STUDENT OUTCOMES RELATED TO ACADEMIC PERFORMANCE, MOTIVATION, AND MENTAL HEALTH IN AN ONLINE MATERIALS AND ENERGY BALANCES COURSE DURING THE COVID-19 PANDEMIC

AraOluwa Adaramola, Allison Godwin, and Bryan W. Boudouris
Purdue University • West Lafayette, IN 47907

INTRODUCTION

The COVID-19 pandemic impacted many higher educational institutions across the United States.[1–3] Engineering education has historically relied on traditional lectures in a physical space as the primary mode of instruction.[4] However, the pandemic forced educators to reconsider these norms and quickly adapt to an online learning environment.[5] This pivot provided opportunities to incorporate best practices for online instruction and re-think the future of engineering education beyond the global pandemic.

The transition to online learning is not a simple transformation of modality. Online learning environments present different challenges relative to traditional face-to-face learning for students and instructors,[1, 6, 7] particularly in situations created by a global pandemic. Virtual learning environments require reliable technology, which raises concerns about equitable access to resources.[8] In addition, online environments require more intentional efforts to create a sense of community and authentic learning experiences to reduce isolation and motivate independent learning in students.[6–8] Previous studies have investigated the socio-psychological effects of online learning environments on students' success.[9] This study focuses on a chemical engineering education context and examines how students' performance in an online, asynchronous sophomore materials and energy balances (MEB) course during the COVID-19 pandemic was linked to motivation and psychological distress. Lessons learned from this work can better support chemical engineering students'

AraOluwa Adaramola *is a chemical engineering Ph.D. student at Purdue University. Her research focuses on engineering education, particularly how to support students during their transition into the chemical engineering discipline. Her research interests are motivation, problem-solving and self-regulation in engineering students. ORCID: 0000-0002-2322-7932*

Allison Godwin, *Ph.D. is an Associate Professor of Engineering Education and of Chemical Engineering at Purdue University. She is also the Engineering Workforce Development Director for the Center for Innovative and Strategic Transformation of Alkane Resources. Her research focuses how identity, among other affective factors, influences diverse students to choose engineering and persist in engineering. She also studies how different experiences within the practice and culture of engineering foster or hinder belongingness and identity development. ORCID: 0000-0002-0741-3356*

Bryan Boudouris, *Ph.D., is a Professor of Chemical Engineering and of Chemistry (by courtesy) at Purdue University. He is currently serving on an Intergovernmental Personnel Agency (IPA) assignment as a rotating Program Director at the NSF. His primary teaching responsibilities have focused on the introductory materials and energy balances course where he has collaborated on research projects to evaluate how the classroom environment, content delivery methods, student engagement, and motivation impact student learning in engineering courses. ORCID: 0000-0003-0428-631X*

mental health and motivation to learn challenging coursework, especially under difficult circumstances.

THEORETICAL FRAMEWORKS

In this study we frame students' motivation using Self-Determination Theory (SDT). SDT suggests that people are motivated to achieve psychological well-being by satisfying their basic psychological needs of *autonomy*, *competence*, and *relatedness*.[10, 11] Autonomy is the need to be in control and make decisions; competence is the need to master and successfully perform given tasks; and relatedness is the need to form secure relationships and community with others.[10, 11] Behavior can be intrinsically motivated when driven by personal satisfaction and fulfillment, or extrinsically motivated when driven by external goals or factors.[10, 11] Through self-regulation individuals can align their personal goals and intrinsic motivations with external objectives.[11] For instance, genuine interest in coursework and positive learning strategies displayed by high-autonomy students align with the external objective of satisfying course requirements.[11] However, low autonomy in students is associated with anxiety, lack of interest, and negative learning strategies. [11–13] During a global pandemic, online learners may find it difficult to form relationships with their peers and instructors. Thus, students may not sufficiently engage with the course content or be confident in their ability to learn independently, which can be associated with low competence. Students' low perceptions of their psychological needs may significantly impact their ability to self-regulate and exhibit behavior that supports positive academic performance.

