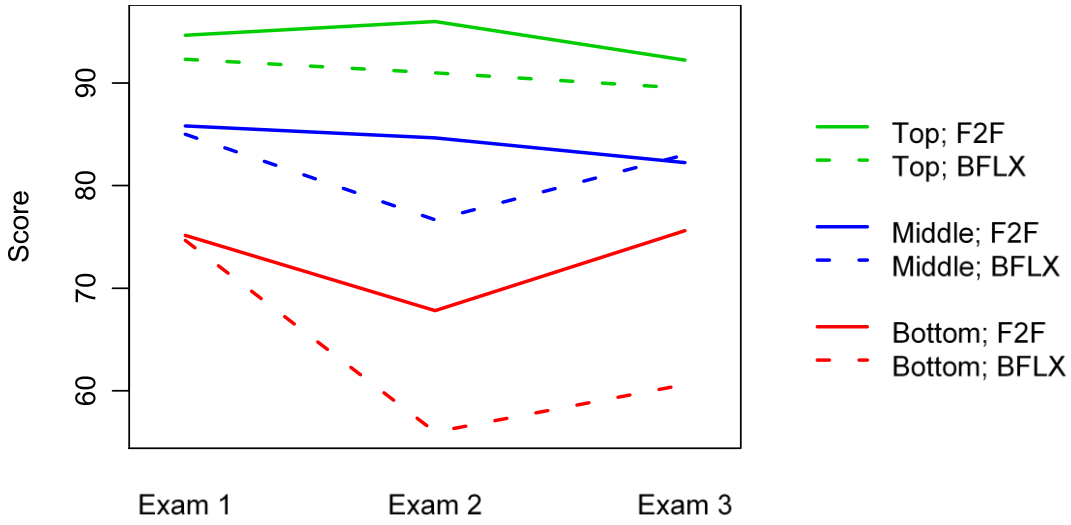

Figure 1: Interaction plot for instructional design, Face-to-Face (F2F) versus BlendFlex (BFLX), by student caliber (top-, middle-, bottom-third). Performance is consistently worse in the BlendFlex format compared traditional Face-to-Face instruction, but significant drops are mostly with respect to Exam 2.

Significant interactions were found between student caliber and BlendFlex versus Face-to-Face instruction ($F[5,249]=29.45$, $p=0.0002$) and required versus optional homework ($F[3,249]=3.24$, $p=0.024$). Having a Learning Assistant (LA) did not seem to significantly impact student performance ($F[1,249]=2.07$, $p=0.132$). In general, performance on exams was better in Face-to-Face sections compared to those with a BlendFlex model. In particular, course design did not matter on Exam 1; however, there was a significant impact on Exams 2 and 3. Specifically, performance was significantly lower across all BlendFlex sub-groups compared to their counterparts in Face-to-Face sections ($p<0.002$, see Figure 1). The bottom-third of BlendFlex students did significantly worse on Exam 3 than those in the bottom-third of Face-to-Face classes ($p=0.038$). No difference was found between the middle- and top-third cohorts across both course designs on Exam 3 ($p=0.2$). Table 3 summarizes performance on the three exams for all student caliber levels.

Table 3: Median Exam Performance by Instructional Design and Student Caliber

Student Caliber	**Exam 1**			**Exam 2**			**Exam 3**		
	F2F	***BFLX***	***P-value***	***F2F***	***BFLX***	***P-value***	***F2F***	***BFLX***	***P-value***
Top	94.7	92.3	0.2	96.0	91.0	0.005	92.3	89.5	0.2
Middle	85.8	85.0	0.2	84.7	76.7	0.0001	82.3	83.0	0.2
Bottom	75.2	74.7	0.2	67.8	56.0	0.002	75.6	60.6	0.038

BlendFlex (BFLX) sample size n=58 and Face-to-Face (F2F) sample size n=203.

While sections with required homework typically did better than those with optional assignments, instructors did not notice a change in office hours attendance. The only significant difference was on Exam 2. Students that are likely to be in the middle-third of the class at the end of the course, do significantly better (about 5.2 points) on Exam 2 if they are in a section that requires homework as opposed to making homework optional (p=0.02). Figure 2 provides a visual comparison of exam performance between required versus optional homework sections.

