FOSTERING MOTIVATION FOR CHEMICAL ENGINEERING STUDENTS' ACADEMIC SUCCESS: AN EXAMPLE FROM A SOPHOMORE MATERIALS AND ENERGY BALANCES COURSE

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INTRODUCTION

Student success and engineering attrition are pressing issues in engineering education. Students are admitted to engineering programs with the promise of success; however, many students still leave engineering programs, which hinders the development of well-rounded engineering students, limits the quality of the engineering field, and restricts access to the social and economic capital available to those in engineering careers.[1-3] More than 40% of students leave engineering in the first two years of college.[4] In the second year of study, engineering students face the academic pressure of demanding schedules and discipline-specific coursework that affects student successes and retention. While the transition to college for first-year students is difficult, the transition into the second year – termed the "sophomore slump" – is even more challenging.[5] It is at this time point that most students leave engineering.[4]

These national findings are also true of students at Purdue University. A slightly greater proportion of students leave engineering in the second year as compared to the first. Specifically, 88% of students who start in engineering are still enrolled in engineering studies at the end of their first year. In contrast, 85% of students who begin their second year of engineering are still enrolled in engineering at the end of their second year for an overall retention rate of 74.7%.

Students leave engineering for a number of reasons. A literature review of 75 studies indicated six common reasons students leave: (1) classroom and academic climate; (2) grades and conceptual understanding; (3) self-efficacy and self-confidence; (4) high school preparation; (5) interest and career goals; and (6) race and gender.[6] This literature review found that students often leave during the "sophomore slump" because of factors related to course performance and environment. Successful retention efforts act on one or more of these factors. However, the practical ways to support these factors, especially in larger-enrollment courses, are less clear from the literature. This study begins to fill the gap by examining the effect of the classroom structures and environment to promote student motivation and academic success in a sophomore-level chemical engineering course through cyber-assisted learning.

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THEORETICAL FRAMEWORK

Motivation is essential for individuals to find energy, mobilize effort, and persist towards a particular goal. This psychological factor is important for student learning and engagement in university classrooms and has been linked to student success and persistence in STEM degrees.[7-9] Studies of motivation in engineering education have used a wide range of frameworks to understand student motivation across four areas drawn from Eccles and Wigfield's taxonomy: (1) expectancy (e.g. belief about the difficulty of a task and a person's ability to perform it successfully); (2) reasons for engagement; (3) integrating expectancy and value constructs; and (4) integrating motivation and cognition.[10] One often-used framework of motivation is self-determination theory. This theory focuses on reasons for student engagement.[11]

Self-determination theory consists of three basic psychological needs to foster positive experiences and well-being: autonomy, relatedness, and competence.[12,13] Autonomy is an individual's ability to be empowered to act in a way that is consistent with his or her interests and values. Relatedness is a desire to interact or connect with others. Competence is the desire to control or master an outcome. These three basic needs influence intrinsic and extrinsic motivation, which are shaped by an individual's own curiosity, care, or interests (i.e. intrinsic motivation) or by external factors and people (i.e. extrinsic).

Self-determination theory research has shown that intrinsic motivation and forms of extrinsic motivation, particularly where behaviors are aligned with an individual's sense of self, are associated with positive outcomes including belonging,[14.15] successful problem-solving,[16] academic success,[17,18] and retention.[15,17,19-21] Improving student motivation in the classroom can support not only student academic success in a particular course but a host of other factors important to long-term success. For example, Jones et al. showed that students' judgments of their ability to perform engineering tasks (similar to competence) were a strong predictor of students' academic success.[7] However, this measure decreased over the first year of engineering study, and more so for women. A more recent study showed that students' beliefs about how their engineering efforts connect to their future goals were the strongest predictor of retention.[22] Supporting student motivation in classrooms can promote academic success and retention in engineering programs.

PURPOSE OF STUDY

This study examined how changing the course structure of an introductory sophomore material and energy balances course, *CHE 20500: Chemical Engineering Calculations*, using a cyber-assisted engineering education platform to promote student motivation (i.e. autonomy, relatedness, and competence), influenced students' feelings of motivation pre- and post-semester as well as their overall performance in the course compared to a previous semester. In this study, we answer the following research questions:

RQ1: Did students perform better in the redesigned course?

RQ2: Did students' autonomy, relatedness, and competence change during the semester?