Self-determined individuals are more likely to be successful in their academic careers. However, stress has a documented negative effect on students' motivation, performance, and mental health.[12, 13] Engineering students' mental health issues are a rising concern linked to a lack of belonging, which is connected to students' relatedness.[13] This trend is concerning as a lack of belonging and lower feelings of competence contribute to students leaving STEM programs.[13] We theorize that online learning environments during the global COVID-19 pandemic may increase chemical engineering students' stress and reduce their perceptions of autonomy, competence, and relatedness. These conditions may ultimately result in lower course performance. Chemical engineering has been a field traditionally dominated by White, middle-class men,[14, 15] and the norms within the field cater to stereotypical male ways of knowing and standards of behavior.[16] While women overall are underrepresented, Black and Indigenous women and Latinas enroll in lower numbers relative to White and Asian women. Research on the recruitment and retention of women in engineering has found that success is linked to connectedness.[17, 18] In a longitudinal study of chemical engineering women over five semesters, Felder et al. found that women entered chemical engineering with academic credentials as good or better than their male peers.[19] However, they often lost confidence in their abilities over time and did worse in the curriculum. These results are consistent with other work studying engineering more broadly that emphasizes these gendered differences vary across racial and ethnic groups.[20–22] This research emphasizes a need to consider how motivation may impact student success differently for women, Black, Indigenous, and Latino/a/x students, as well as students at the intersections of these groups.

PURPOSE OF STUDY

This study will examine the impact of COVID-19 on students in the online MEB course by answering the following research questions:

- **RQ1**. Does motivation predict students' performance in an online learning environment for COVID-19, and do these factors vary by race/ethnicity or gender identity?

- **RQ2.** Does psychological distress predict students' motivation and subsequently their academic performance in this online learning environment?

STUDY CONTEXT

Chemical Engineering Calculations is a required four-credit introductory MEB course for chemical engineering students at Purdue University. This course covers introductory thermodynamics concepts in materials and energy balances on single and multiphase systems. Chemical engineering students typically take the MEB course in the first semester of the second year of their plan of study. In Spring 2019 the course format was redesigned to support students' motivation and academic success.[23] Three 50-minute traditional lectures and a 50-minute recitation section were replaced by two 110-minute classroom meetings each week. In addition to the longer sessions, students were introduced to course topics through online videos before class, which allowed for more team-based problem-solving and active learning in the classroom. The results indicated that the course redesign positively influenced competence beliefs, which subsequently predicted higher course grades.

Due to the COVID-19 pandemic, the MEB course transitioned into an asynchronous online format in Fall 2020. In-person instruction was replaced by short (< 15 min), pre-recorded lectures and tutorial videos that served as asynchronous learning resources. Online synchronous office

hours provided students with opportunities to interact with the instructional team. These office hours were recorded for students who could not attend the live sessions. In addition, homework and exams were distributed and submitted online. Like other semesters, students were assigned to homework groups and had the flexibility to meet with their groups in person or collaborate online. The final grades in Fall 2020 comprised of exams (75%), homework (15%), and online assessment questions (10%). In the absence of in-person interactions, the teaching team utilized discussion boards to facilitate dialogue among students, communicate information, and answer questions. The asynchronous resources allowed students to learn at their own time and pace, while the synchronous office hours provided instructor-student interactions. These changes provided opportunities for student engagement; however, the online version of the course was dramatically different from the previous motivation-supporting, in-person instruction.

Researcher's Positionality

As in any social science research, the instructors and researchers had a significant role in the choices of course offering, research design, and communication of findings and implications.[24] Below, we provide information on our prior experience and positioning to give context and acknowledge this influence.

Adaramola has a BS degree in chemical engineering and is currently pursuing a PhD in chemical engineering. She was one of the two teaching assistants for the MEB course during the Fall 2020 semester. She took this course as an undergraduate at the same institution and is familiar with the course format. In this study Adaramola was involved in analyzing the data and writing efforts.

Neither Godwin nor Boudouris instructed the MEB course during the Fall 2020 semester. However, both authors are familiar with the course. Godwin has a PhD in engineering education and a BS in chemical engineering. She co-taught the MEB course with Boudouris during the Spring 2018 and Spring 2019 semesters. In this study she functioned as an honest data broker to gather student surveys, course grades, and academic records and match these data before anonymizing the data to share with the research team. She also supported the data analysis and writing efforts. Her prior research on identity and motivation guided the conceptualization of this study.

Boudouris has instructed the MEB course ten times prior to Fall 2020, including during the Fall 2019 semester, when the initial course redesign was first implemented. In most of these situations, he has co-instructed the course with another faculty member. Boudouris obtained both his BS and PhD degrees in chemical engineering. In this study he acted as the principal investigator and supported the writing efforts.

METHODS

Research Design

This study utilized a multimethod research approach to quantitatively and qualitatively describe the learning experiences of students enrolled in the MEB course. Surveys provided quantitative measures of motivation and psychological stress. In addition, open-ended portions of the surveys asked students to reflect on the online environments and the effect of the COVID-19 pandemic on their educational experiences. Final course grades, previous grade point averages (GPA), and demographic information were collected from university records. The Purdue Institutional Review Board approved this research study under study number IRB-2020-1300.

Participants

A total of 130 students ($N_{women} = 61$; $N_{men} = 69$) were enrolled in the online course in Fall 2020. The sample population's demographics are shown in Table 1.