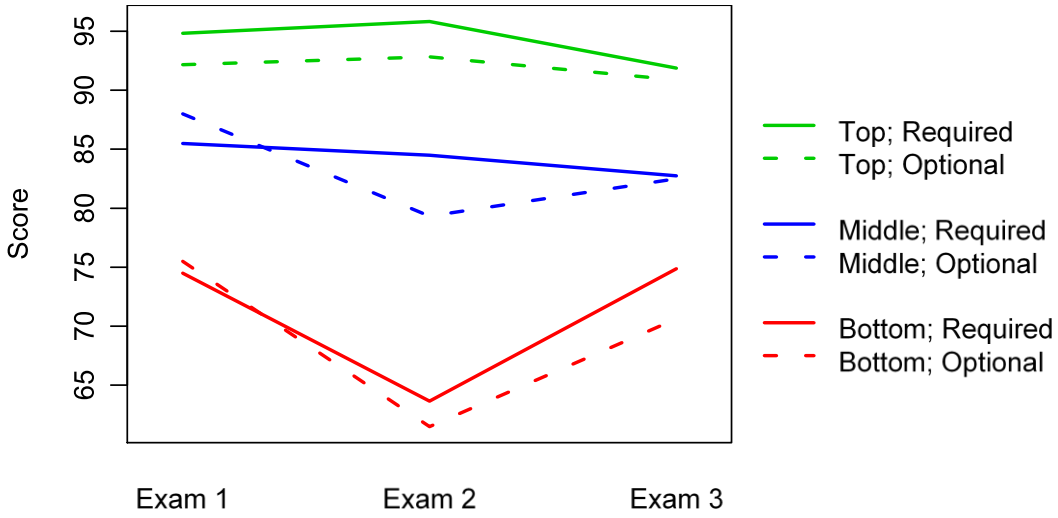

Figure 2: Interaction plot for homework assignments, required versus optional, by student caliber (top-, middle-, bottom-third). Performance is usually worse in sections with optional homework assignments compared to those with required homework. The decrease for the middle-third on Exam 2 is statistically significant.

The effect homework has on performance was further explored using the data obtained from survey questions on exam wrappers. One item asked students to report the percentage of homework problems they completed in preparation for quizzes leading up to an exam. Possible choices were 0, 25, 50, 75, and 100%. With 20% not responding to this item on the Exam 2 survey, regression imputation was performed with missing entries predicted using an ordinal logistic regression model based on those that completed this item on both wrappers. Although homework was optional during the fall 2020 term, Wilcoxon Rank Sum tests revealed that students who completed most of the homework problems (i.e., 75% or 100%) did significantly better on Exam 1 than those that did half or less (W=381, p=0.0393). The same was observed on Exam 2 (W=318, p=0.0416). Table 4 shows the median performance (and interquartile range) on Exams 1 and 2 for those that completed most of the homework compared to those that did not. A z-test highlighted a significant difference in the percentage of students that completed most of the homework problems pertaining to Exam 2. Results showed that 88% of those who did most of the homework problems for Exam 1 continued to do so for Exam 2, whereas only 46% of those that initially did less of the homework problems, increased their efforts for Exam 2 (Z=3.48, p=0.0005).

Table 4: Descriptive Statistics by Homework Completed

Percent	Exam 1			Exam 2		
	n	***Median***	***IQR***	***n***	***Median***	***IQR***
≤ 50%	42	82.3	21.2	47	68.8	31.7
> 50%	24	88.3	17.1	17	83.0	22.0

Greater than 50% includes those who did 75% or 100% of the homework.

Student Perception of BlendFlex Design

Students' perception of the BlendFlex design, with asynchronous online video lessons and in class face-to-face problem-solving session, was assessed during the semester by an informal survey as part of the Exam Wrapper administered after Exam 2 (see Appendix, Table A3). Few students, between 11.5% and 39.7%, perceived the videos to be an effective tool for learning course material, based on a 95% confidence interval. Most favor traditional Face-to-Face instruction over a BlendFlex design (95% confidence interval of 60.8% to 85.5%). Despite 88.7% of students saying that enough time and practice were provided, only 23.1% felt the in-class worksheets helped them learn the course material. Just 14.2% to 38.6% (95% CI) believe they could succeed if the course were purely asynchronous. Fisher's exact test showed a relationship between whether students felt a flipped design enabled them to make better use of their time to learn material at their own pace and whether they preferred the flipped classroom to the traditional Face-to-Face model ($p<0.0001$), such that students that appreciated the flexibility of a flipped classroom tended to favor the BlendFlex design.

Students' perception about their performance in the course was assessed by a formal, anonymous survey as part of the Student Perception of Instruction (SPoI) questionnaire administered at the end of each semester for every course taught at FGCU. Instructors have the option of adding supplemental questions to the SPoI, and five questions regarding students' perception of factors influencing/impacting their performance, ranking of these factors, self-reflection, adjustments, and course improvements were added as detailed in the Appendix, Table A4. Out of 65 students, 46 (71%) responded to these additional questions in the SPoI.

