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Student Anxiety and Belonging in a Mastery-Based-Learning Course

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Introduction

Almost 1/3rd (31%) of U.S. adults will experience an anxiety disorder at some point in their lives; with females affected more than males (about 1.5:1) [1]. In 2017, 61% of college students seeking counseling services listed anxiety as the most frequent issue they were facing, and about 23% said it was the problem causing them the most concern (Center for College Mental Health at Penn State [2]). Anxiety can impact physical, cognitive and emotional health, impacting how students perform in their classes and consequently in their careers.

For college students, anxiety is frequently manifested in relation to exams—it is estimated that 10-40% of students are affected by test anxiety. Test anxiety can impact motivation and academic achievement and lead to higher rates of alcohol use and leaving college without a degree [3,4,5,6].

There is high stress among engineering students due to the difficulty of their degree program. Grades and rigor have been identified as some of the most significant stressors for engineering students. High levels of stress can become part of the engineering culture and can be passed on to new students. This cycle of expecting stress can lead to further elevating stress levels for students and can even result in other mental health challenges. One study showed that students enrolled in engineering programs are two times more likely to experience anxiety than their non-engineering classmates. In addition, another study found that engineering students who were experiencing mental health issues sought treatment less often than other students [7].

The engineering culture at a college or university is an essential aspect of educational success. This culture largely contributes to individuals' sense of belonging. Culture that fosters a sense of belonging has greater student retention. A 2012 study found that lack of belonging was a top reason that engineering students left the program [7].

Competency-based (or mastery-based) course structure allows students to learn at their own pace, so they can complete topics they understand more quickly and focus more time reviewing topics they struggle to understand. Literature suggests that this course structure makes students more autonomous. This leads to higher achievement and motivation since students feel as though they have more control over their education [8]. Mastery-based-learning (MBL) also eliminates the "one-shot" mindset for students taking exams. If students are not able to demonstrate mastery on their first attempt, they are given additional chances and, if they demonstrate mastery, they will receive the same score as students who succeeded on their first attempt [9]. This allows students to learn from their mistakes and try again without any penalties.

Since the curriculum in engineering courses continually builds on itself, it is extremely important that students understand prerequisite materials. If students are struggling with the more basic content, they will inevitably struggle with subsequent content. Falling behind can lead students to leave their major or college entirely. Competency or mastery-based-learning structures courses so that students always master basic skills before they can begin to tackle more complex material. With this structure, it is much more difficult for students to fall behind in their courses resulting in a smaller probability that students will leave the program. Findings have shown that students performed better, were more knowledgeable, and had more positive/enthusiastic attitudes toward learning when taking competency or mastery-based courses compared with traditional courses [8].

Using MBL has shown an increase in proficiency rates among students [10]. Establishing an ideal curriculum requires finding the proper balance between breadth and depth. While MBL gives students as much time as they need to practice and get assistance with key skills, if they do not master the essential skills quickly enough, they may not reach all the skills that would be covered in a traditional course. On the other hand, when taught in the traditional model, many students do not master the key, fundamental skills [10, 11].

The grading structure for MBL evaluates students on the number of skills that they can do well. This structure favors proficiency in a few key skills over limited competency in many skills. While high-achieving students can reach proficiency in all skills regardless of how the class is structured, the proficiency of average and below-average students improved with MBL when compared with a traditional assessment structure [10].

Instructors who utilized MBL techniques noted that there are benefits including easier grading and better insight into students' progress throughout the semester. They also noted some downfalls such as student's frustration with an unfamiliar pedagogical approach [12]. Additionally, since students work on different topics within the same class, classroom management can become difficult [11].

At Missouri University, MBL was used in an upper-level environmental engineering course. When the class ended, students were given the chance to "suggest improvements" and to point out "strengths" and "weakness" of the course. Using responses from this survey, the following strengths were identified: course structure, grading system, and student motivation. Several weaknesses were also identified. These include time spent learning about the unfamiliar course structure, student motivation, and lack of traditional lectures [12].

At Elizabethtown College, a mastery-based approach to foundational engineering courses has been employed to boost student learning and success. To support students as they master skills at their own pace, instructors provide active coaching during some class times. A mastery-based approach in mathematics has been shown to reduce student anxiety [13], perhaps due to increased autonomy, individual pace [8], or because assessments cover smaller sections of material and may be retaken as often as needed. Frequent assessments also provide instructors with individualized feedback, so they can help each student at their level. These targeted interventions may also boost student confidence and sense of belonging.