TABLE 1	
This Table Reports the Racial, Ethnic Demographics of Students Enrolled in the MEB Course in Fall 2020 (N=130). The Demographics are Reported as the Population and Percentages of each Racial, Ethnic Group (Rounded to 1%).	
Racial, Ethnic Demographic	Percentage (%)
White	61
Asian	17
International	8
Hispanic/Latino	4
Black/African American	2
Two or more races	6
Native Hawaiian/Other Pacific Islander	1
Unknown	1

Survey Instruments

The survey instruments were administered online to students enrolled in the MEB course in Fall 2020. Students were incentivized to participate in the study by awarding extra credits for completed surveys. We excluded responses with less than an 80% completion rate from the statistical analysis. From 128 students in the sample population (two students with incomplete grades were excluded), 84% participated in the pre-survey (at the start of the semester), and 71% participated in the post-survey (at the end of the semester).

We used the Basic Psychological Needs Scale (BPNS) to

measure motivation. The BPNS consists of 21 Likert items — autonomy (seven items), competence (six items), and relatedness subscale (eight items) — each rated on a seven-point Likert scale from "Strongly Disagree" to "Strongly Agree."[25, 26] The instrument included statements such as "I feel like I can make a lot of inputs in deciding how my course-work gets done" (autonomy), "I do not feel very competent in this course" (competence), and "I really like the people in this course" (relatedness). The categorical responses to the statements were numerically interpreted as follows: 1 = "Strongly Disagree"; 2 = "Disagree"; 3 = "Somewhat Disagree", 4 = "Neither Agree nor Disagree"; 5 = "Somewhat Agree"; 6 = "Agree"; and 7 = "Strongly Agree." The score of each motivation subscale was determined from the average of the sum of responses to each subscale consistent with prior studies.[26, 27] There is acceptable validity evidence for these measures, as demonstrated by the internal consistency of each subscale measured by Cronbach's alpha ($\alpha > 0.58$).[25, 28]

The Depression Anxiety Stress Scales (DASS-21) were used to assess the severity of *depression*, *anxiety*, and *stress* symptoms experienced by participants over the past week at the time of survey administration.[29] This scale has been reliable in detecting mental health symptoms in clinical and non-clinical samples.[30] We used the DASS-21 to measure students' mental health conditions at the end of the semester. The DASS-21 consists of 21 Likert items, 7-items per subscale, that measure depression, anxiety, and stress on a 4-point Likert scale.[29] Sample statements from the DASS-21 instrument include "I couldn't seem to experience any positive feeling at all" (depression), "I was aware of dryness of my mouth" (anxiety), and "I tended to over-react to situations" (stress). The categorical responses were numerically interpreted as follows: 0 = "Did not apply to me at all"; 1 = "Applied to me to some degree"; 2 = "Applied to me to a considerable degree," and 3 = "Applied to me very much." We scored the items according to the published literature; for each DASS-21 subscale, we summed the items for each subscale and multiplied the sum by 2.[30, 31] The total DASS-21 score was calculated as the sum of the depression, anxiety, and stress scales. This score provides a robust overall score of students' *total psychological distress* and has strong validity evidence for its use (Cronbach's $\alpha > 0.8$).[29, 30]

Finally, to understand the effect of the online learning environment and the COVID-19 pandemic on students' mental health, we asked students to rank the different components of the course from the highest to lowest sources of stress. Students rated course items in the order of perceived stress on the following scale: 1 = "Contributed Most" to 13 = "Contributed Least."

The BPNS instrument was administered at the start of the semester (pre-survey) and the end of the semester (post-survey). In contrast, the DASS-21 instrument was only administered once at the end of the semester in the post-survey. At the end of each survey, students were prompted to reflect on the effect of the online learning environment and the COVID-19 pandemic on their educational experiences (motivation and mental health) using open-ended questions.

Data Analysis

Survey responses were matched to institutional records to understand the effects of the measured items on academic performance for each participant. To answer the first research question, we compared students' average scores for each motivation factor at the beginning and end of the semester using paired t-tests. Then we used multiple linear regression to predict students' performance in the MEB course in Fall 2020 using changes in the motivation constructs during the semester and controlling for prior academic performance, race, and gender. This method provided insights on how changes in student motivation influenced student success in this classroom context and considered different students' experiences, not just students who fit the traditionally dominant norms in chemical engineering. To answer the second research question, we tested the effect of psychological distress on students' motivation and subsequently academic performance using path analysis. This test allows for simultaneously structured regressions to account for direct and indirect effects. The data obtained from the survey instruments were sufficiently normally distributed for use in these tests, as evidenced by the skewness ($< |2|$), kurtosis (< 7), and normally distributed residuals.[32, 33] To contextualize the findings from the statistical analysis, the written responses to the open-ended survey questions were qualitatively coded.[34] We used the open-ended responses from the post-survey because the response quality and rate (67%) were higher in the post-survey than the pre-survey. All tests were conducted in R Statistical Software with an alpha value of 0.05.[35]

