ChE curriculum

DIRECT AND INDIRECT ASSESSMENT OF STUDENT PERSPECTIVES AND PERFORMANCE IN AN ONLINE / DISTANCE EDUCATION CHEMICAL ENGINEERING BRIDGING COURSE SEQUENCE

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INTRODUCTION

Chemical engineering graduate programs often receive applications from students whose undergraduate degree is in chemistry, physics, biology, or another engineering discipline. These typically are excellent students with undergraduate research or work experience, but their lack of chemical engineering background can present challenges in their successful acceptance to and progress in a chemical engineering graduate program. Some students are asked to take several undergraduate courses as prerequisites to prepare them for graduate work, which may delay the completion of their degree.

Michigan State University (MSU) has offered a spring-summer online "bridging" course, *Foundations in Chemical Engineering*, for this target audience since 2000,[1] and faculty at North Carolina State University have directed multiple prospective graduate students to this resource. AIChE Academy[2] and ACS[3] also offer a large variety of workshops and online courses related to chemical engineering, but each of these courses are shorter (e.g. 30 total hours of instruction) and so, on their own, would not be expected to offer the same depth as a two-semester university bridging course spanning 45 or more hours of instruction. While AIChE and ACS courses do not count as college credit, one may obtain Professional Development Hours (PDHs) and Continuing Education Units (CEUs) for completed courses, which may be required for renewal of professional licensure.[4-6] Besides prospective graduate students, the course may also provide a suitable option for employees in technical fields who desire understanding of core chemical engineering concepts.

As an alternative to this approach, we describe the development and assessment of an online ChE "bridging" course sequence that is part of an initiative at NC State to broaden its reach of distance education. Prospective students who complete the two-course sequence will be able to count six elective credit hours toward a MS Chemical Engineering degree at NC State, which may be attractive to prospective graduate students. Non-chemical engineering students who

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enter the graduate program are expected to take these two courses along with technical electives before taking the core graduate courses. While it is not a requirement for admission to the graduate program, students who have taken these courses prior to entering the graduate program can immediately take the core graduate courses. The courses may be taken by students outside the university prior to admission to NC State or another graduate program. This is consistent with the university's goal to expand distance education through its sixteen nationally ranked online graduate programs in engineering. Since this bridging course was initially offered on a different timetable (fall-spring) than the MSU course (spring-summer), it expands course offerings for interested students.

The rationale, development, and assessment strategies for the courses have been documented in previous work.[7-10] The first course in the module, Core ChE Concepts: I, was offered for the first time in the Fall 2018 semester; likewise the second semester course, Core ChE Concepts: II, was first offered in Spring 2019. A concerted effort was made to evaluate students' experiences in the course using both *direct assessment* (i.e., student academic performance) using problem-by-problem scoring metrics as well as *indirect assessment* (e.g., task value, engagement, self-efficacy) through validated pedagogical inventories emerging from relevant theoretical frameworks. Indirect assessments were collected at the beginning, middle, and end of the courses, while direct assessments were made continuously.

This work presents the results of these direct and indirect assessments as well as post-hoc analyses with respect to variables such as learning perceptions and student motivation. This analysis is unique in that it provides insight into relationships between concepts such as course design/structure, motivation, and perception with student academic performance in an online ChE course, and as such helps to reveal best practices in this growing area. The objective of this work is to apply the assessment strategies on the first offering of the course sequence to collect baseline data for use as the control or comparison case for future changes to the course (which will be discussed in later publications). This objective informs a data-driven strategy intended to identify opportunities for improvement and evaluate pursuant pedagogical strategies as the course is further refined. As part of this work, the students' goals in taking the bridging courses are also identified. Moving forward, the authors plan on attempting (within IRB regulations) to "follow" students' careers after taking the bridging courses to determine if the courses are successfully allowing students to reach their big-picture goals.

Information that is transferable to other ChE departments through this work includes the actual direct and indirect assessment strategies employed to evaluate the course, which are of value to other departments undertaking an online course effort. The assessment data presented also provide benchmark data against which other departments could compare data from their online courses. For instance, as discussed in this paper, a common goal in improving online courses is to improve students' sense of connectedness – if another department tries an excellent strategy toward this end, they are invited to use findings presented here as a comparator.

STUDY DETAILS AND METHODS

The two courses studied here make up the two-course sequence intended to teach ChE fundamentals to students with backgrounds outside of chemical engineering. The first semester course focused on material and energy balances (*Elementary Principles of Chemical Processes*, 4th ed. by Felder, Rousseau and Bullard),[11] first and second laws of thermodynamics (*Introduction to Chemical Engineering Thermodynamics*, 8th ed. by Smith, Van Ness, Abbott and Swihart),[12] and momentum transport phenomena (*Transport Phenomena*, rev. 2nd ed. by Bird, Stewart and Lightfoot).[13] The high-level learning objectives for this first course in the sequence were:

1. Solve steady-state and transient material and energy balance problems for single and multiple unit processes, with and without reaction, involving components in both vapor and liquid phases (later referred to as "MEB").
2. Perform thermodynamic analyses of closed and open systems based on first and second laws. Relate thermodynamic properties of interest to measurable physical parameters and calculate the thermodynamic properties for a specified change of state (later referred to as "classical thermodynamics").
3. Describe and analyze transport processes for flows of Newtonian fluids (later referred to as "momentum transport").