We hypothesized that:

(1) Students will have less test-related anxiety and anxiety related to the course in general when compared with a traditional assessment (3 during the term exams and final exam). With this aim we hope to confirm what others have reported [13].

(2) Students will have a greater sense of belonging, accomplishment, hope and enjoyment with mastery-based learning.

To study the effect of MBL on student anxiety and belonging, students completed multiple surveys throughout the semester while enrolled in either a traditional or MBL version of our circuit analysis course.

Implementation of Mastery-Based Learning (MBL):

An MBL course prioritizes depth over breadth, so begin by viewing your course in terms of the skills you want your students to learn and demonstrate—the key skills and outcomes that students need to be successful in their future courses and careers. While these outcomes can span Bloom's Taxonomy [14], in practice there is a limit to the number of skills students can be assessed (and reassessed) on, so skills based on the apply, analyze, evaluate or create outcome levels are generally more appropriate. The goal of this section is to describe the process through which we transitioned our traditional assessment course (fall 2022, Circuit Analysis) to a mastery-based course (fall 2023) with enough details and tips that others could follow a similar process. One of the authors also served as the instructor for both versions of the course. The study was approved by the Elizabethtown College Institutional Review Board.

Class and Student Demographics

During the fall 2022 semester, two sections of an electric circuit analysis course were taught in a traditional assessment manner: the first section had 23 students, and the second 12 students. Of these, 22 students consented to participate in this study (about 26% female, 74% male). All students were second-year engineering students, except for 1 physics education major. During the fall 2023 semester, two more sections of the course were taught with an MBL approach: the first section had 29 students and the second 25 students. Of these, 28 students consented to participate in this study (about 18% female, 82% male). All these students were second year engineering students.

Identify Mastery Skills:

First, we began by listing all the skills taught in our circuit analysis course. These could be book chapters, exam problems, or important outcomes from projects or reports. We tried to frame them as measurable skills using questions such as: "Students will do...", "Students will solve….", "Students will analyze…". Next, we grouped skills by importance and reduced the list to 12 skills we could assess. We selected 5 essential skills (Fig. 1, Foundational skills) that all our students should master to be successful in our curriculum, 3 priority skills that we wanted students to master next (Fig. 1, Important skills) and 4 supplementary skills (Fig. 1, Additional skills) that are 'nice-to-know' but not a priority for most of our students. While all our assessments were exam based, it is possible to use projects or papers to assess mastery, particularly for the important or supplemental skills.

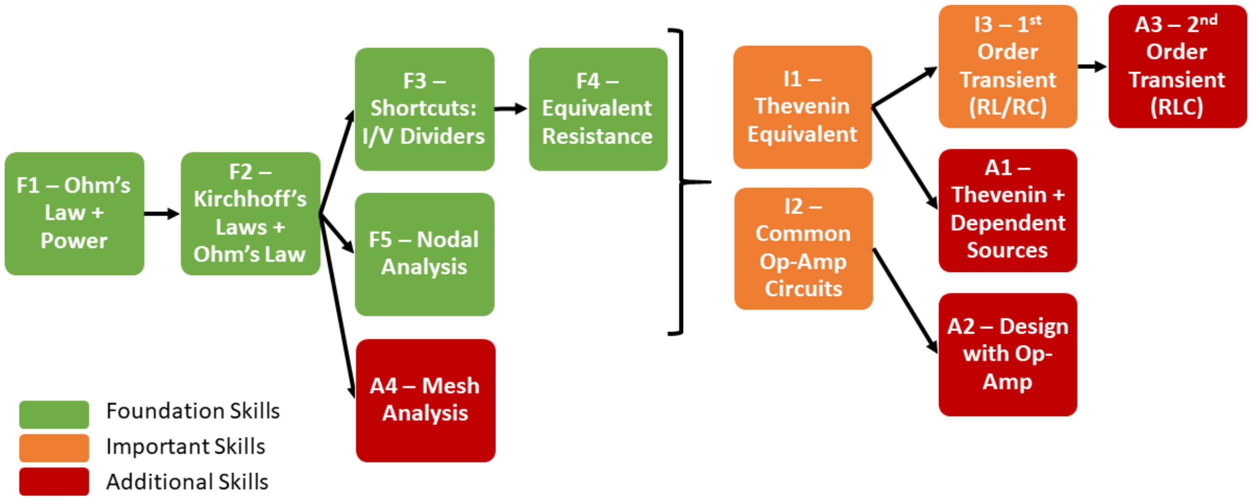

Figure 1: Dependency chart for mastery skills. Students must master the Foundational skills before attempting the Important skills, and the Important skills before attempting the Additional skills.