RQ3: Does motivation predict students' overall success in the course by term (i.e. the traditional course in Spring 2018 as compared to the redesigned course in Spring 2019)?

This study contributes to the chemical engineering education literature by providing evidence from structural classroom changes to a required chemical engineering course to support students' academic success. Lessons learned from this effort can provide actionable ways for chemical engineering faculty to develop students' motivation in their courses.

Study Context

CHE 20500: Chemical Engineering Calculations is the first discipline-specific course taken by chemical engineering undergraduate students at Purdue University. A required four-credit course, CHE 20500 is similar to introductory courses offered at many other chemical engineering programs across the United States. The course content encompasses material balances, energy balances, and the associated introduction to thermodynamic principles that are required in order to connect materials balances with energy balances. During the academic year, the course is offered in both the Fall and Spring semesters with a semester being 16 weeks in length. Historically, the Fall semesters have ~160-180 students enrolled, and the Spring semesters have ~60-80 students enrolled in this course.

Historical Pattern of Course Grades. In order to progress in the chemical engineering undergraduate program at Purdue University, a student must complete all required courses and receive a mark that is a "C" or higher in these courses. CHE 20500, the first required course in chemical engineering, is a gateway course to progress through the major. As such, the rate at which students receive a mark of "D" and "F" or withdraw (i.e. receive a "W") from the course is important to track student academic success and progression through the chemical engineering program. These outcomes are combined into the "DFW" rate, which is used to evaluate student success in core university courses.

Prior to the course redesign, the historic DFW rate, which was independent of whether the course was offered in the Fall or Spring semester and over a number of different instructors, ranged between 25% and 35%. Moreover, the average class grade point average (GPA, on a 4.0 scale) was 2.3 ± 0.3 over the course of the seven semesters prior to the course redesign. This historic rate allowed students who earned a "C" or higher to continue in the program with solid foundational training; however, there was also an opportunity to improve the course to better support student academic success. Our goal was to raise the average GPA of the class while maintaining the same high standards that were in place for the program. Therefore, the implementation of this cyber-assisted engineering education platform was introduced in order to improve student outcomes.

Course Redesign. Prior to the redesign, the four credit-hour course was structured with three 50-minute lecture periods (on Mondays, Wednesdays, and Fridays) led by a faculty instructor(s). In these situations, the entire class would meet in a large lecture room during these three lecture periods. Then, the class would be broken into smaller sections for recitation periods (on Fridays), and these 50-minute sections (of ~40 students) were led by a graduate student teaching assistant (TA).

The course was redesigned in several ways, including changes to the course timing (from meeting four times per week to two times per week), more team-based learning in the classroom, and an emphasis on introducing course concepts before class through cyber-assisted online videos. In the redesign, the recitation period was eliminated. Moreover, the lecture periods were combined into two 110-minute sessions per week (on Mondays and Wednesdays). In these sessions, the entire class met in one room, and these sessions were led by a faculty instructor(s).

As such, the amount of in-class contact time was not altered based on the redesign. Instead, two key ideas guided this instructional change. First, the amount of contact time with both the faculty instructors and fellow students increased, which we hypothesized would improve relatedness. Prior to the redesign, teaching assistants (i.e. not the faculty instructors) led the recitation sections, and these sections were subsets of the entire class. Thus, the redesign led to more faculty-student interactions and the ability for students to interact with the entire class on a more regular basis. This change was implemented after consistently finding that the ratings for the recitation periods were significantly lower than those associated with the faculty instructors. Second, the longer class periods allowed for more active learning in the classroom, which we hypothesized would improve students' competence. That is, students were able to engage with and process the lecture content and implement the underlying principles by working example problems in small teams (with assistance provided by the course instructors) during the class period. This working time was student-directed and flexible based on the challenges that students brought up during the class period, which we hypothesized would increase autonomy. Students were assigned to two teams during the semester using the Comprehensive Assessment of Team Member Effectiveness (CATME) Team-Maker and Evaluation tools.[23,24] Students not only worked in these teams in class but also submitted their homework problems as a team. The teams were assigned for the first half of the semester, after which students rated their peers on their contributions to the team and a new team was assigned. At the end of the semester, students also rated their teammates on their contributions to the team through the CATME system. The CATME generated adjustment factor without self-ratings (a composite index with a maximum of 1.05) was used as a multiplier for homework scores to hold students accountable for team assignments.