The second semester course focused on heat and mass transport phenomena (*Transport Phenomena*, rev. 2nd ed. by Bird, Stewart and Lightfoot),[13] solution thermodynamics (*Chemical Engineering Thermodynamics*, 8th ed. by Smith, Van Ness, Abbott and Swihart),[12] and kinetics / reactor design (*Elements of Chemical Reaction Engineering*, rev. 5th ed. by Fogler).[14] The high-level learning objectives for this second course in the sequence were:

1. Describe and analyze energy and heat transport through single and multiple phases as well as steady-state and transient mass transfer processes (later referred to as "heat/mass transport").
2. Apply first and second laws to multicomponent systems to calculate thermodynamic properties (later referred to as "solution thermodynamics").

3. Develop rate equations from known elementary reactions or available kinetic data, size a reactor given reaction kinetics, and evaluate reactor design options for multiple reactions (later referred to as "kinetics").

For the interested reader, more granular lecture-level learning objectives for the courses, along with direct assessment data of each of these learning objectives, are provided in the Appendix.

The courses were offered in an online/distance education format, with course lectures, homework, quizzes, and office hours provided electronically using course management software (Moodle). Exam testing was arranged by individual students with approved proctors. Homework and exams were "typical", i.e., they were generated by instructors who used problems in required course textbooks as inspiration for the problems. Quizzes contained selected conceptual problems from LearnChemE.com[15] and the AIChE Concept Warehouse.[16] Grading components for each course are shown in Table 1. Final letter grades in the course (not reported here) were "curved" as is typical for graduate courses in the instructors' department. There were 20 students enrolled in the first course of the sequence at the beginning of the semester. One student dropped the first course of the sequence prior to the university class drop deadline, and this student was not included in the analysis. A total of 14 of these students returned to enroll and complete the second semester course.

TABLE 1
Weighted grading calculation for studied courses.

Component	Weight
Homework Set (13 sets total)	10%
Conceptual Quizzes (11 quizzes total)	5%
Exams (3 exams total)	60%
Final exam	25%

Appropriate IRB approval was secured for direct and indirect data collection. The assessment scheme presented here was described in authors' earlier work.[9] Direct assessment of the courses was derived from student performance on individual homework, quiz, and exam problems mapped to each of the course learning objectives. Indirect assessments were collected through end-of-semester course evaluations and responses to constructional inventories of qualitative metrics related to motivation (task value, cost, interest, and self-efficacy) and course experience (time spent on course, connectedness, and Moodle structure). The constructional inventories and background used in this work to assess student motivation are presented in Table 2; a similar discussion of assessment of student experiences within the course structure is presented in Table 3.

During the initial offering of the online course sequence in Fall 2018 – Spring 2019, the goal of assessment was to collect initial baseline data to use as a comparator with equivalent data collected in future course offerings. This approach intends to allow statistical evaluation of the effectiveness of any future changes against baseline data.

RESULTS AND DISCUSSION

The course design and delivery are consistent with best practices for online education, including dividing the course content into brief modules (typically 5 minutes or less) using "content chunking,"[17] writing detailed learning objectives for each module,[18] and using clear and consistent organization and navigation.[19] In addition to the short video lectures, the instructors integrated multiple modern "lightboard" videos. These are videos which use visualization technology to feature visual concepts. Such videos are well suited to illustration or complex equations which could be stepped through in a visual process; a still from one of the course's lightboard lectures is shown in Figure 1. In order to create a welcoming environment, the instructors created "portrait videos" (stills shown in Figure 2) to introduce themselves to the students, a practice which has been shown to increase online student satisfaction and engagement.[20,21]

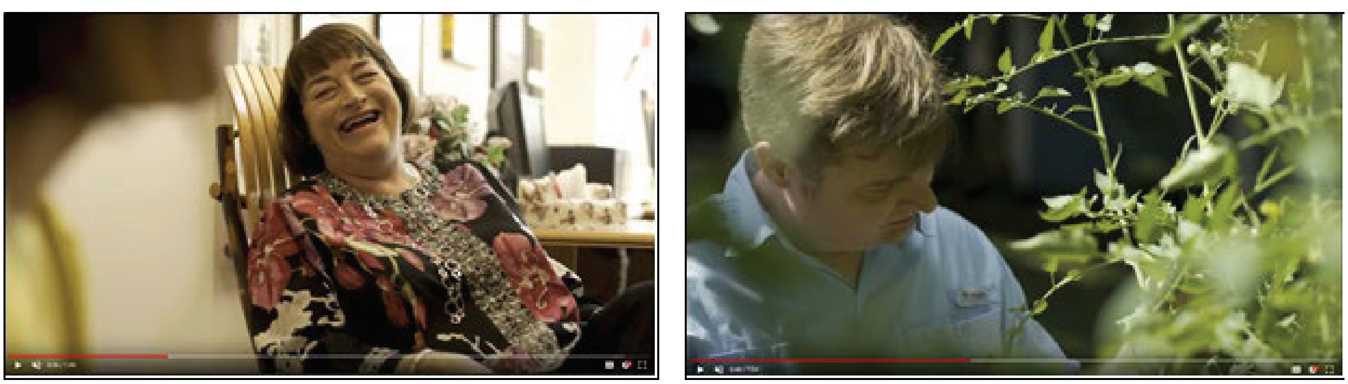
Direct Assessment

In order to directly assess student performance in each course, all problems contained in homework, quizzes, exams, and the final exam were mapped to individual course-level learning objectives in a similar fashion as one might for