Sample of students' responses to the Question 1 in the SPoI survey, Table A4, are reported here. Many factors were cited, but the positive factors that were repeatedly mentioned by students were: receiving help and guidance from the Learning Assistant (LA), watching videos before class, practicing problems in class, reviewing solutions. These were highlighted in comments such as:

> *"The most helpful parts of the class were watching the videos before class and practicing problems in class so the professor can help in any part that you don't understand."*

"Positive impact: 1) Our Learning Assistant was very helpful in my learning. 2) All of the practice problems were very helpful in my learning as well, especially with all of the worked-out solutions."

"The Learning Assistant for this course was exceptional. The recorded video lectures and problem solutions were a huge help."

Factors that student perceived to negatively impact their performance include falling behind on course material due to having to quarantine, not keeping up with watching lesson videos before class, having to learn from videos instead of in-person lectures, reduced face-to-face interactions since the class was split into cohorts. Students' comments pertaining to these factors were:

"Being exposed to COVID-19 and having to quarantine impacted my performance because I wasn't able to go to class for two weeks. Also, due to COVID-19 and splitting up the class having us only meet once or twice a week and every other week impacted my learning significantly."

"Having short class times without previous instruction on how to do problems in class hindered those who didn't watch lecture videos beforehand."

"1) Watching videos of notes and only doing practice problems in person; I learn better with in-person notes. 2) Only having class once a week sometimes."

The ranking of students' perception of the factors that may have negatively influenced/impacted their performance in the course (Question 2, Table A2) is shown in Figure 3. Students were instructed to select among "Foundation, Mindset, Precision, Knowledge, and Motivation" as described in Table A5 in the Appendix.

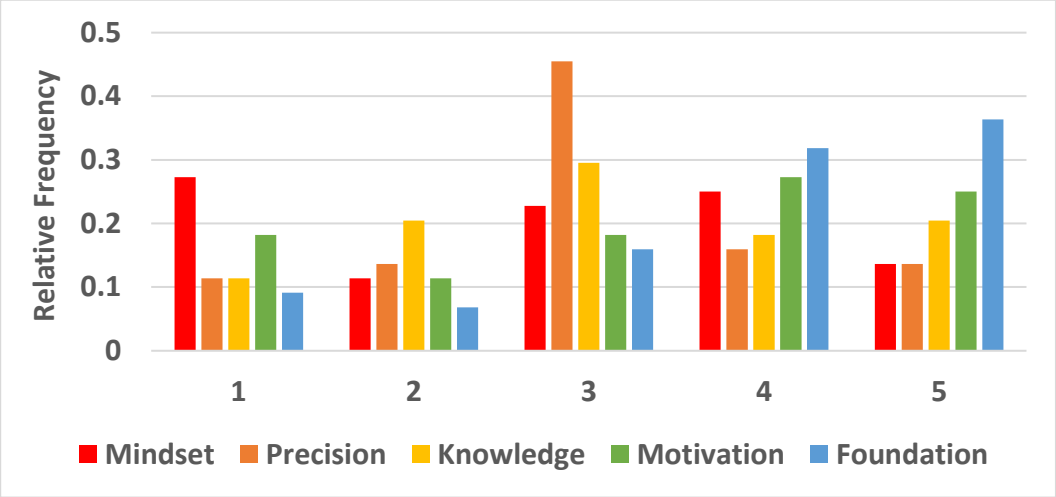

Figure 3. Students' perception of the factors that may have negatively influenced/impacted their performance in the course. Students ranked factors from primary (1) to minor (5).

By assigning a weight to each response and normalizing the values, it was found that the students ranked "Mindset" as the overall primary factor negatively impacting their performance. The overall order of importance as perceived by the students are found to be (1) Mindset, (2) Precision, (3) Knowledge, (4) Motivation and (5) Foundation (see Figure 4).