Critical to the success of the course was the ability to take some portions of the traditional lecture content outside of the classroom and into the online space. This cyber-assisted learning occurred through short (i.e. ~5-10 minute) videos. These videos were available to the students through the online course website, and they were released to the students in a piecemeal fashion. This approach meant that the students were only allowed to watch the videos, for the first time, immediately prior to the class period in which the material would be utilized. This decision was intended to incentivize students to review the materials within 24 hours prior to the start of the class period. The students were not required to watch or graded on whether they watched these videos prior to class; however, tracking of student views through the cyber-based Learning Management System indicated that a large fraction of the students watched the videos prior to attending the class period. Moreover, a number of students returned to these online videos outside of the class period, especially as mid-term exams approached. We found that each minute of video content saved ~3 minutes of lecture time during the period. For instance, one video presented an introduction to recycle and bypass streams. During the video, example process flow diagrams that included these concepts were introduced, and the terminology was shown to the students for the first time. By having the students study these lower-level concepts (e.g. recalling definitions) outside of class, the class period was used to work example problems such that the students utilized these concepts in the context of chemical engineering solutions. Thus, this cyber-assisted learning approach allowed for a more interactive class period. Specifically, the faculty instructors were then able to implement a variety of active learning techniques (e.g. think-pair-share, team-based problem solving, Socratic questioning, polling, and group discussions), which varied depending on the specific subject material being covered in that particular class period.

This key modification was only made possible due to the ability to provide cyber-based materials to the students in an organized manner. These videos were constructed based on scaffolding associated with the previous notes prepared by the instructors and the course text. Then, the material was converted to a slide deck, and the videos were filmed in a host of green screen rooms across the Purdue campus. Due to the automated nature of these rooms, only the faculty instructors needed to be present to record the videos. An external service was used to caption the videos.

Researcher's Positionality. As in any social science research, we as the instructors and researchers had significant influence on the course offering and the research design. Below, we provide information on our prior experience and positioning to provide context for the study and to acknowledge this influence.

Godwin has a PhD in engineering education and an undergraduate degree in chemical engineering. She co-taught the CHE 20500 course with Boudouris during the Spring 2018 and Spring 2019 semesters that are the focus of this study. The course was offered with the same text as when she was enrolled in a similar course at her undergraduate institution and in a similar manner. Godwin brings her knowledge about engineering education research and her interest in identity and other psychological factors in student learning, success, and pathways to her instruction. Her teaching philosophy emphasizes a constructivist approach to learning, or that students develop their own understanding and knowledge of the world through their experiences and reflection on those experiences. She views students as active co-constructors of knowledge in the classroom and works to foster a dynamic exchange of knowledge. She views her role as the instructor as one who models learning (both successes and failures) to students and supports the process of reflection on how new material connects to previous knowledge.

Boudouris had instructed CHE 20500 nine times prior to the redesign, and he has taught the course two times since the redesign. In most of these situations, he has co-instructed the course with another Purdue University faculty member. Boudouris obtained both his BS and PhD degrees in chemical engineering. In fact, the equivalent course to Chemical Engineering Calculations in which he was enrolled as an undergraduate student used the same text (although an earlier edition) as that used currently at Purdue University. Moreover, the style of instruction was extremely similar to what was observed prior to the redesign. Therefore, he comes from a position in which the original format of the course was familiar. Boudouris views student success as the ability of students to achieve higher-level learning objectives related to both chemical engineering and engineering in the broader context. Prior to the redesign, Boudouris' teaching style was one that was more lecture-focused with a small number of active learning activities (e.g. short think-pair-share segments) sprinkled throughout the class period. After the cyber-assisted redesign, Boudouris' teaching philosophy is one that removes a great deal of the lecturing that occurs in the class in favor of a more free-flowing, highly interactive classroom.