Figure 1: *Example "lightboard" video from course.*

TABLE 2 Constructs and associated inventories / measures used in analysis to assess student motivation.		
Construct	***Measure Definition & Description***	***Rationale***
Task value	***Definition:*** In the current context, task value relates to an individual's perspective on the importance of the mastery of chemical engineering content, as well as success in chemical engineering tasks.[23] ***Measure Description:*** Six items from the Motivated Strategies for Learning Questionnaire[24] were used to measure task value. Items referenced the course (e.g. "Understanding the subject matter of this course is very important to me") and required the individual to rate their level of agreement for each statement.	***Prior Literature:*** The construct of task value has been linked to performance, persistence, and choices of which activities students engage in.[25] ***Inclusion in Study:*** The current project outlines a bridging course designed to build individuals' chemical engineering knowledge and skills for professional development and building a foundation for further academic pursuits. As a result of this, it is important to understand how this course may influence students' perceptions of the value of the content they come into contact with, as well as the value they place on completing course-related tasks.
Cost	***Definition:*** Cost is the valuation of the worthwhileness of time and effort required to complete a task.[26] ***Measure Description:*** Cost was measured using two subscales of the Flake et al.[26] cost scale. Specifically, measurement focused on task effort (5-items relating to work put forth to engage in the task) and outside cost (4-items relating to work put forth for tasks other than the task of interest).	***Prior Literature:*** Cost has been found to be moderately negatively correlated with motivation, interest, and student outcomes at the college level.[26] ***Inclusion in Study:*** Based on the course covering a large amount of content, and the intended path of students upon completing the course, it was important to understand whether the students in the course had outside constraints influencing their ability to engage in course tasks (outside cost), or if they felt negatively about the amount of work/effort required to engage fully in course tasks.
Interest	***Definition:*** Two forms of interest were measured in the current study: initial interest and maintained interest. Initial interest refers to the level of interest an individual has in a topic prior to the beginning of a course, based on their prior experiences. Maintained interest refers to interest developed during a course that endures beyond the particular situation (e.g. lecture or module). ***Measure Description:*** Two scales from Harackiewicz et al.[27] were used to measure initial interest and maintained interest. The measure of initial interest included seven items adapted to specifically refer to the chemical engineering prior to students engaging in the course (e.g. "I'm really looking forward to learning more about chemical engineering"). Maintained interest contained nine items that assessed students' feelings regarding the course material (e.g. "I think what we are studying in CHE 596 is useful for me to know").	***Prior Literature:*** Initial interest has shown to influence the development of other forms of interest (e.g. maintained interest), as well as predict achievement at the college level.[27] Further, maintained interest has also been linked with maintained engagement in a task, increased self-efficacy, and self-regulation.[28] ***Inclusion in Study:*** We felt it necessary to see if the course develops (and maintains) interest in the subject area.
Self-efficacy	***Definition:*** Self-efficacy relates to an individual's belief of their ability to perform a task within a specific domain.[29] ***Measure Description:*** Self-efficacy for the course was measured using an eight-item scale adapted from Nietfeld, Cao and Osborne (2006).[29] Further, a measure of self-efficacy was also taken relating to students' beliefs about their ability to accomplish/complete the specific course learning objectives.	***Prior Literature:*** Self-efficacy has been linked with student performance in the college classroom.[29] ***Inclusion in Study:*** As the course developed in the project is built as a "stepping stone", it is important that it increases students' beliefs about their ability to engage in these tasks moving forward/in the future.

TABLE 3 **Constructs and associated inventories / measures used in analysis to assess student experiences within the course structure.**		
Construct	***Measure Definition & Description***	***Rationale***
Time spent on course	***Measure Description:*** Students self-reported how long they spent engaging in course-related activities, as well as their time being tracked in the course itself via the Learning Management System (LMS).	***Prior Literature:*** Time spent on course has shown to be predictive of performance.[30] ***Inclusion in Study:*** As this was the initial undertaking of the course, both in the amount of content and instructional format, from a design standpoint it is helpful to understand the amount of time students spend on the course. Further, having multiple measures allows us to compare students' perceptions of time with LMS-provided time stamps.
Connectedness	***Measure Description:*** Students feelings of connectedness were measured using three researcher-developed items relating to how they felt the course kept them connected with their peers/instructor, created an active learning community, and allowed them interactions with their peers on a regular basis.	***Prior Literature:*** Positive interactions with other students, content, and the instructor are all highlighted as being important to student achievement in online education.[31] ***Inclusion in Study:*** Based on prior literature and need to understand if the design of the course resulted in students feeling isolated.
Moodle structure	***Measure Description:*** Students' perceptions of the LMS structure were measured using six researcher-developed items. These items related to course navigation, access to materials, and clarity of instructions in the LMS.	***Prior Literature:*** LMS structure and organization can impact students' (and faculty) engagement, communication, and feedback,[32] as well as learning.[33] ***Inclusion in Study:*** Primarily for the design team/ internal review purposes.



(a) (b)

Figure 2: *Stills from instructor "portrait videos" intended to improve online student/teacher relationships.*

accreditation purposes.[22] The mean performance of the class in each of these categories is given in Figure 3 for the first semester and Figure 4 for the second semester. A blunt quantitative measure of student performance can be calculated using the assignment weights provided in Table 1 to provide a "course average" for aggregate performance in each learning objective; these values are also shown in Figures 3 and 4.