RESULTS

The results of the paired t-tests to determine changes in motivation from the beginning to the end of the semester are reported as the mean difference between paired observations (M), the 95% confidence interval (CI), and the t-test results: t(degrees of freedom) = t-statistic and two-tailed p-value. There was no significant difference between the pre- and post- relatedness scores (M= -0.0027, 95% CI [-0.15, 0.15]; t(91) = -0.036 , p = 0.97). However, there were significant decreases in autonomy (M= -0.39, 95% CI [-0.55, -0.22]; t(91) = -4.7 , $p = 0.0000094$) and competence (M = -0.38, 95% CI [-0.59, -0.17]; t(91) = -3.6 , $p = 0.00056$). The effect size on the significant motivation factors was measured using Cohen's *d* with a small effect in the change in competence (-0.42) and a medium effect in the change in autonomy (-0.50).[36] The observed changes in competence beliefs were

supported by the qualitative responses to the open-ended survey items. Of the 86 write-in responses, 52% of these responses were coded as "low competence." Students reported facing difficulties and feeling less confident about directing their learning in the online learning environment. Ten percent of responses were coded as "low autonomy." Students reported uncertainty due to final grades and changing course structure and exam protocols during the semester. According to the statistical analysis, relatedness was unchanged; however, 38% of the responses were coded as "low relatedness."

We used hierarchical multiple linear regression to examine the relationship between motivation and students' final grades in the course. The regression results are reported in Table 2 as the unstandardized regression coefficient (slope) estimate, standard error, and significance level (indicated by asterisks). In all the regression models, a one-unit increase in an independent variable corresponds to a change in the dependent variable (final grades) by the unstandardized regression coefficient estimate, when all other independent variables are held constant. Model 1 controlled for the relationship between students' final grades, prior academic performance (prior GPA), gender identity, and racial/ethnic identity. In the

control model, prior academic performance is a significant predictor of students' final grades with a one-point increase in prior GPA (on a 4-point scale) predicting a 22.04-point increase in final grades (on a 100-point grade scale). We aggregated the data for students who identified as Black, Hispanic/Latinx, Native Hawaiian/Other Pacific Islander, and Two or More Races because of small sample sizes and to meet statistical requirements; we describe this group as *systematically minoritized students*. We acknowledge that the experience of students across these groups is not homogenous. Additionally, we emphasize that language about race and ethnicity is continually developing. Where possible, we have referred to student identities as authentically as possible within the limitations of institutional data. For this analysis, we used the term *systematically minoritized* to emphasize that the low representation of students from these racial and ethnic groups is due to systemic issues in higher education rather than a deficit in the students. It is important to include these controls because historically, and in our data, the predominant perspective captured is White/Asian and male.[14] Examining differences in experiences of White and Asian and male students to their Black, Latino/a/x, Indigenous, and

TABLE 2
Unstandardized Multiple Regression Coefficients and Standard Errors for the Relationship Between Students' Final Course Grades and Autonomy and Competence Beliefs in the MEB Course in Fall 2020. (N = 92) Significant Variables are Written in Bold Face Text.

Independent Variables	Model 1		Model 2		Model 3	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Intercept	1.29	9.00	3.89	9.11	5.18	8.96
Prior Academic Performance (GPA on 4.0 scale)	**22.04 *****	**2.47**	**21.26 *****	**2.50**	**21.03 *****	**2.46**
Race/Ethnic Identity White/Asian = 0 Systemically Minoritized = 1	-4.86	2.77	-4.42	2.78	-4.55	2.73
Gender Identity Man = 0 Woman = 1	-2.77	1.79	-2.81	1.79	**-4.23 ***	**1.89**
Delta Autonomy			1.54	1.56	1.53	1.54
Delta Competence			-2.00	1.23	-0.53	1.40
Gender (Woman)*Delta Competence					**-3.60 ***	**1.75**
R^2	0.50		0.52		0.54	
Adjusted R^2	0.49		0.49		0.51	
R^2 Change			0.015		0.019	
F-statistic	29.62		18.44		16.65	
DF	88		86		85	

*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$.

female student peers in this study ensures that the estimates for motivation changes accurately reflected student experiences and are not biased by the raced and gendered nature of the data. The results of this modeling can also be used to understand how classrooms potentially perpetuate inequity. At the same time, we acknowledge that this aggregation limits the interpretation of our results.