METHODS

Data Sources

Data for this study were collected from two sections of CHE 20500, one offered in Spring 2018 and one offered in Spring 2019, both co-instructed by Boudouris and Godwin. The Spring 2018 course was prior to the redesign of the course, and the Spring 2019 course was after the redesign. Students took a survey about their motivation at the beginning of the semester (within the first three weeks) and at the end of the semester (within the last three weeks). The survey included the Basic Need Satisfaction scale, which used 21 items to measure autonomy, relatedness, and competence on a 7-point Likert scale.[25] The Likert scale used the responses corresponding the each listed value: 1 = "Strongly Disagree"; 2 = "Disagree"; 3 = "Somewhat Disagree"; 4 = "Neither Agree nor Disagree"; 5 = "Somewhat Agree"; 6 = "Agree"; and 7 = "Strongly Agree". The autonomy subscale included seven items with statements like, "I felt like I would feel free to express my ideas and opinions in this class." The relatedness subscale included eight items containing statements like, "I felt like I would get along with the people in this class." The competence subscale has six items including, "I felt like most days I would get a sense of accomplishment from going to class." The internal consistencies of the scales met standard validity criteria (i.e. the set of items measure a single underlying construct) as measured by Cronbach's alpha (α between 0.58 and 0.80).[26] With consent from the students, we also matched these survey responses to students' final grades in the course as a measure of academic performance. The Purdue University Institutional Review Board approved all study procedures.

Data Analysis

To answer each research question, we compared student responses across the two terms (Spring 2018, which was offered in a traditional format, and Spring 2019, the redesigned course). We compared the DFW rate using Fisher's exact test for each course. Fisher's exact test is more accurate than the chi-square test or G–test of independence when the expected numbers are small.[27] We took an average score for autonomy, relatedness, and competence and compared students' pre- and post-course scores in the Spring 2019 redesigned course using paired t-tests. Finally, we predicted students' final grades in the course, controlling for the term (0 = Spring 2018 traditional course; 1 = Spring 2019 redesigned course) and investigating the effects of students' changes in autonomy, relatedness, and competence. This analysis in effect controlled for the starting values of each student and the relative change during the course. We also included interaction effects of the motivation factors and the term to understand if there were differential changes by course offering. All tests were conducted in the R Statistical Software[28] with an alpha value of 0.05.

RESULTS

Below we provide the results of each of the statistical analyses used to answer each of the three research questions posed in this paper. We found no statistically significant differences in DFW rates by term or systematic changes in students' motivation for the redesigned course. Despite a lack of statistical significance, the descriptive statistics for course performance and motivation did show promising progress. We hypothesize that small sample sizes may account for a lack of statistical significance and discuss these results below. We also used multiple linear regression to examine the effect of term and students' changes in motivation simultaneously. We did find statistically significant effects for predicting students' GPA for changes in competence beliefs, and these changes had a larger positive effect for students in the redesigned course.

To answer RQ1, we examined the proportion of DFWs for students each semester. The DFW rate was 27.1% (13/48 students) in Spring 2018 compared to 16.4% (11/67 students) in Spring 2019. The results of the Fisher's exact test for each course is reported as the odds ratio, 95% confidence interval (CI), and two-tailed p-value (odds ratio = 1.45, 95% CI [0.6, 3.59], p = 0.258). The odds ratio indicates that that students in the Spring 2019 redesigned course were 1.45 times as likely to have passing scores in the course; however, these results are non-significant indicating no true difference between the course offerings was detected even though the DFW rate decreased dramatically from Spring 2018 to Spring 2019 (a 10.7% reduction). After conducting a power analysis, with the sample sizes and proportional differences, at an alpha level of 0.05, there was only a 27% chance of detecting differences. We believe that the small enrollment in each course is the reason for not detecting significant differences in the data. Our future work will continue to investigate the effects of this course redesign on students' DFW rates. A comparison of historical patterns with future ones may allow us to establish more definitive results.

The second research question was tested for each motivation factor. A paired t-test was conducted to see if there were differences between the survey scores at the end of the semester compared to the beginning of the semester in the redesigned course for each students' responses. The t-test results are reported as the mean at each time point (M), the 95% confidence interval (CI), and the t-test results, i.e. t(degrees of freedom) = t-statistics, two-tailed p-value. There was not a significant difference in the scores for autonomy changes at the beginning of the semester (M = 4.608, 95% CI [4.399, 4.819]) and end of the semester (M = 4.537, 95% CI [4.313, 4.761]); t(41) = -0.801, p = 0.428). We also found no significant difference for relatedness [t(41) = -0.334, p = 0.740] pre- (M = 5.006, 95% CI [4.769, 5.243]) and post-semester (M = 4.967, 95% CI [4.664, 5.270]) or competence [t(41) = 1.453, p = 0.154] pre- (M = 4.984, 95% CI [4.768, 5.243]) and post-semester (M = 5.143, 95% CI [4.664, 5.270]). Competence showed the largest gain for students with an average increase of 0.16 points on a 7-point scale. The confidence intervals for these motivation factors were relatively large for Likert-items, indicating that different students may have larger or smaller individual gains in motivation during the course.