<u>Grading Structure:</u>

In a mastery-based course, skill mastery is directly connected with the student grade, so we designed a path that makes sense for students to earn a C, B or A. In our traditional course, four exams over the course of the semester made up 60% of a student's overall grade (see Table 1)—a lot of pressure to perform well at those critical assessments. As in many traditional courses, students also received credit for pre-class preparation, participation, homework, and laboratory work (Table 1).

Table 1: Grading structure for traditional circuit analysis course

Assessment Category	% of Total Grade
Pre-class preparation	5%
In-class participation	5%
Homework	10%
Partial exams	35%
Final Exam	25%
Lab	20%

In our mastery-based course, a student earned a C- (the grade required for pre-requisite courses like ours) after mastering all the Fundamental skills (Table 2). Beyond this, any Important skill that a student passes increased their grade by 1/3 of a letter, a pattern that continued with mastery of the Additional skills. Even though students who only passed the Fundamental skills may not get as much practice with the Important and Additional skills, they were still exposed to these skills during in-class instruction and through homework and laboratory exercises. By achieving mastery on the Fundamental skills, students will have a full understanding of these topics that they can apply to future engineering courses and in their career. In contrast, with the traditional grading structure, students could earn a C- through a partial understanding of many topics (e.g., partial credit on exams) without a proficient understanding of and ability to apply the foundational topics.

Table 2: MBL grading structure for Circuit Analysis

<table>
<tr><td rowspan="5">Foundation Skills</td><td>Pass any 1 F skills</td><td rowspan="5">F1: Use Ohm's law to calculate power in sources and loads for a power budget
F2: Use KVL and KCL and Ohm's law to calculate V, I or R in circuits with unknown variables.
F3: Shortcuts: using voltage dividers, current dividers and equivalent R's to find V, I or P in circuit with several loads.
F4: Use equivalent resistance to simplify circuits.
F5: Use Nodal analysis to find V, I and P in complex circuits with multiple sources.</td><td>F</td></tr>
<tr><td>Pass any 2 F skills</td><td>D-</td></tr>
<tr><td>Pass any 3 F skills</td><td>D</td></tr>
<tr><td>Pass any 4 F skills</td><td>D+</td></tr>
<tr><td>Pass all 5 F skills</td><td>C-</td></tr>
<tr><td rowspan="3">Important Skills</td><td>Pass any I skill</td><td rowspan="3">*** Must pass all F skills to earn credit for I skills ***
I1: Apply Thevenin theorem to analyze/simplify a complex circuit (Independent Sources only)
I2: Common op-amp circuits, find the output voltage (or gain) for several cascaded amplifiers.
I3: Find the analytical solution describing the voltage (and current) in a RC or RL circuit as a function of time.</td><td>C</td></tr>
<tr><td>Pass any 2 I skills</td><td>C+</td></tr>
<tr><td>Pass all I skills</td><td>B-</td></tr>
<tr><td rowspan="4">Additional Skills</td><td>Pass any A skill</td><td rowspan="4">*** Must pass all F and I skills to earn credit for A skills ***
A1: Apply Thevenin theorem to analyze/simplify a complex circuit (Dependent Sources included)
A2: Design an op-amp circuit to transform input signal to meet specified output criteria. Build and demo for an optional bonus skill.
A3: Find the analytical solution describing the voltage (or current) in a series or parallel RLC circuit as a function of time.
A4: Use Mesh analysis to find V, I and/or P in complex circuits with multiple sources.</td><td>B</td></tr>
<tr><td>Pass any 2 A skills</td><td>B+</td></tr>
<tr><td>Pass any 3 A skills</td><td>A-</td></tr>
<tr><td>Pass all A skills</td><td>A</td></tr>
</table>