In Model 2 the changes in each motivation factor between the pre- and post-semester survey (i.e. delta autonomy) were added to the control model. We used the change in motivation to account for the baseline measurements of students' motivation at the beginning of the term to the end of the term. Delta relatedness was excluded from Model 2 because relatedness was unchanged over the semester. Similar to Model 1, prior GPA was the only significant predictor of final grades in the class.

Finally, we simultaneous examined the interaction between the control variables (i.e. gender and racial/ethnic identity) and the change in the motivation factors (i.e. delta autonomy). Interaction effects are the combined (non-additive) effect of two or more independent variables on a dependent variable.[28] These interactions allowed us to understand if changes in motivation were different for systemically minoritized students. The results after nonsignificant interaction effects were removed from the regression model are reported in Model 3. In addition to the significant relationship between prior GPA and final grades, we observed a statistically significant interaction effect between gender identity and the change in competence (represented by an asterisk, Gender (Woman) * Delta Competence). The significant results predict a 4.23-point reduction in final grades for women and an additional 3.60-point reduction in final grades for women with a one-point increase in competence beliefs. Together, these results predict a 7.83-point reduction in final grades for women in the sample population with a one-point increase in competence, relative to men and women with a one-point decrease in competence. Therefore, women who had positive changes in their competence beliefs were statistically more likely to perform worse relative to their peers in the class.

Based on the results from Model 3, we compared the marginal effect of the change in competence (delta competence) on the final course grades for each gender identity. Figure 1 shows how competence beliefs predict final grades for men and women in the course when all other variables are held constant at their mean values. These results further

illustrate women with negative changes in competency beliefs performed better than women with positive changes in competency beliefs.

To address RQ2, we used path analysis to model the relationship between DASS-21 (the psychological distress factor), motivation factors, and final course grades at the end of the semester. Figure 2 reports the results of the path analysis showing the standardized regression coefficients and statistical significance for each path. The overall fit to this path model is evaluated using several fit statistics, including chi-square (χ^2 = 0.071, p-value = 0.79), Comparative Fit Index (> 0.90), Root Mean Square Error of Approximation (≤ 0.05), and Standardized Root Mean Square Residual (≤ 0.05).[37] We observed that post-survey scores for autonomy and competence were statistically significant predictors of the final course grades, autonomy and competence significantly covaried, and autonomy and competence were negatively predicted by total psychological distress. Together, these results indicate that higher total psychological distress reduced students' motivation, higher autonomy predicted higher final grades, and higher competence predicted lower final grades. Figure 2 reports the path analysis model and the standardized estimates for each path. Psychological distress negatively impacted the autonomy and competence of students in the sample.

Students also ranked course components based on how much stress they contributed over the term. Figure 3 summarizes the high-, medium-, and low-stress items as reported by the students. Students' mental health was most affected by examinations, final course grades, weekly homework as-
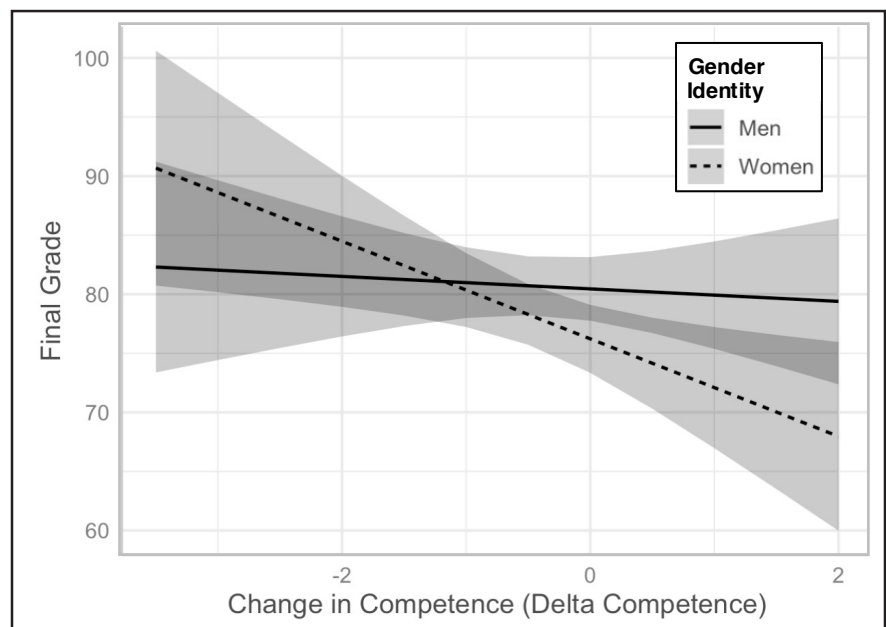

Figure 1. The marginal effect (and 95% confidence intervals) of change in competence on students' final course grades grouped by gender identity.

signments, and GPA concerns. Relative to these items, the students perceived the impact of COVID-19 on the course modality as moderately stressful. The ranking reports were supported by students' responses to the open-ended survey responses. 44% of the qualitative responses in the post-survey reported students experiencing "low mental health."