Finally, we examined the third research question by predicting students' final grade in the course on a 4.0 GPA scale with the academic term (Spring 2018 = 0 or Spring 2019 = 1) as a fixed effect and controlling for prior academic performance with each student's GPA prior to beginning the semester. We included students' changes in autonomy, relatedness, and competence to understand the effects of decreasing or increasing motivation. These changes were calculated as the difference between the post-semester survey scores and the pre-semester survey scores to create a Delta term for each motivation factor. Interaction effects between the motivation differences and the term also provided evidence for the effectiveness of the course redesign on specific motivation factors. The regression results are shown in Table 1 and the results are described below. The regression results are reported as the unstandardized regression estimate (B) and the two-tailed p-value. The main effects of single independent variables (i.e. prior academic performance, term, and Delta motivation factor scores) indicate that a one-unit increase in the independent variable predicts the change in the dependent variable by the unstandardized regression estimate. The interaction effects are represented with an asterisk between the two independent variables being multiplied (i.e., Delta Autonomy*Term). The presence of a significant interaction indicates that the association of one independent variable with the dependent variable is different at different values of the other independent variable. In this study, this interaction term would indicate that the changes in a particular motivation construct were different by the term in which the course was offered. Only statistically significant results are discussed below because non-significant results should be interpreted as a zero estimate or that there is no association with the independent variable on the dependent variable.

We controlled for prior academic performance (i.e. the GPA of students at the beginning of the semester in all prior university courses). The estimate in Table 1 indicates that an increase of 1.0 GPA point predicts an increase of 1.841 GPA points in CHE 20500 with a p-value of less than 0.001. The estimates for term in Table 1 indicate that, compared to the traditional course in Spring 2018, being enrolled in the Spring 2019 term had no statistically significant association with academic performance in the course. This result is consistent with the Fisher's exact test results discussed previously. The estimates for the main effects of the changes in motivation factors (i.e. Delta scores for each motivation factor) in Table 1 indicate the average predicated increase in GPA for a one-

TABLE 1
This table reports multiple linear regression results examining the relationship between students' autonomy, relatedness, and competence beliefs and performance in a sophomore materials and energy balances course (GPA on a 4.0 scale). The sample includes students from a traditionally taught course in Spring 2018 (n = 48) and a redesigned course taught in Spring 2019 (n = 67). p-values are reported for two-tailed tests. In this table, *, **, * represent statistical significance at the 0.05, 0.01, and 0.001 levels respectively.**

Independent Variables	Estimate	Standard Error	p-value	Significance
Intercept	-3.050	0.630	< 0.001	***
Prior Academic Performance (GPA on 4.0 scale)	1.841	0.197	< 0.001	***
Term (0 = Traditional course Sp18; 1 = Redesigned course Sp19)	-0.206	0.185	0.271	
Delta Autonomy	-0.250	0.225	0.271	
Delta Relatedness	-0.105	0.249	0.676	
Delta Competence	0.637	0.239	0.010	**
Delta Autonomy*Term	0.118	0.315	0.709	
Delta Relatedness*Term	-0.098	0.304	0.748	
Delta Competence*Term	0.647	0.295	0.032	*

point increase in motivation during the term. Even controlling for this prior performance, changes in students' beliefs about their abilities to succeed (i.e. competence) was a significant and positive predictor of success in the course, regardless of the academic term in which the course was offered ($B = 0.637$, $p < 0.01$). Finally, the interaction effects examined if the changes in motivation factors during the semester may have systematic differences by the term in which the course was offered; thus, allowing us to test the association of the course term and student motivation changes with the final course score at the same time. The interaction effect of the change in competence beliefs and the term in which the course was offered was significant (i.e. Delta Competence*Term; $B = 0.647$, $p < 0.05$). Not only did changes in students' competence beliefs have a significant relationship with final GPA in the course, but students who had a positive increase in competence in the redesigned course had an even greater positive effect on the final grade in the course (over a full GPA point; 1.284). We examined the mean differences between the traditional Spring 2018 and redesigned Spring 2019 course and found that while the Spring 2018 course had an average decrease in competence of 0.070, the Spring 2019 course had an average increase in competence of 0.159. These results indicate the course redesign may positively influence students' competence beliefs, which may also have a positive effect on their academic performance in the course.