The benchmark for students to have "met expectations" in this study was a score greater than 69.5%. This benchmark was selected to be congruous with the authors' ChE department's ABET benchmark for students having met expectations in undergraduate coursework; this score is equivalent to the lowest score suitable to receive a C- grade in an undergraduate course. The authors felt using the same expectations in the bridging courses as for general undergraduate courses was appropriate since the content of the bridging courses comprises undergraduate course content.

The data shown in Figure 3 for the first semester of the two-course sequence indicate that students met expectations for Course Objective 1 (MEB) and Course Objective 3 (Transport) in aggregate and for most assignment types, but their performance typically did not meet expectations for problems related to Course Objective 2 (Thermodynamics). This result may indicate that teaching materials / examples as well as assessment instruments used for thermodynamics need to be revised in future offerings of the course, but there are multiple factors confounding this analysis. For instance, it is possible that assessments associated with thermodynamics had a higher difficulty relative to the MEB and transport assessments. In addition, since most of the students taking the course have a chemistry background, they may have felt confident in their thermodynamics background based on prior chemistry coursework but be unfamiliar with some of the more applied thermodynamics covered in the bridging course. Figure 4 shows assessment data for the second semester of the sequence, which indicates students met expectations for all course objectives in aggregate and for most assignment types. In particular, however, students struggled with the conceptual quizzes associated with solution thermodynamics and kinetics; these comparatively lower performances by students on quizzes were also found in the first semester as shown in Figure 3. It was interesting that students met expectations for solution thermodynamics content in the second course, but not for classical thermodynamics in the first course. In an effort to better investigate the trends of student performance on quizzes as well as in classical thermodynamics, student self-assessments of their competency in each learning objective and student comments will be examined by indirect assessment in the next section. As a reminder, more granular lecture-level learning objectives for the courses along with direct assessment data of each of these learning objectives are provided in the Appendix.

Indirect Assessment

As described in Table 2, indirect assessments were completed using validated constructional inventories. These surveys were administered online using Qualtrics. In order to collect results that would allow for longitudinal analysis throughout the semester, students were asked to complete surveys on three occasions: Survey 1 was given during the 2nd and 3rd weeks of the course, Survey 2 during the 9th and 10th

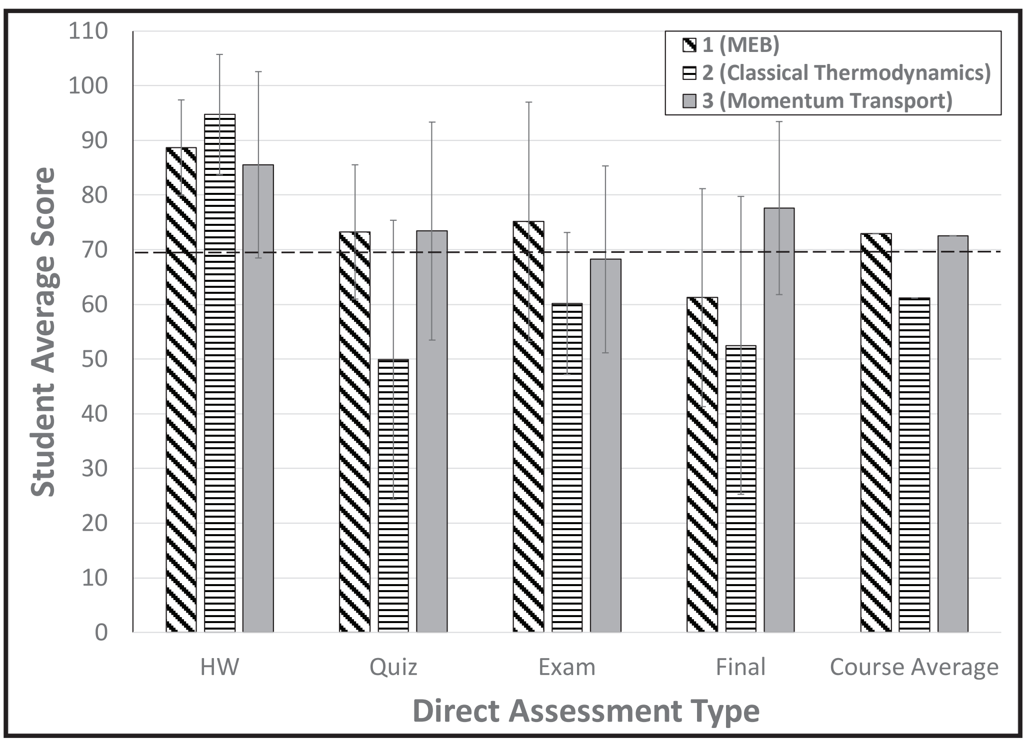


***Figure 3**: Mean scores on homework (HW), quiz, exam, and final exam problems mapped to individual course-level learning objectives for the first course in the two-semester sequence. Dashed line indicates benchmark for meeting expectations. Error bars show one standard deviation above and below the mean. Course average calculated using weights listed in Table 1 (standard deviation not shown).*

weeks, and Survey 3 during the 15th and 16th weeks.