DISCUSSION

This study examined the effect of adapting a traditional MEB course into an online, asynchronous learning environment during the COVID-19 pandemic on students' academic performance, motivation beliefs, and mental health. Students' beliefs about their ability to be in control (autonomy) and succeed (competence) decreased across the semester. We did not observe statistically significant changes in relatedness for students in the sample. We hypothesize that students came into the semester expecting to be socially distanced and unable to interact with their classmates. These expectations may have normed students' motivation from the beginning of the course. The results from the regression analysis indicated that students, particularly women, faced challenges in calibrating their perceived abilities with actual performance in the online learning environment. High-performing women underestimated their ability to succeed, while low-perform-
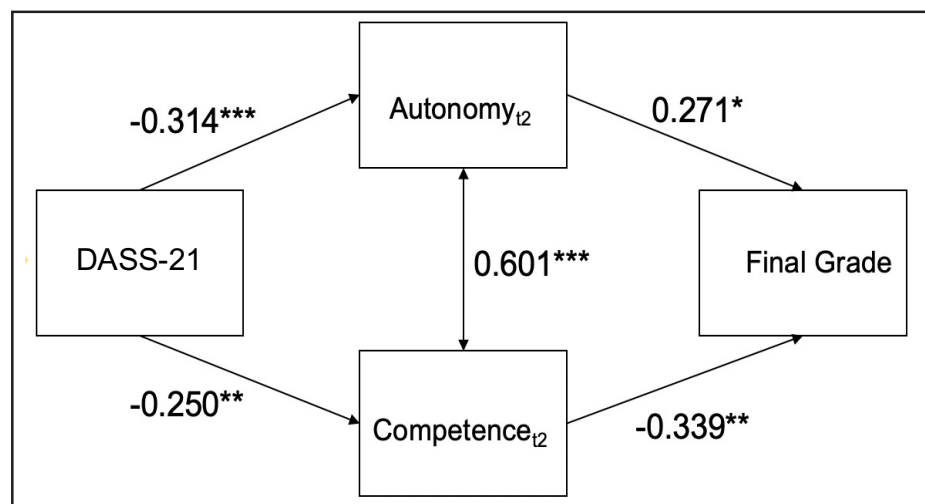
*Figure 2. Path analysis relating psychological distress (DASS-21), motivation, and final course grades at the end of the semester (t2). Chi-square =0.071, degrees of freedom =1, p = 0.790, Comparative Fit Index (CFI) = 1.00, Root Mean Square Error of Approximation (RMSEA) = 0.00, Standardized Root Mean Square Residual (SRMR) = 0.008. *p ≤ 0.05. **p ≤ 0.01. ***p ≤ 0.001.*
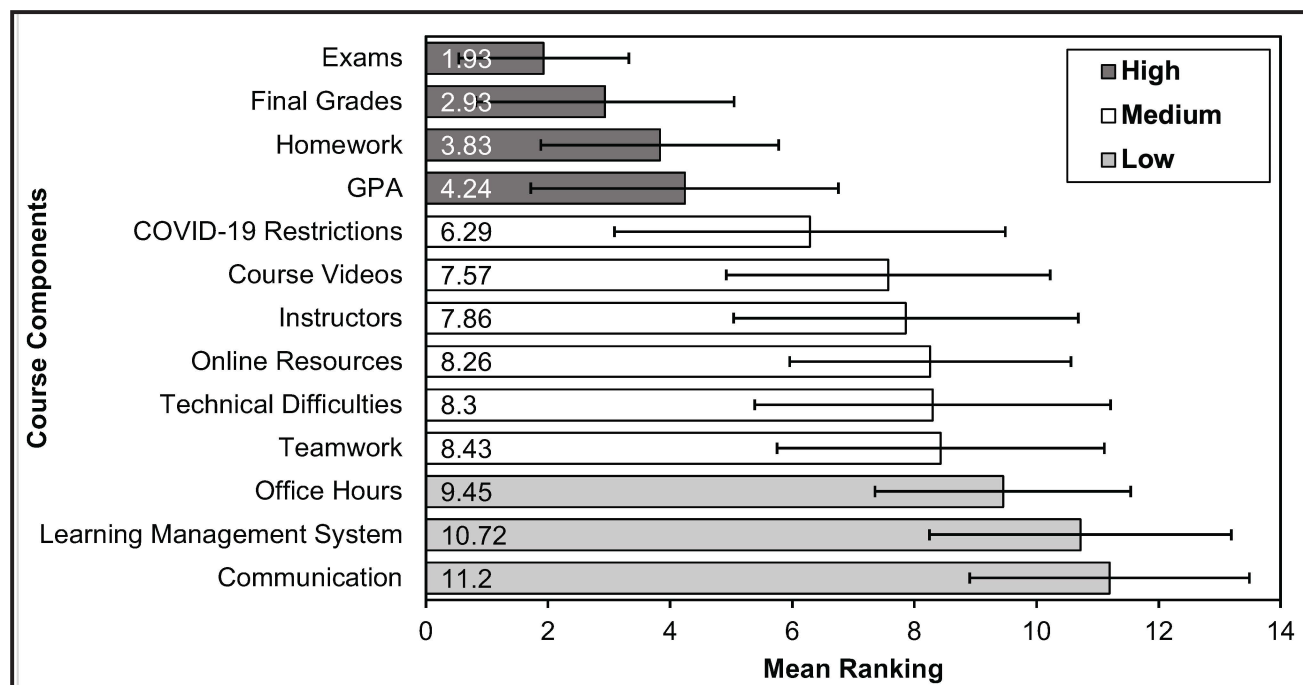
Figure 3. The mean rank and standard deviation of course components classified as high, medium, or low sources of stress, as reported by students in the MEB course. (N = 94)