DISCUSSION

Our results indicate that the changes described in the redesigned course did have a positive influence on students' competence beliefs and academic performance in the course. Additionally, we hypothesize that the intervention did have a demonstrable effect on the DFW rate in the course even though the test showed no statistically significant difference. Our future work will continue to track students' motivation in the redesigned course for a larger comparison to the historic performance data in CHE 20500.

We found that students' increased competence beliefs had a significant positive impact on student performance and that this effect was stronger in the redesigned course. We hypothesize that students felt increased competence for two reasons: (1) students had more time to grapple with difficult problems in class where they were supported by other students and the faculty instructors; and (2) students saw others "get stuck" in problem solving, thus normalizing this struggle. Studies on students' self-efficacy, beliefs about their ability to succeed on a task, support these hypotheses. One study of factors that influenced positive self-efficacy indicated that working on teams and being able to complete assignments increased students' confidence in their ability to succeed.[29] The redesigned course structure provided both opportunities to learn from other students in teams and successfully complete homework assignments with guidance from faculty. Another study that investigated influences on engineering students' success, as measured by GPA, indicated that mastery experiences were the largest contributor to students' increased competence beliefs.[30] Additionally, students' beliefs about their ability to succeed (or not) are informed by seeing others successfully accomplish similar tasks. In a study of early career engineers, students who discussed working closely with their team members and who sought help were more likely to have higher reported beliefs about their abilities to succeed on task. The authors found that students form their beliefs based on the outcomes of others' actions, and this result was especially true for women, who reported being influenced by these sources more frequently than men.[29] The redesigned course structure included more time in class for teaming and help-seeking through faculty and peer interactions. These practices may have created opportunities for students to have mastery experiences as well as see others struggle and succeed in the course, thus increasing their feelings of competence.

Prior research has shown that faculty can act as motivation supporting agents across different educational contexts. For example, Williams and Deci found that medical students who had instructors whom they felt supported their ability to take ownership of their learning and conveyed confidence in their ability to do well became more independent in their learning in a subsequent six month period.[31] In another study, Black and Deci showed that organic chemistry instructors who supported these same beliefs had a positive influence on students' perceptions of competence, interest, enjoyment, and course performance.[32] Finally, a study of high school science students indicated that teachers who supported students' autonomy and competence in the classroom significantly affected students' intentions to enter science domains and persist in science.[33] Together, these studies indicate that instructors can have a significant and long-term influence on students' motivation beliefs, academic success, and persistence.

Our study indicates that a simple course redesign to support student motivation can have significant and positive effects on student learning. We found that students enrolled in the redesigned course had larger mean changes in competence beliefs, and those changes predicted large changes in students' grades (over a whole GPA point). This simple change involved some development of cyber-assisted learning efforts through course videos and team making and evaluation, but it had no significant changes in the number of contact hours with student or course material. Instead, the ways in which the course was taught (rather than what was taught) significantly improved the course. Other evidence-based research provides ways to improve course learning structure and environment. Kusurkar, Croiset, and Ten Cate[34] provide 12 tips: (1) identify and nurture what students need and want; (2) have students' internal states guide their behavior; (3) encourage active participation; (4) encourage students to accept more responsibility for their learning; (5) provide structured guidance; (6) provide optimal challenges; (7) give positive and constructive feedback; (8) give emotional support; (9) acknowledge students' expressions of negative affect; (10) communicate value in uninteresting activities; (11) give choices; and (12) direct with "can, may, could" instead of "must, need, should." These tips provide tangible ways in which instructors can embed motivation-supporting pedagogy into the classroom in addition to the course restructuring described in this study.

CONCLUSIONS

This study examined the effects of a course redesign using cyber-assisted learning on students' motivation beliefs and academic outcomes in an introductory chemical engineering course. We found that the course changes – putting basic course content into videos watched directly before class, working in teams during class on homework assignments, moving from structured lecture and problem-solving sessions to longer student-directed sessions, and normalizing students' struggle with problems in the classroom in problem-solving – had significant positive effects on competence. These changes significantly predicted student academic success in the course. Our future work will continue to monitor student motivation and success in subsequent offerings of the course with different instructors as well as monitor students' progression through chemical engineering to determine longer-term effects on student retention beyond the sophomore year.

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