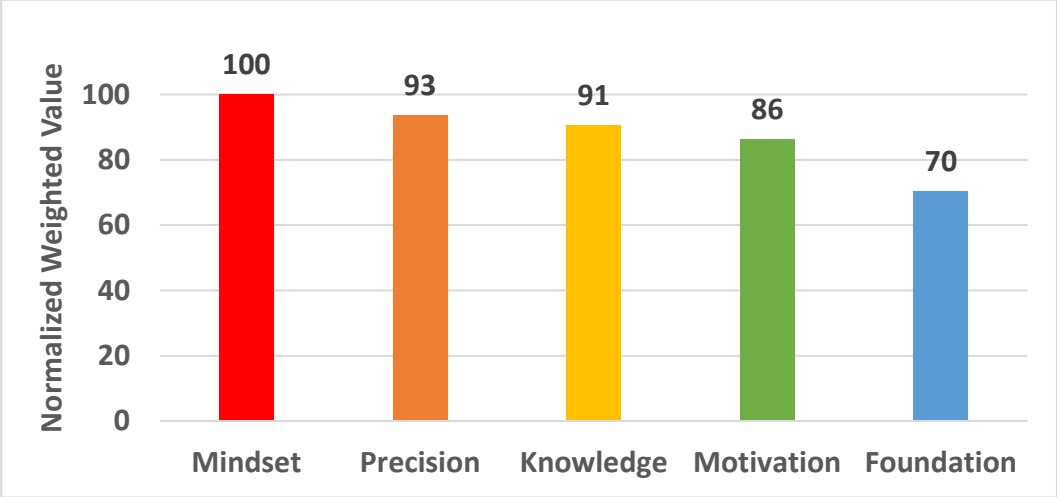

Figure 4. Students' perception of factors negatively impacting their performance in the course. Factors ordered by weighted values.

It is remarkable that students ranked "Foundation" as less of a weakness compared to "Mindset." With the shift to a hybrid teaching mode, issues with sense of responsibility, setting priorities, time management, study habits and preparation before class become more critical for student success.

Students responded to the self-reflection (Question 3, Table A4). Overall, students' answers revealed the benefit of the Exam Wrappers (see Table A1 and A2). The wrappers helped them: reflect on common mistakes they tend to make, realize they need to ask more questions, learn how to better prepare for exams, and identify their conceptual weaknesses. Students' reflective comments included:

> *"I became more consistent at identifying correct direction and minute details."*
>
> *"I noticed the more I prepared for the exam the better I would do. I noticed how I prepared for the exam mattered just as much as how much time I put in."*
>
> *"I realized that I needed to ask more questions when I got stuck and do more homework exercises."*

In terms of the adjustments that students made (Question 4, Table A4), they reported: adjusting their study habits, attending study sessions hosted by the Learning Assistant, watching the videos before class, working with peers outside of class, and completing a lot of practice problems.

Students' suggestions for course improvement (Question 5, Table A4) included mixed feedback. Some students' responses reflect the fact that traditional Face-to-Face classes are more popular, especially in an engineering mechanics course, for example:

> *"Take the videos out, that's not a way to learn, you want me to learn well, teach content in class please and practice can be done in class, but I'd rather spend more time learning in class, the videos aren't that easy. Offer the videos but just teach the course in class that's all I ask. I don't think you want to see future engineers who are self-taught. You're the professor, teach us in class please."*

> *"1) Making it all in-person. 2) Having a prep quiz that requires you to answer questions to almost force you to watch the videos before class."*

> *"The flipped class was alright, but it still isn't my favorite style."*

A few offered alternative suggestions, such as a face-to-face format with videos available as additional resources, providing an incentive for doing homework or watching videos prior to in-person classes, and creating more video solutions of problems. Comments like these were depicted in statements such as:

> *"This was my first flipped-classroom and it is interesting, but I don't really like it. I would say offer credit for homework and possible offer video explanations for the practice worksheets."*

> *"I liked having the lesson videos to watch before class, but I did not like how that was the only lecture time. I would have rather had that part of class be a Zoom meeting once a week rather then watch a video. I also think having more classes would be beneficial because it was a lot to learn in two classes instead of three."*

Finally, there were some that appreciated the course design:

> *"I really like the way we have this class set up."*

> *"Design of the class was useful and allowed for more time to work on problems and learn through application. Useful improvements could be more video solutions of problems and more ways to review content."*

> *"It was actually helpful. I've experienced flipped-classrooms in the past that were ineffective, but the professors did a great job with it. It was only a matter of motivating myself to put the time and effort in."*

Discussion

The global COVID-19 pandemic has conveyed enormous changes to college campuses, with the switch to virtual teaching and learning appearing to be here awhile. Faculty must be innovative in using available technology for flexibility in their mode of instruction, while maintaining or enhancing the efficiency of conveying the content of their courses. While adhering to social distancing requirements as set by the Centers for Disease Control and Prevention (CDC) during the pandemic, the BlendFlex mode of instruction was adopted in the best interests of student learning. In this instructional model, lessons were delivered through asynchronous online videos, and students were divided into cohorts with alternate meeting times for face-to-face problem-solving sessions. As each section was divided into two cohorts, this format reduced the overall contact hours for the students as compared to a traditional Face-to-Face format with the full class attending every session. In an effort to engage students through flexible and informal peer mentorship, a Learning Assistant was available to facilitate learning, especially outside of class, to help students with problem-solving through online office hours, posting review materials, and conducting exam review sessions open to all students.