ing women grossly overestimated their ability. While these results were obtained in an online learning environment in the context of the global pandemic, the lessons learned from this work can provide ways to support students' motivation and mental health in challenging introductory chemical engineering coursework.

We used multiple linear regression to predict students' performance in the online learning environment using changes in the motivation constructs. We found that both competence and autonomy in students decreased over the term. Students reported challenges in managing their learning in the asynchronous, online format in the open-ended survey responses. While this environment provided students with multiple learning resources and the option to learn at their own pace, many students struggled with navigating the online course format. Even though the instructor provided a course schedule with suggested deadlines for course content, students still indicated challenges with "teaching themselves."

Additionally, in response to instructor observations and student feedback, exam formats and proctoring changed during the semester. These changes were made to try to support students and maintain academic integrity. However, the uncertainty and changing dynamics of the semester may have made students feel less in control and reduced their autonomy. We hypothesize that this outcome may be due to two factors. First, students may not have fully developed the skills needed to engage in self-directed learning. The first-year engineering courses students take before this course are designed to support students' transition from secondary education into higher education and provide significant structure in learning. The MEB course is the first introduction students have to chemical engineering coursework. It traditionally has embedded expectations that students can manage their engagement and time for the course. Research indicates that students who develop these self-management skills are more likely to have better mental health and more positive academic outcomes; however, most students declined in these skills within the first year.[38] In Fall 2020 the online environment provided less structured accountability than the in-person offerings. Without a regularly scheduled class meeting, many students indicated feeling less connected or unable to maintain course expectations.

Additionally, this course may be the first time many of these students have engaged in a fully asynchronous online class. During their first year, the rapid shift to online learning occurred in the middle of the Spring 2020 semester such that students still had a few months of in-person engagement. Research indicates that asynchronous learning environments can be as effective as synchronous environments for student outcomes; however, careful consideration must be given to the type and nature of interactions fostered.[8] Some studies of synchronous versus asynchronous learning indicate that synchronous structures have more positive impacts on students' perceptions of belonging, positive affect, and cognitive processes.[39, 40]

The act of managing both the coursework and online learning environment during an intense period of social isolation due to the COVID-19 pandemic may have reduced students' beliefs in their ability to succeed in the course (i.e. their competence). Furthermore, the change in the competence beliefs over the semester had a more significant negative relationship with final grades for women than men. These results also suggest a strong response bias (i.e. the tendency for a person to inject biases into their self-assessments) for women in this sample.[28] Women with negative changes in their competence beliefs had higher final grades. It is possible that women who engaged more with the learning materials may have felt overwhelmed and unprepared, which reduced their competence beliefs, even though they were more familiar with the course content than their peers. This outcome is consistent with numerous studies in STEM education that have documented that men tend to overestimate their abilities and women underestimate their abilities, an example of a Dunning-Kruger effect.[41–43] A similar process, calibration, has been described as the degree of congruence between students' self-efficacy beliefs (i.e. beliefs about the ability to succeed on a task) and actual performance.[44] However, we also observed that women with the largest positive changes in competence beliefs scored significantly lower on final grades.