Unlike a traditional grading structure (which might include homework, labs, or participation) the mastery-based structure is not percentage-based, and student grades are primarily a function of the skills mastered. However, to encourage students to engage in important learning activities that guide students toward skill mastery, four policies were adapted in regard to homework, laboratory assignments, pre-class preparation (i.e., fill out gapped notes from short videos in our semi-flipped classroom) and attendance: (1) students will receive a 1/3rd letter grade deduction for an overall homework grade below 80%; (2) students must get a final lab grade of at least 80%

to achieve a C- or above, 85% to achieve a B- or above, and 90% to achieve an A- or above; (3) students will receive a 1/3rd letter grade deduction if fewer than 80% of the pre-class preparations are not completed; and (4) there will be a 1/3rd letter grade deduction for more than three unexcused absences. While these policies are not unreasonable, they tend to motivate students to participate in these activities. We recommend similar policies adapted to your courses to incentivize students (e.g., those who benefit from more guiding structure or who are tempted to procrastinate) to stay engaged and not fall behind.

Observations and Tips: This is a very different grading structure that many students are not familiar with, so it is helpful to review the grading structure and the retesting process more than once (e.g., after the first testing session when they may have more motivation to understand the structure than on the first day of class when the syllabus was presented). In the end, we didn't impose grade deductions if a student gave a good effort (e.g. almost 80%) but failed to reach the thresholds for homework and pre-class preparation. In general, students were very motivated to meet the threshold requirements. In fact, in some cases they were so focused on homework and pre-class preparation that they benefited from a reminder that their grade (and our desired outcome) was to pass the next Foundational or Important skill at hand rather than completing homework or pre-class preparations associated with the 'nice-to-know' Additional skills. One benefit of students knowing exactly what their grade is at every moment of the semester is they get to make choices about their studying priorities. Some students were content with earning a C- and chose to focus their time during the final week of class on other challenging courses they also needed to pass (e.g., statics, calculus); however, most continued to master new skills and improve their grade).

<u>Assessments:</u>

In preparation for the course to be taught using MBL, we created problem banks for each skill. Two short homework assignments were assigned each week. The first included 3-4 instructor-designated problems from the bank based on the new topics covered in class (automatically graded using an online learning environment, McGraw-Hill Connect). The second required students to submit their work for an any 4 problems of their choosing (e.g., problems from the problem bank they were actively studying in preparation for an upcoming skill test) which were graded for completion, not correctness (to reduce grading).

To incentivize student engagement with the homework and problem banks, the weekly skill tests consisted of randomly selected problems from the banks, with different numerical values. Because of this, the problem banks for our Foundational skills included more than 20 problems as some students tested on these skills several times each. The problem banks for the Important and Additional skills were smaller (~15 questions) as students had fewer opportunities to retest on them.

At each scheduled assessment, we allowed students to test up to three skills during a 25-minute class period. This created a lot of grading so little or no individual feedback was provided; rather, students were assigned a 3 for mastery (pass, no conceptual errors), a 2 for approaching mastery (at least one conceptual error) or a 1 for far from mastery (many conceptual errors). With this rapid grading, there were occasions when a student conceptually analyzed the circuit correctly but made a numerical error. Thus, we allowed students to challenge their initial score if they thought they were conceptually correct (quickly scanning the stack of exams after scoring provided a digital record for the instructor in these circumstances).

Observations and Tips: In hindsight, we recommend only allowing students to test on a maximum of 2 skills per session as this will reduce the amount of grading while also helping students focus on a realistic amount of mastery from week-to-week. Some students would show up and test from week-to-week without much practice in between and you could impose a threshold that requires students to complete a specified portion of the problem bank prior to testing on a given skill. However, this increases the logistical management for the instructor that is already spending a lot of time grading (though an online learning system that tracks problem bank completion could help such as McGraw-Hill Connect). Less frequent testing (i.e., not weekly) could also help students take each opportunity more seriously, but it also increases the stakes (and anxiety) with each test and allows fewer retest opportunities. Student excitement to learn whether they passed or not was often very high, and students waited after class to discuss with and learn from the instructor and their peers. Because of this we recommend taking advantage of this interest and scheduling office hours following class or regularly using the next class session to provide feedback to small groups of students seeking to master the same skill. Finally, one of the benefits of mastery-based assessment is that course grades are assigned objectively: going into the final exam both the student and the instructor know the likely final grade. There were no student requests to round up and grading the final exam was also a quick and painless process.