Interim and year-end surveys of students' perception of course design and instruction, showed students felt that the Learning Assistant (LA) was exceptionally helpful and vital to their learning and success in Engineering Mechanics. While it is desirable to have the LA present in class to assist with in-person learning, students perceived the LA to be a helpful resource, whether the LA maintained an in-class presence or not. This was a valuable finding as it was the first year a Learning Assistant was utilized in this core engineering course. Historically, Engineering Mechanics has had an average overall passing rate of 72% and is perceived as a "difficult" course in the engineering curriculum. The BlendFlex format resulted in an average passing rate; however, since it was shown that having students submit homework assignments for a grade did not improve their performance on exams, graded homework were not incorporated in the BlendFlex format. Results of the statistical analysis revealed that BlendFlex with optional homework had a detrimental effect on student performance. Although students perceived the LA as one of the most helpful aspects, due to having a peer mentor offer guidance and insight from a student-learning perspective, the positive effect of the LA was not enough to overcome the negative effects of BlendFlex with optional homework on overall student performance.

Supported by quantitative analysis and student comments, "Mindset" was perceived as the primary factor negatively impacting student performance. It is not surprising that the shift to a hybrid teaching mode places added responsibility on students to manage their time, set priorities, regulate their study habits and preparation for class, quizzes, and exams. These are all critical for student success, but even more so in a blended learning format, where time in the classroom is shifted to incorporate asynchronous learning for flexibility. In fact, evidence was found that students who appreciated the flexibility of the BlendFlex model tended to be those that are more adept independent learners; enjoying the freedom to manage learning at their own pace. This finding

agrees with others who have observed that students with greater maturity and that are better self-motivators tend to appreciate asynchronous learning more [12]. Providing resources and putting the onus on students to utilize them at a reasonable pace is likely not the best practice as most students are not independent learners. To improve student success in a BlendFlex model, more structure and accountability should be incorporated to encourage independence. For example, during the spring 2021 semester, students were required to take notes on the videos for each lesson as if it were a live class and submit the notes before attending class. The LA scored the notes on a scale of 1-5, and the grade for these notes accounted for 10% of the students' overall grade for the course. Although students maintained the autonomy to watch lesson videos on their own time, the structure was present to keep students on pace for productive class meetings and hold them accountable for their learning. Hence, the intent for this added component was to facilitate the execution of a BlendFlex instructional model by scaffolding independence through structure and accountability. Follow-up analysis will be conducted to compare student performance between fall 2020 and spring 2021 to determine whether this component improved student outcomes in a BlendFlex format. Other recommendations for ensuring that students complete asynchronous course activities (e.g. videos, readings, etc.) prior to class meetings are to use the course Learning Management System (LMS) for short pre-class quizzes or have students complete a graded activity at the start of in-person meetings to check students' understanding.

The greatest negative impact of the BlendFlex model was found to be on Exam 2 performance, with a significant decrease in scores compared to a traditional Face-to-Face format. Students mostly get through Exam 1 unscathed and feel they can redistribute their efforts elsewhere or become overwhelmed with other courses during the middle of the semester which, in turn, may explain the significant decrease in Exam 2 performance compared to traditional Face-to-Face instruction. After the exam, they may be motivated by their poor performance to increase their engagement with the course material, resulting in a better Exam 3 score. The significant difference in the bottom-third is likely due to the presence of students that are unlikely to pass, but refrain from withdrawing from the course to minimize potential financial or academic repercussions. Furthermore, although the current analysis showed that having students submit homework assignments for a grade did not improve their performance within a traditional Face-to-Face course format, this may not necessarily be the case with BlendFlex. Given that the course was not run as BlendFlex *with* graded homework assignments, conclusion on whether homework is a vital factor cannot be made. However, even with optional homework assignments, students who completed the majority of the homework problems performed significantly better on Exams 1 and 2 compared to those that chose not to do most of the homework.