Regarding participation, in the first course 7/19 students completed Survey 1 (though one student indicated they did not want their answers recorded, leaving 6 respondents), 6/19 students completed Survey 2 (though one student only partially completed the survey) and 3/19 students completed Survey 3. It is possible that the smaller number of respondents to Survey 3 was due to fatigue over taking multiple surveys during the semester, or the fact that Survey 3 took place across the last week of classes and first week of final exams. In any event, the impact of this small sample size unfortunately diminishes the precision of aggregate indirect measurements from Survey 3 in the first semester course. Disappointingly, low response rates worsened for the second semester course, where none of the 14 students completed Survey 1 and only 2/14 students completed each of Surveys 2 and 3. This lack of robustness in data should be noted by the reader as a key limitation of the indirect assessment portion of this study, which will aim to be improved in future work; one strategy will be to offer a small amount of course credit for participating in the surveys, while remaining within IRB stipulations for proper consent. With this limitation in mind, the authors have chosen to only examine indirect assessment data for the first semester course in any depth; though indirect assessment data for the second semester course is presented in the supplemental information associated with this paper for the sake of completeness, due to the exceedingly low response rate it would be impossible to draw any definitive conclusions from the opinions of only two students.

Demographic information was collected through Survey 1 for the first course in the sequence; since there were no respondents to Survey 1 for the second semester course, this data is unavailable. In Survey 1 for the first course, 50% of students identified as male and 50% female. Race demographics were 66% White, 17% Black/African American, and 17% Asian/Asian American. When asked about their prior experience in chemical and/or biomolecular engineering, 50% had no experience, 16% had taken 1-3 courses, 16% had taken more than 3 courses, and 16% (one respondent) had received a degree in chemical and/or biomolecular engineering.

Course expectations for the first semester course were probed in Survey 1. Sixty-seven percent of respondents noted that they were taking the course as they were applying to a graduate program, 16% as they were changing career path/professional development, and 16% wanted to refresh/solidify core principles. Eighty-three percent expected to spend 5-10 hours on the course per week, with the remaining students (17%) indicating an expectation of 10+ hours. Sixty-seven percent of students expected a medium level of engagement with other students and 33% a low level of engagement. All respondents expected to interact with the instructor on a weekly basis. Fifty percent expected to obtain an A grade, and 50% expected to obtain an A- in the course.

Assessment of student learning in learning objectives for this online course was a key goal of this work, so an assessment strategy built on triangulation[22, 34] was used. In addition to the direct assessment of student learning discussed in an earlier section, results of indirect assessment of students' self-reported ability to accomplish the course learning objectives are shown in Figure 5. This figure indicates that students' own perceptions

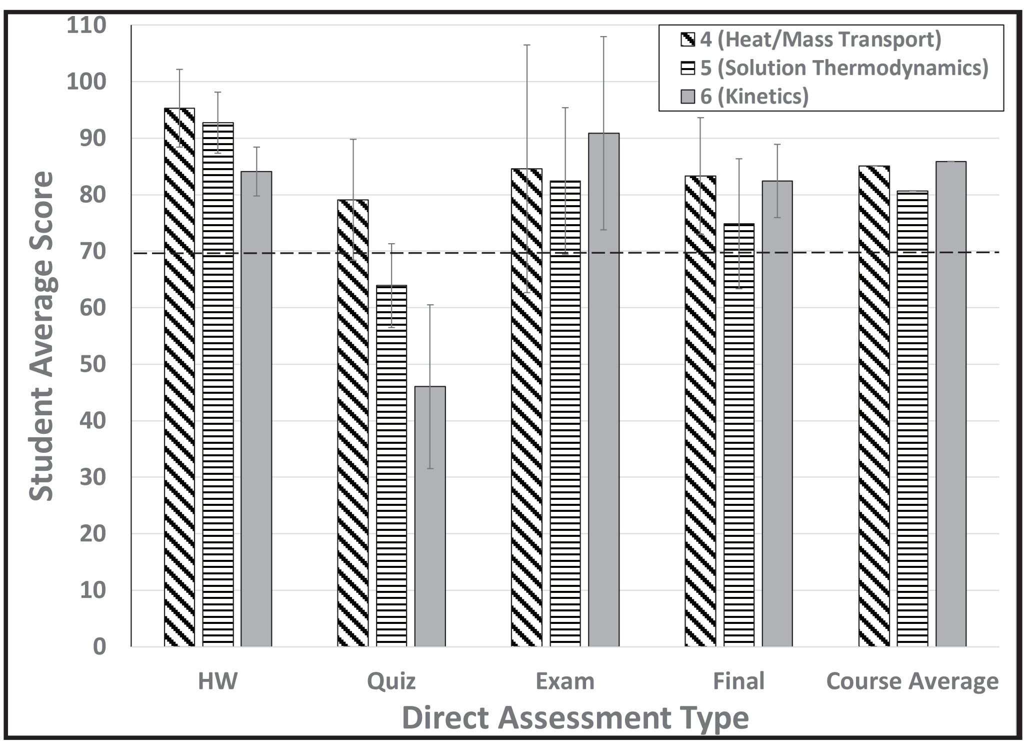


***Figure 4**: Mean scores on homework (HW), quiz, exam, and final exam problems mapped to individual course-level learning objectives for the second course in the two-semester sequence. Dashed line indicates benchmark for meeting expectations. Error bars show one standard deviation above and below the mean. Course average calculated using weights listed in Table 1 (standard deviation not shown).*

of their abilities to accomplish Course Objective 1 (MEB) and Course Objective 3 (Transport) modestly increased from the beginning to the end of the semester, while a modest decrease was observed for Course Objective 2 (Thermodynamics). While appropriate caveats regarding the small sample size in Survey 3 of the first semester course apply, these indirect assessments are in agreement with the direct assessments shown in Figure 3 where student performance in Course Objective 2 was below that achieved for the other objectives. In response to these triangulated findings, we plan to re-examine the thermodynamics teaching and assessment materials prior to the next offering of the first course. In particular, a comparison of teaching styles and assignments between the classical thermodynamics material of the first semester course (with which students struggled) and the solution thermodynamics material of the second semester course (with which student fared better) will be examined.