The traditional explanation for why unskilled students tend to overestimate their abilities is that poor performers lack the necessary metacognitive expertise to realize their ineptitude.[43] However, this explanation does not include how motivation is connected to students' beliefs about their abilities. When a task or outcome is particularly important to an individual's identity (i.e. has high self-relevance), then the individuals are more likely to have a stronger response bias in estimating abilities; that is, when students feel like the task is particularly important to how they see themselves, they are more likely to overestimate their ability.[45] This strategy may protect individuals from threats to their sense of self and help promote better reactions to challenging situations.[46] The stark difference in men's and women's over/underestimating their abilities in the MEB course may indicate particular coping mechanisms being used by women in a stressful period. Slightly higher beliefs than actual ability can promote motivation and increase effort and persistence on tasks, but a gross overestimation is problematic and can take a heavy toll. When individuals are unaware of their incompetence, they do not recognize the need for improvement. Consequently, they do not take action to improve their skills and ultimately do not do as well.[47] This finding, while needing additional study, may indicate potentially powerful motivation mechanisms that differentially impact women in engineering, particularly in an asynchronous online environment during the COVID-19 pandemic.

IMPLICATIONS

Our results support SDT and previous STEM education studies while suggesting an interaction between motivation and gender identity for the sophomore chemical engineering students in this online learning environment during the pandemic. Our research findings provide a few implications for chemical engineering educators grappling with online course development and considerations. We also provide some questions that could be explored in future research. Our results indicated that students' motivation decreased over the semester (particularly autonomy and competence). We recommend that instructors set clear expectations early in the semester and frequently communicate with the students if changes are made for early-career engineering students. Based on qualitative comments, we also suggest providing robust organizational components to the learning management system and learning resources to help guide students on expected weekly tasks. These strategies seem particularly important for supporting students' mental health, psychological well-being, and autonomy. When students have a clear understanding of their expectations and a role in the decision-making process, they may be more motivated.

Additionally, some students were generally overconfident in their abilities compared to their actual performance in the course. Without the typical classroom environment to provide social comparisons, students, and particularly women, may be less able to determine how well they are doing in the course. This result is concerning if students believe that they can succeed, but their performance does not match their beliefs. Such students may not have the ability to determine the changes that need to be made. More incremental formative feedback (e.g. narrative evaluations or self-knowledge checks) rather than summative feedback alone (i.e. exam grades) may provide ways for students to better gauge their current mastery outside of a traditional classroom setting. Another option may be to focus on mastery-based learning, where students are required to achieve a level of competency before progressing in the course. Some engineering programs or courses have taken this approach with positive effects on student learning and motivation over traditional methods.[48, 49] Finally, we note the mounting evidence that the COVID-19 pandemic had a disparate impact on women.[50] Much of these reports have focused on employment numbers,[50] academic productivity,[51] or other economic measures. Our data may indicate more ways that the pandemic had a differential toll on women. Programs and universities will need to consider additional resources to help support students during a global pandemic and other unusual circumstances.

We also recommend planned activities to foster community within the virtual classroom, especially during periods of a global pandemic where students are already feeling isolated.

While relatedness did not emerge as a significant predictor in our models, it is connected to autonomy and competence. Students must feel connected and engaged in the classroom to also feel capable of achieving their goals and controlling their learning.[52] Much of the research on effective motivational strategies focuses on the importance of social relations among instructors and peers within the classroom,[53] and more research is needed on evidence-based strategies to support motivation in online environments. In addition, prior research has primarily investigated students who have chosen to take online courses,[54] as compared to the current situation where many students in the online class indicated a preference for face-to-face instruction.

LIMITATIONS

We acknowledge several limitations in concluding this work. First, in this paper, we have utilized a binary representation of the gender of the participants. The institution collects non-binary gender identity; however, student data were collected from institutional records when students were admitted and may not reflect the students' current gender identity. Additionally, due to statistical sample size requirements, we aggregated the responses from Black, Latino/a/x, and Indigenous students. This decision does limit our ability to understand the impact of this course on particular racial and ethnic groups. Future work will include qualitative interviews and focus groups with students to better capture their lived experiences.

CONCLUSIONS

This study examined the relationship between motivation and psychological distress and students' performance in an online, asynchronous sophomore-level MEB course during the COVID-19 global pandemic. We found that students' motivation declined over the term, particularly for autonomy and competence. Furthermore, changes in competence beliefs had an unexpected relationship with final grades, particularly for women. This result indicates challenges in students' calibration of their perceived abilities with actual performance in an online environment.

Additionally, psychological distress, as expected, negatively predicted students' motivation. Qualitative data provided additional details to understand the impact of psychological distress and motivation on students' course performance. The results of this study indicate particular areas for supporting students' motivation in an online course, particularly during unusual and challenging circumstances, and areas for future research.

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