Based on observations and initial experience with delivering course content through asynchronous videos online, there were inconsistencies in whether students watched the video lessons *prior* to attending their cohort's face-to-face problem-solving sessions. Videos varied in length (10-30 minutes) and recording style (voice-over presentation slides, handwritten notes via a pen tablet, or whiteboard presentations simulating a classic classroom experience). A recent

study investigated student satisfaction with 8 different lecture recording formats and found that the three styles used in this present BlendFlex study yielded *moderate* levels of satisfaction among students [13]. The highest-ranked style, called Looking Glass, may produce better learning outcomes as it provides a more personal experience for the students with the presenter facing the camera while writing notes on a glass screen. Lengthy videos or variation in recording style may be a factor in why some students did not watch or stopped watching the lesson videos. These students were ill-prepared for class, did not know how or where to begin solving problems, which showed through them relying heavily on their classmates to "take the lead." This inconsistency in students' preparation for class significantly impacted the productivity of the already-reduced face-to-face contact time due to splitting by cohorts. As the faculty and Learning Assistant circulated to help groups of students, more time would be spent reviewing and reminding students of lesson concepts for those not as well-prepared for class. For these reasons, and because exposure to the lesson topic precedes application in the learning process, strategies to scaffold student accountability are being considered; first, focusing the effort to ensure that *all* students watch lesson videos prior to class, and next, potentially increasing their contact with the material outside of class whether through homework assignments or some other required component (refer to above discussion about spring 2021 semester). Moving forward, the use of Learning Assistants will be expanded for this course and the impact of this added resource on student learning will be assessed.

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Appendix

Table A1. Exam Wrapper Questions (Exam 1)

The purpose of this survey is to reflect on your exam preparation and performance. This will highlight some habits that are helpful to continue, as well as reveal some areas that could be adjusted to optimize your preparation and performance in this course. Answer honestly, truthfully, and to your best ability.

1. What was your letter grade in each foundational subject?

   Rate your current level of confidence in utilizing each foundational subject on a scale from 1 to 10: Algebra, Geometry/Trigonometry, Calculous 1, Physics 1.

2. What do you consider your typical level of preparation before for class?
   - Excellent (watched all videos completely, attempted worksheets, read textbook, noted questions)
   - Good (watched most videos completely, looked at worksheets, skimmed textbook)
   - Fair (watched some videos completely, looked at worksheets, did not read textbook)
   - Poor (watched few videos completely, did not look at worksheets nor the textbook)

   What do you consider your typical level of participation during class?
   - Excellent (took your own notes during examples, involved in class discussions, led group work)
   - Good (copied examples, listened to class discussions, assisted group work)
   - Fair (watched examples, distracted during class discussions, watched group work)
   - Poor (distracted during examples and class discussions, did not do group work)

   What do you consider your typical level of engagement after class?
   - Excellent (always reviewed examples/notes and solved worksheets, usually in online office hours)
   - Good (usually reviewed examples and solved worksheets, sometimes in online office hours)
   - Fair (sometimes reviewed examples and solved worksheets, rarely in online office hours)
   - Poor (rarely reviewed examples and solved worksheets, never in online office hours)

   How many classes did you miss for lessons covered on this exam?

3. Approximately how many hours in total did you spend preparing for this exam?

   What percentage of this time was in the 24 hours prior to the exam?

   What percentage of your preparation time was individual rather than group?

   What percentage of your preparation time was spent on the following study activities: reading lesson videos, reworking worksheets, working new problems, reading the textbook, looking over solutions, outside online content.

What percentage of your prep time would you attribute to each level of productivity?

- Highly productive (studying notes/videos, solving problems, reflecting on approaches/strategies)
- Productive (skimming notes/videos, looking over solutions, identifying approaches/strategies)
- Non-productive (locating resources, chatting with others, "spinning wheels" on approaches)

Frequency you sought help from instructor/LA/TA out of class: Often, Sometimes, Rarely, Never.

4. How many points did you lose in total on this exam?

   Of those points, how many points were due to the following sources of error:

   - Approach: uncertainty on how to approach the problem, drew a blank, got stuck, etc.
   - Timing: did not attempt or left incomplete or blank due to time consumed elsewhere
   - Documentation: any of the following missing or incorrect on free-body diagram… coordinate axes; dimensions or distances; magnitude, units, and direction angle or slope
   - Free-body diagram: reactions at supports, zero-force members, two- force members, internal forces
   - Equilibrium equations: write equals zero; missing or extraneous term; did not take component so missing ratio or sine or cosine (if incorrect then count as geometry / trigonometry error below); moment arm perpendicular distance (if position vector error then count as vector error below)
   - Geometry / trigonometry: sine or cosine of angle; common right triangles (e.g., 5-12-13) and proportional triangles; hypothenuse given slope (e.g., a2 + b2 = c2); surface of contact (radians)
   - Vectors: coordinates and head minus tail; position; unit vector; force and weight (down); moment
   - Computation: miscalculation; wrong direction or sign (+/–); substitution error; solving system of equations simultaneously; unit conversion; orders of magnitude
   - Answer format: significant figures too few or too many; units missing or incorrect; direction for vector quantities (e.g., forces) missing or incorrect

5. What are the 2 most valuable habits and/or activities that contributed to your performance on this exam?

   What are 2 things you plan to do differently and/or better to prepare for or when taking the next exam?