As described in Table 2, a number of validated instruments were used for indirect assessments of student motivation; the measurements resulting from these various instruments for the first semester course are shown in Table 4. As a note for reading Table 4, for each construct listed on the left-hand side of the table, the maximum score on the inventory for the construct is given in parentheses; for instance, the "Task Value" inventory used had a maximum score of 42. With this in mind, the students' initial task value was high in the initial survey, with an average score of 37.7 out of a maximum score of 42, with a standard deviation (SD) of 5.4. This high score was maintained throughout the semester, indicating that students held a high valuation of the importance of the mastery of chemical engineering and success in related tasks. Regarding cost, perceived task effort was relatively low at the beginning of the course, with an average of 17.4; a high score in this inventory would indicate that students felt they were spending too much time / resources on the course considering the value of the content, while a lower score indicates that students felt they were not spending too much time / resources on the course. This modest value was maintained at the end of the semester (16.3), showing that students viewed the time and effort required for learning chemical engineering in the course as worthwhile and not onerous. Outside cost/effort was also relatively low with an average score of 12.6 at the beginning of the semester, which was also maintained throughout the semester (13.3), indicating that students did not view outside commitments or responsibilities as limiting their ability to spend time on the course. Positive results were found for student interest, with high initial interest at the beginning of the semester (42.7) and remaining high throughout the semester. These results indicate that students were excited about the course and viewed it as personally meaningful while believing what they were learning was important. Students began with high scores on the self-efficacy inventory (mean value of 31.3), and these strong scores lasted through the end of the semester (31.3), which shows students had a strong perception of their ability to complete chemical engineering tasks. In total, these measures of student motivation during the course suggest students entered the semester with high levels of motivation toward the course and maintained this level throughout the semester.

TABLE 4
Indirect data regarding various measures taken to indicate student motivation for the first semester course.

Construct (maximum inventory score)		Survey Number 1	2	3
Motivation	**Task Value (42)**	37.7 (SD=5.4)	35.7 (SD=7.9)	34.0 (SD=6.9)
	Cost			
	Task Effort (45)	N/A	17.4 (SD=11.0)	16.3 (SD=12.1)
	Outside Cost (36)	N/A	12.6 (SD=7.1)	13.3 (SD=10.1)
	Interest			
	Initial (49)	42.7 (SD=5.2)	N/A	N/A
	Maintained (63)	N/A	55.8 (SD=8.8)	57.7 (SD=4.7)
	Self-Efficacy (40)	31.3 (SD=4.5)	N/A	31.3 (SD=3.5)

Students' course experiences were also probed using survey instruments. Students were asked to self-report the time they spent per week on the course as part of Surveys 2 and 3. The average reported number of hours spent (per week) for the first semester course were slightly higher at Survey 2 (mean = 10 hours, SD = 4.9) compared to Survey 3 (mean = 7.7 hours, SD = 3.8). For the second semester course, students reported number of weekly hours spent on the course as 13.5 hours in Survey 2 and 10.5 hours in Survey 3. All of these values are within typical expectations for a 3-hour graduate course.

Of special concern to the authors was students' feelings of connectedness in the course; this was the instructors' first time teaching online courses, and there was concern that the somewhat impersonal online (as opposed to in-person) format would negatively impact student-teacher and peer relationships. Indeed, student estimations of their feelings of connectedness during the first semester (Figure 6) course were mixed. The authors have identified this as an area for improvement and subject of future work.

Survey 3 included questions regarding the structure of the Moodle course website. All respondents strongly or somewhat strongly agreed that it was easy to navigate through the web pages covering each topic-based module; the coded bars clearly indicated the part of the module they each represent; the coded icons clearly indicated the part of the topic they each represent (e.g. lectures, examples, homework); it was easy for students to navigate through the course Moodle site; and it was easy for them to find the course materials they wanted on the Moodle site. The majority of respondents strongly or somewhat strongly agreed that the instructions and directions provided in the lessons were clearly written.

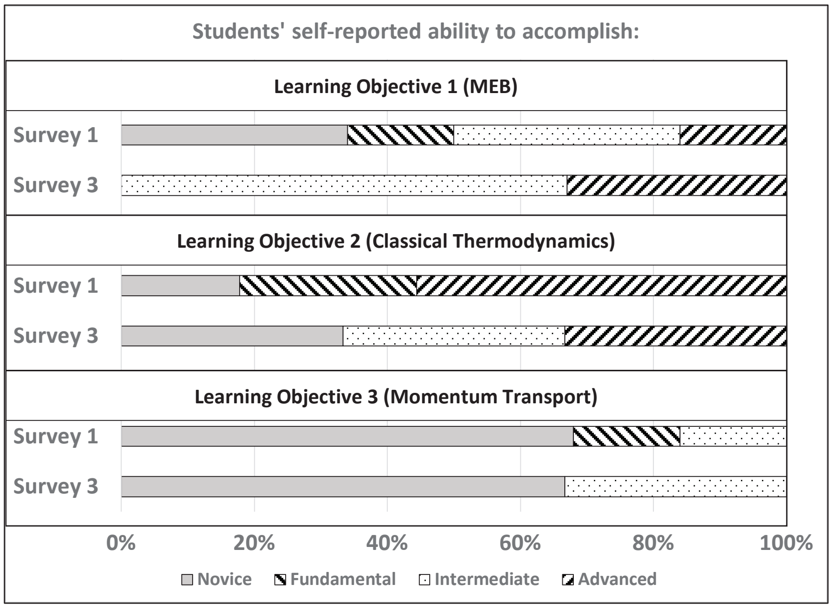


Figure 5: *Self-reported assessment of students' ability to accomplish course-level learning objectives for the first semester course.*