<u>Course Schedule</u>

In both the traditional and mastery-based courses, the classroom was flipped, requiring students to watch 15-20 minutes of video prior to class and come to class with filled in notes (i.e., 'gap-notes'). Thus, the traditional course included a brief review of key concepts from the video, followed by significant active learning and hands-on practice during class time—exams occurred occasionally (3 during the semester and 1 final exam). In the mastery version of the course, the course schedule was adapted to include instruction, coaching and testing on a weekly basis (Table 3). On instruction days, students came to class having watched the pre-class videos and completed notes for that skill. As in the traditional version of the course, the instructor reviewed the key concepts and guided the students through hands-on practice. On a coaching and testing day, students worked in small groups on problems related to any skill of their choice, while the instructor provided informal coaching as needed (about 50 minutes). During the last 25 minutes of class, students could take their skill exams to demonstrate mastery. Most students finished testing on 1 or more problems before the 25 minutes expired, and only a handful (perhaps 3 to 7, depending on the week) used the full time. The well-prepared students often finished within the first 10 minutes. With more testing opportunities than skill exams, students can learn through failure and the assessment process instead of simply being evaluated by it. Over the whole semester, the total amount of in-class testing only increased by 85 minutes (roughly 1 class period) for the mastery (thirteen 25-minute testing sessions) compared with traditional (three 80-

minute exams). During the final exam, students were given 1 last chance to demonstrate mastery of any skill remaining. Most students only tested on 1 or two skills for the final exam and were finished within the first half-hour. No students remained in the final testing period longer than 45 minutes.

On coaching days, the mastery-based curriculum is flexible: students choose which skills they would like to spend time practicing and they decide when they are ready to attempt the exam. This means that in a given week (particularly in the second half of the semester) many students will be learning about advanced topics on instruction days while practicing skills from previous topics during coaching days. This could be confusing, and students may be less engaged with the advanced material. However, because interleaving of instructional topics improves understanding and retention students may learn more with the mastery structure, even though it may be challenging in the moment. One-on-one (or small group) interaction with the instructor during coaching days also helps to provide targeted learning support, regardless of student trajectory through the course materials.

Table 1: Course Schedule for Mastery Based Learning Structure

	Tuesday	Thursday
Aug.	22 Introduction/F1 Instruction	24 F1 Instruction
	29 F2 Instruction, Testing of F1	31 F2 Instruction + Coaching
Sept.	5 Coaching/Testing of F1, F2 skills	7 F3 Instruction
	12 Coaching/Testing of F1, F2 skills	14 F4 Instruction
	19 Coaching/Testing of F1, F2, F3 skills	21 F5 Instruction
	26 Coaching/Testing of F1, F2, F3, F4 skills	28 F5 Instruction cont'd
Oct.	3 I1 Instruction/Testing of F skills	5 **Fall Break, No Class**
	10 Coaching/Testing of F skills	12 A1 Instruction
	17 Coaching/Testing of F skills and I1	19 I2 Instruction
	24 Coaching/Testing of F skills and I1, A1	26 A2 Instruction
Nov.	31 I3 Instruction/Testing of F skills and I2, A1	2 I3 Instruction
	7 Coaching/Testing of F skills and I1, I2, A2	9 A3 Instruction
	14 Coaching/Testing of F skills and I2, I3, A2	16 A4 Instruction
	21 Coaching/Testing of F skills and I3, A3	23 **No Class**

	28 Coaching/Testing any skill	30 Coaching
Dec.	Final Exam will be used as a chance to retest on any remaining skills	

Observations and Tips: Even though mastery-based assessments only cost 85 more minutes of testing compared with the traditional assessment, the coaching sessions before testing were too short and students probably could have benefited from more coaching. In addition, coaching immediately before testing felt less effective: students who were prepared to pass the skill required less coaching, while students who were not prepared to pass a skill that day usually needed more individual practice to ensure they fully understood the concept and could adapt to any variations that might appear on the skill test. We suggest scheduling coaching to follow each skill test so that the instructors can help students to respond positively to and learn from failure (and student motivation was high following skill tests).

Because many students will not attempt the additional skills, it became a challenge for the instructor during the last month of the semester to motivate and engage students in the new material. For these students, the motivation of a looming mid-term or final exam on these skills no longer existed in the mastery version of the course. So rather than proceeding with complicated analyses, we suggest in-class instruction should focus on engaging demos and activities that help students grasp the big picture conceptual ideas rather than the sometimes detailed and complicated analyses. We still expected the high-achieving students to master these analyses; however, teaching the class in a flipped format allowed us to include the detailed analyses as a separate video resource for high-achieving students to watch on their own. As motivation, we encouraged these students to take on the challenge and responsibility for their own learning, and they responded. We did not track student progress in the video and notes for the additional skills as these students had proven they were self-motivated and could learn the material effectively, without much oversight.