   What can instructors and/or assistants do to assist or support your mastery of course knowledge and skills?

   (You may list things you find helpful that are already being done or things we should add).

Table A2. Exam Wrapper Follow-Up Questions (Exam 2)

The purpose of this survey is to reflect on your exam preparation and performance. This will highlight some habits that are helpful to continue, as well as reveal some areas that could be adjusted to optimize your preparation and performance in this course. Answer honestly, truthfully, and to your best ability.

Same questions 1-5 from first Exam Wrapper, with follow-up questions:

6. For EXAM 2 (this exam), how many points did you earn in total?

   For EXAM 1 (previous exam), how many points did you earn in total?

   Calculate your percent change in score from Exam 1 to Exam 2: % change.

   How was your performance on the 2nd exam (this exam) compared to on the 1st exam (previous exam)?
   - Significantly better (increased more than a 10% in score from 1st to 2nd exam)
   - A little better (increased 6-10% in score from 1st to 2nd exam)
   - About the same (within 5% increase or decrease in score from 1st to 2nd exam)
   - A little worse (decreased 6-10% in score from 1st to 2nd exam)
   - Significantly worse (decreased more than a 10% in score from 1st to 2nd exam)

7. Did you make any changes to your course involvement in general?
   - If YES – What primary changes did you make in your involvement in this course?
   - If NO – Why did you not make changes to your involvement in this course?

   Did you make any changes to your study habits from the 1st exam to the 2nd exam?
   - If YES – What primary changes did you make in your approach to studying for this exam?
   - If NO – Why did you not make changes to your approach to studying for this exam?

   Based on your own experience, provide 2 most valuable advice to help future students do well in this course.

Table A3. Interim Survey Questions on Student Perception of Course Design

This course uses a "flipped classroom" blended learning design, where students learn course material outside of class through video lessons and then attend class sessions to practice solving problems. Use the following scale to rate your feeling towards the statements regarding aspects of this course: Strongly Agree, Agree, Disagree, Strongly Disagree.

1. I prefer the "flipped classroom" design over traditional face-to-face instruction.
2. The "flipped classroom" design allowed me to make better use of my time learning at my own pace.
3. A sufficient amount of time and number of opportunities were provided for me to practice problems.
4. I watched the prerequisite lesson videos prior to coming to class for problem-solving.
   Typically, how many times did you watch each video? 0, 1, 2, 4, 5.
5. Lesson videos were an effective tool for learning the course content on my own outside of class.
6. I needed to refer to other videos beyond the videos provided in this course.
7. By watching the lesson videos, I could solve worksheet / homework problems on my own.
8. I would be able to succeed in this course if regular attendance were not required.
9. Even after watching the lesson videos, I still needed "live" instruction to be able to solve problems.
   What type of instruction do you prefer? face-2-face, in-person, online via zoom.
10. I watched the review / summary videos posted by the Learning Assistant (LA) after the lessons.
    Typically, how many times did you watch each video? 0, 1, 2, 4, 5.
11. I attended online office hours with the LA each week.
    On average, how many times per week did you attend office hours? 0, 1, 2, 4, 5.
12. In-class worksheets helped me to better understand course topics.
13. I continued / finished solving worksheet problems outside of class.
14. I tried to solve problems on my own without looking at posted written solutions or video solutions.
    What percentage of homework problems did you attempt to complete prior to quizzes? 100%, 75%, 50%, 25%, 0%.
15. Doing the best that I could on quizzes was important to me.
16. The experience of taking the quizzes in class helped highlight what I needed to work on more.
17. The graded feedback returned on my quizzes helped me understand and learn from my errors.

18. When quizzes were returned to me, I solved the problems correctly prior to looking at posted solutions.
19. I usually complete all assigned homework problems in my courses by the time they are due.
20. Solving homework problems helps me understand the concepts discussed in the lessons.
21. Working homework problems helps me perform better on quizzes and exams.
22. I can use my study time more effectively than by working on homework problems.
23. I need to have required / graded homework in order to motivate me to do it.
24. I need written / verbal feedback on my homework beyond reviewing the posted solutions on my own.
25. I practiced the exam review problems without notes or other resources like I was taking an exam.