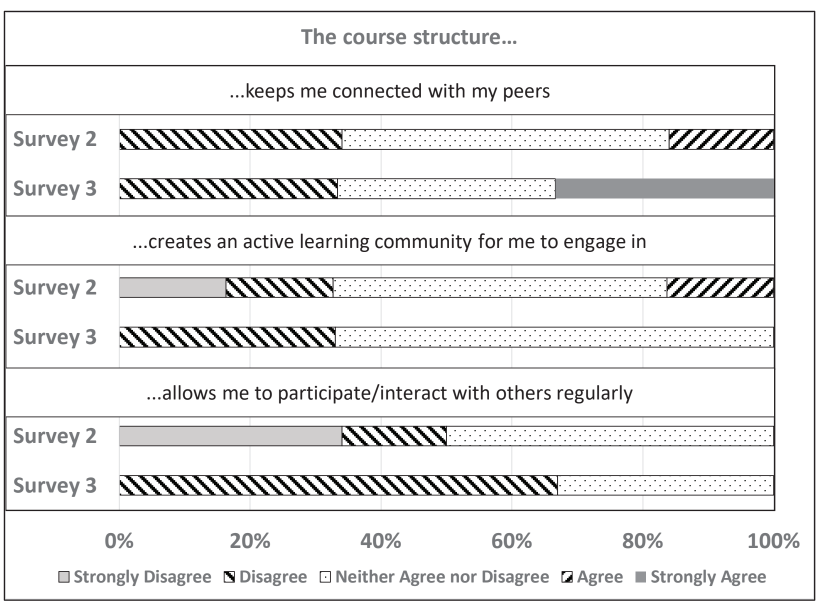


Figure 6: *Indirect data regarding various measures taken to indicate student motivation for the first semester course.*

In each tested semester, both Survey 3 and the university's standard end-of-semester course evaluations were used to collect open-ended responses to various questions. Positive, reinforcing comments centered around instructor communication and quality of visual aids and textbooks:

- "The materials were well-organized and the progression of material was perfect. The topics on the website were even color coded! There was attention to details in the presentation of this class."
- "Can all online courses follow the format of this class? This class was very well done and I really felt like it was designed with the student in mind."
- "Effective Communication - The professors were always available to answer questions and kept us abreast with any updates. It was such a pleasure being in the class."
- "I love having the in-class video lectures without going to school. I also appreciated both a PDF and video solution to practice and homework problems."
- "The textbooks were an excellent resource and I was very glad to be able to use them on the exams. It is also more helpful to have a familiar resource to look up constants and use tables than it is to look it up in the provided exam materials, so being able to use the books and notes on the exams was very helpful to me."

Students also provided constructively critical comments and suggestions, which mainly focused on ambiguous instruction and testing instruments:

- "Based on my schedule, I would sometimes work ahead of class to ensure homework was done in a timely manner. Sometimes the homework questions which I had already completed were replaced with other questions. This was frustrating because I had to go back to redo another set of homework questions to ensure I got credit for completing the task. In the future, please stick to the questions posted and if needed make changes weeks ahead of time."
- "I believe having more in-depth and rigorous example problems would benefit most students."
- "The videos for the example problems were not helpful. They were exactly the same as the book explanation, and did not break the problems down to be easily understood."
- "In the example problems, I did not always understand where they were getting certain numbers and a lot of steps were skipped."
- "Quizzes - The questions were ambiguous and only one attempt was given. In the future, please make the questions more straightforward and allow multiple attempts."

While changes should not necessarily be made to courses based strictly on student comments, since this is the initial offering of the course (and the authors lack experience in online teaching), these comments would seem to be more likely to identify areas of instructor oversight or naiveté than for an offering of an established on-campus course. These constructively critical comments identify a number of key areas for the authors to consider for improvement moving forward:

- Since this was the first time the course was offered, at times errors were found in homework problem statements, or homework was found to involve a topic that was not well-covered in the lecture or example videos. In these cases the authors made adjustments to the material at least a week in advance of the expected due date, but students who worked well ahead in the online class may have already downloaded and completed the earlier versions. The authors anticipate that since these problems have been identified and addressed during the first offering of the course, this issue will not persist in future offerings.
- Example problem solutions, which were provided in both PDF format as well as an annotated video, sometimes did not show all intermediate steps in a problem and at times lacked discussion of "why" steps were made. Since online students miss the experience of working problems in class with the instructor (not to mention the ability to ask questions when they are confused on an intermediate step), it is possible that giving especially rigorous and detailed explanations for steps in worked example problems is important for online engineering courses. This will be investigated in future work.
- While undeniably valuable, the conceptual testing instruments on LearnChemE.com and AIChE Concept Warehouse can be challenging, and students commented that they had a hard time understanding what was being asked at times; this was reflected in comparatively poor performance on quizzes opposed to other assessment instruments as described in an earlier section. In an effort to alleviate this frustration, we intend to allow at least two attempts (with feedback on incorrect initial responses) for quiz questions in future course offerings.