Survey Questions

During the two introductory circuit analysis courses, an online survey was administered to assess student anxiety and belonging. In the fall 2022 semester, students taking the course with a traditional grading structure were given the survey three times: week 6 (after the first exam), week 11 (after the second exam), and week 15 (after the third exam and before the final exam). Students completed the survey at their leisure over approximately the next two weeks. During the fall 2023 semester, the class was taught using MBL and the survey was administered at the same intervals. Survey questions were selected from the Achievement Emotions Questionnaire (AEQ) that focused on anxiety, enjoyment, hopelessness, hope, pride, and shame. We used a short version of the questionnaire (shown to be an adequate substitute [15]) where four questions were selected to assess each subcategory from the AEQ (e.g., four questions were chosen to assess student levels of anxiety related to testing). The full survey is included in the supplemental material (S1). Using the shortened survey, the average student response time was eight minutes and fifty-two seconds. Students answered questions by selecting the amount that they agree with chosen statements on a Likert scale. For example, students were given the statement “I am optimistic that everything will work out fine” in reference to taking exams. Then they could select an answer between strongly agree and strongly disagree (Figure 2).

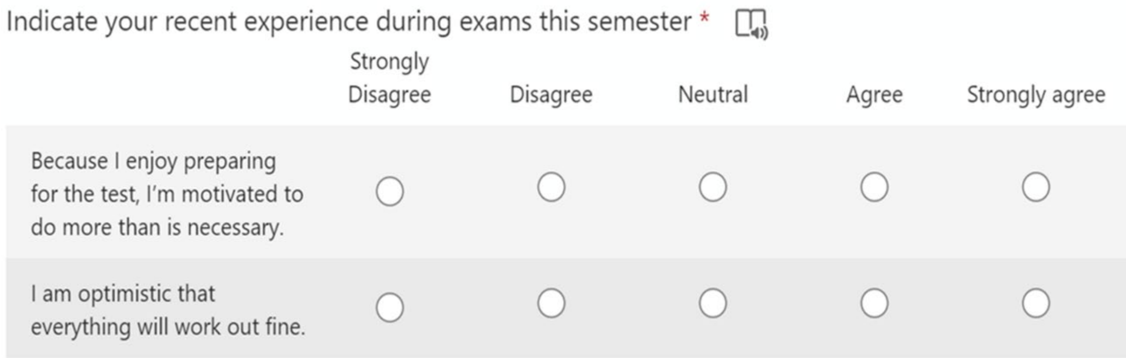

Figure 2: Sample survey questions given to students. The full survey administered to the students can be seen in supplemental material (S1).

There were also three survey questions from the Belonging Uncertainty Scale [16] to assess student belonging in the classroom. These questions allowed students to select the amount that they agreed with a given statement by choosing an answer between “strongly agree” and “strongly disagree”.

<u>Data Processing</u>

Likert data were analyzed using a two-way ANOVA with the factors of time (week of the semester) and course type (mastery or traditional). Individual pair-wise comparisons were performed using Tukey’s honest significant difference test. The survey results were downloaded from Microsoft Forms as excel files and uploaded into MATLAB® for data analysis. We summed the survey questions associated with each emotion type (e.g., anxiety, enjoyment, hopelessness, hope, shame, pride, and belonging) and then divided by the number of questions for each ($n = 4$ or 3 for the AEQ and Belonging Uncertainty Scale, respectively) so that the result fit within the Likert scale (strongly disagree = 1 to strongly agree = 5). One of the questions for the belonging data was reverse scored, per instructions, prior to averaging. All data are presented as the mean ± standard deviation.