Table A4. Student Perception of Instruction (SPoI) Survey Questions

Supplemental questions added to the University's year-end questionnaire for all courses:

1. Influential Aspects: Think about aspects that influenced/impacted your performance in this course. In other words, possible reasons/causes that hindered or helped your performance. DESCRIBE/DISCUSS/EXPLAIN at least two (2) aspects that negatively influenced/impacted your performance and at least two (2) aspects that positively influenced/impacted your performance in this course.
2. Rank of Factors: Review the following list of factors that may have negatively influenced/impacted your performance in this course. These are possible issues that may have caused you to perform less than desired in this course. RANK/ORDER the factors from #1 (i.e., major or primary) reason/cause for poor performance to #5 (i.e., minor) reason/cause for poor performance. Assign a unique rank for each factor (i.e., do no use same ranking for multiple factors).
    - "FOUNDATION" --- issues with gaps in pre-requisite knowledge; poor performance (e.g., letter grade) in pre-requisite courses; lack of confidence in utilizing pre-requisite subjects (e.g., algebra, geometry, trigonometry, calculus, physics); errors/confusion in core concepts (e.g., sine/cosine, slope, common/proportional triangles, etc.).
    - "MINDSET" --- issues with sense of responsibility, setting priorities, time management (e.g., courses, work, activities, etc.); poor study habits and/or productivity; lack of initiative to seek help and/or utilize resources available; level of preparation (before class), participation (during class), engagement (after class).
    - "PRECISION" --- issues with attention to detail and/or carelessness (e.g., reading/answering questions being asked, documentation/organization of diagrams and work); answer format (e.g., significant figures, units, direction); computation (e.g., miscalculations, sign (+/-), substitution, system of equations, unit conversions, orders of magnitude).
    - "KNOWLEDGE" --- issues with concepts learned in this course (e.g., remembering/recalling, understanding, seeing similarities/differences, physical relationships); issues with problem-solving process (e.g., determining approach, applying concepts, executing analysis procedures/steps, interpreting/comparing results).
    - "MOTIVATION" --- issues with sense of connection/support/belonging within community of peers, assistants, instructors; lack of confidence in ability to succeed in this course; issues with sense of autonomy (e.g., control of own learning, deciding when/how to do things, expressing/communicating thoughts/ideas); issues with recognizing relevance to future profession.
3. Self-Reflection: Think about your exam performance and the analysis we have conducted through the use of exam wrappers in the course. DESCRIBE/DISCUSS/EXPLAIN at least two (2) trends you saw and/or realizations you have made after analyzing/reflecting on your exam performance/experience.

4. Adjustments: Think about the incremental adjustments you have made in effort to improve your exam performance throughout the course. DESCRIBE/DISCUSS/EXPLAIN at least two (2) adjustments you have made and comment on whether these adjustments resulted in an improvement of your exam performance. If no improvement, speculate on why these adjustments did not affect your exam performance.
5. Improvements: This course used a “flipped classroom” blended learning design, where students learned course material outside of class through video lessons and then attended class sessions to practice solving problems. This course also had a Learning Assistant (LA) to offer additional consultations in/out of class as well as deliver review content. DESCRIBE / DISCUSS / EXPLAIN at least two (2) improvements that could be made to this course to more effectively / efficiently support your mastery of course knowledge and skills.

Table A5. Description of Factors Impacting Student Performance

Factors	**Description**
Foundation	Issues with gaps in pre-requisite knowledge; poor performance (e.g., letter grade) in pre-requisite courses; lack of confidence in utilizing pre-requisite subjects (e.g., algebra, geometry, trigonometry, calculus, physics); errors/confusion in core concepts (e.g., sine/cosine, slope, common/proportional triangles, etc.)
Mindset	Issues with sense of responsibility, setting priorities, time management (e.g., courses, work, activities, etc.); poor study habits and/or productivity; lack of initiative to seek help and/or utilize resources available; level of preparation (before class), participation (during class), engagement (after class)
Precision	Issues with attention to detail and/or carelessness (e.g., reading/answering questions being asked, documentation/organization of diagrams and work); answer format (e.g., significant figures, units, direction); computation (e.g., miscalculations, sign (+/-), substitution, system of equations, unit conversions, orders of magnitude).
Knowledge	Issues with concepts learned in this course (e.g., remembering/recalling, understanding, seeing similarities/differences, physical relationships); issues with problem-solving process (e.g., determining approach, applying concepts, executing analysis procedures/steps, interpreting/comparing results).
Motivation	Issues with sense of connection/support/belonging within community of peers, assistants, instructors; lack of confidence in ability to succeed in this course; issues with sense of autonomy (e.g., control of own learning, deciding when/how to do things, expressing/communicating thoughts/ideas); issues with recognizing relevance to future profession.