CONCLUSIONS

Direct and indirect assessment of student learning, motivation and course experience were completed for a two-semester online chemical engineering graduate bridging course. It was found that students tended to perform better in the portions of the course associated with material and energy balances, momentum transport, heat/mass transport, solution thermodynamics and kinetics, while comparatively less so in those associated with classical thermodynamics. These direct measures were corroborated by indirect self-assessment by students of their ability to accomplish the course learning objectives. Student motivation and interest in the course were found to begin and remain high throughout the course, portending good engagement with the material. Students reported they spent about 8-10 hours each week on tasks associated with the course. Of special concern to the authors were students' feelings of connectedness considering the online course format; indeed, student estimations of their feelings of connectedness during the course were lower than desired. Students agreed that format, structure, and organization were strengths of the online course.

Based on the results of this study, the authors have identified a number of areas for improvement and future work. Since both direct and indirect assessments indicated classical thermodynamics learning was weaker than for other content in the course, teaching and assessment materials related to classical thermodynamics content in the course will be re-evaluated. The authors' concerns about students feeling a lack of connectedness in the online course were confirmed, and measures aimed at improving the students' sense of connectedness and community will be investigated, including adding an online discussion forum to each homework assignment to allow students to discuss the homework strategy and approach, with instructors and TA's monitoring and contributing to the discussion. Students felt that the recorded example problems needed additional depth in discussion and explanation as part of the solution, so new recordings will add to or replace existing example problems. Finally, students felt the conceptual quizzes taken from LearnChemE.com and the AIChE Concept Warehouse were challenging enough such that multiple attempts should be offered (perhaps with diminishing scores for additional attempts); this will be investigated in the next offering of the course.

NOTICE

Preliminary discussion and findings from the first semester of the two-course sequence were previously included in the Proceedings of the 2019 ASEE Annual Conference,[10] while background information on rationale, development and assessment strategies for the courses have been documented in previous work.[7-9]

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APPENDIX

Lecture-Level Learning Objectives and Direct Assessment Results.

Table A1 shows a sample of the granular direct assessment data collected for each of the lecture-level learning objectives of the two online ChE graduate bridging courses. Direct assessments were completed by mapping individual problems from homework, quizzes and exams to the learning objectives relevant to solving each problem. Lecture-level learning objectives without listed assessment data indicate these objectives were not assessed in the first offering of the course sequence. The full table of lecture-level learning objectives and associated direct assessment data can be accessed online at https://www.cbe.ncsu.edu/wp-content/uploads/2015/07/Granular-LO-Direct-Assessment-for-NCSU-Website.pdf or by contacting Matthew Cooper at mecoope3@ncsu.edu.

TABLE A1
Lecture-level learning objectives and direct assessment results

Course-Level Learning Objective	Course Module	Lecture-Level Objective	Homework Problem Average Score	Quiz Average Score	Exam Problem Average Score	Final Exam Problem Average Score
Heat/Mass Transport	12.1	Describe mechanism of heat transfer by conduction	87.9			
		Analyze conductive heat transfer in systems using Fourier's law of conduction for various geometries		70.0	84.6	85.1
	12.2	Identify the effect of temperature and pressure on thermal conductivity				
	12.3	Explain the impact of boundary layer flow on convective heat transfer		73.6		
		Describe mechanisms of heat transfer for free and forced convection	92.1	70.0		
		Analyze Newton's Law of Cooling	95.6	77.1	84.6	85.1
	12.4	Analyze the impact of thermal conductivities of composite materials (such as insulated walls) and convection on heat transfer	92.1	70.0	84.6	85.1
	12.5	Describe mechanism of heat transfer for radiation		70.0		
		Analyze heat transfer by radiation using Stefan-Boltzmann equation		70.0		
	13.1	Describe the concept and procedure of shell momentum balances in solving energy balance problems		77.1		
		Derive the equation of energy for non-isothermal flow in terms of the transport properties	95.4		84.9	
		Identify boundary conditions for a given non-isothermal energy balance problem	95.9	77.1		
		Identify when to use special forms of the equation of energy	95.9		84.9	
		Apply special forms of the equation of energy to solve differential steady-state heat transfer boundary value problems	95.9		84.9	
	13.2	Identify dimensionless groups important in heat transfer				
	13.3	Define function and describe construction of various types of heat exchangers		77.1		
		Determine overall heat transfer coefficients and log mean temperature difference for double-pipe heat exchanger operation	95.4			
		Analyze double-pipe heat exchangers	95.4	77.1		
	14.1	Describe mechanisms of mass transfer by diffusion		76.2		
		Analyze diffusive mass transfer in systems using Fick's law of diffusion for various geometries	92.9			
	14.2	Identify the effect of temperature and pressure on diffusivity				
	14.3	Define common terms and notation used in convective mass transport, including mass/mole concentrations, mass/mole fractions, and mass/molar average velocities	94.3			
		Describe combined mass flux and molar flux vectors for diffusive and convective mass transport	94.3	84.5		
	15.1	Derive the general equation of continuity for mass transfer processes	99.6		88.1	78.6
		Identify boundary conditions for a given mass balance problem	96.3	92.9		
	15.2	Identify commonly-used specific forms of the equation of continuity for mass transfer and in which cases to apply them	96.3	92.9	88.1	78.6
		Analyze and apply specific forms of the equation of continuity for mass transfer to determine concentration profiles	96.3	92.9	79.0	78.6
	15.3	Define function, mechanism and applications of common types of industrial processes requiring mass transfer				