Results

<u>Student Performance and Perception:</u>

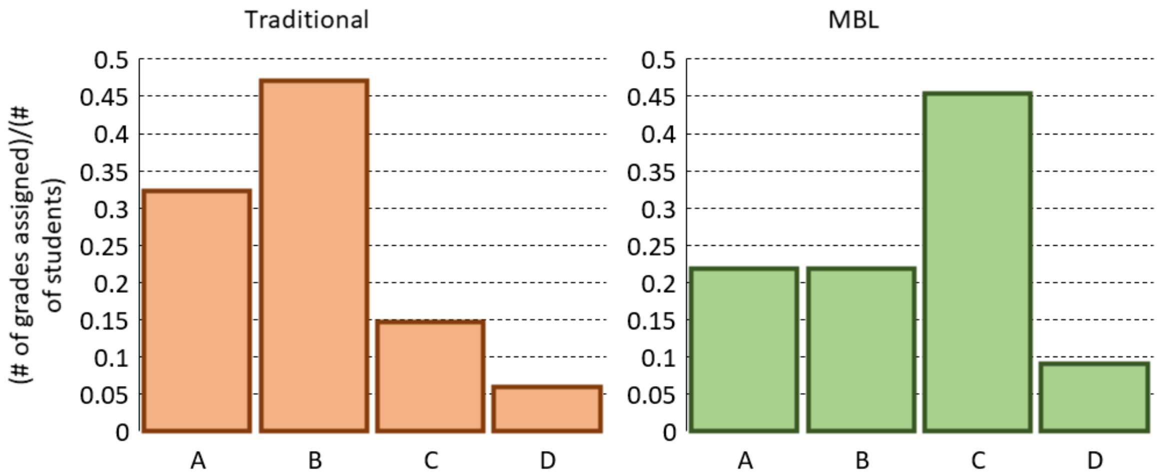

Figure 3: Student grade distribution in the traditional and mastery-based (MBL) versions of the course. Converted to a 4-point scale, the average course grade changed from about a B (3.1 ± 0.8, traditional) to about a C+ (2.4 ± 1.0, MBL; mean ± stdev, significant, Student's t-test, p < 0.01).

In the traditional course offering, student grades were higher (79% received an A or B) compared with the MBL course where only 43% of the class earned an A or B and 45% earned a C. Converted to a 4-point scale, the average course grade changed from about a B (3.1 ± 0.8, traditional) to about a C+ (2.4 ± 1.0, MBL; $p < 0.01$). There was no significant difference between student perception of course difficulty: 4.1/5 ± 0.7 for traditional compared with 3.6/5 ± 0.7 for MBL. Similarly, students indicated that the MBL and traditional versions of the course required similar amounts of course work: 3.5/5 ± 0.6 for traditional compared with 3.1/5 ± 0.6 for MBL (not significant).

As with any new implementation, student feedback on the course was mixed: some students recognized the benefits of mastery-based learning while several others expressed preferences against the approach. Students praised the utility of the problem banks for practice and the benefits of in-class coaching, wished the course moved more quickly through material, and noted the difficulty of earning a good grade compared with traditional courses they were taking. One student expressed:

"I think the mastery based has made this course a lot more challenging then in the past. Sure, it helps me understand certain material better but makes the course a lot more difficult to get a good grade."

Another had similar sentiment:

"Mastery Based classes seemed that they would be a lot more beneficial at the beginning of the semester, but after taking this class along with others, I believe that I would have received a better grade with a traditional testing approach."

Survey Results

The data gathered during the semester with traditional course structure and the semester with MBL course structure showed a statistically significant difference in ten out of thirteen categories. All these differences were in favor of the MBL course structure. From the Achievement Emotions Questionnaire, we measured students' levels of anxiety, enjoyment, hopelessness, hope, shame, and pride in relation to testing and class in general. We divided these results into "negative" emotions (Figure 4) and "positive" emotions (Figure 5).

Overall, the two-way ANOVA showed a statistically significant effect ($p < 0.05$) due to course type (MBL vs. Traditional) for classroom anxiety, classroom enjoyment, classroom hope, classroom hopelessness, testing anxiety, testing enjoyment, testing hope, testing hopelessness, testing pride, and testing shame—all of which improved (up for positive emotions and down for negative emotions) in response to the MBL structure (Figures 4 and 5). Individual comparisons at weeks 6, 11, and 15 were not significant (i.e., only two-way ANOVA indicated an effect due to MBL).

The two-way ANOVA indicated no effect on student emotions because of the time of the semester, indicating that students' feelings about the classroom, testing, or sense of belonging did not change over the course of the semester (see Table 4). Because of this, and for simplicity, the figures only include the data at week 15, whereas all the data are presented in Table 4.

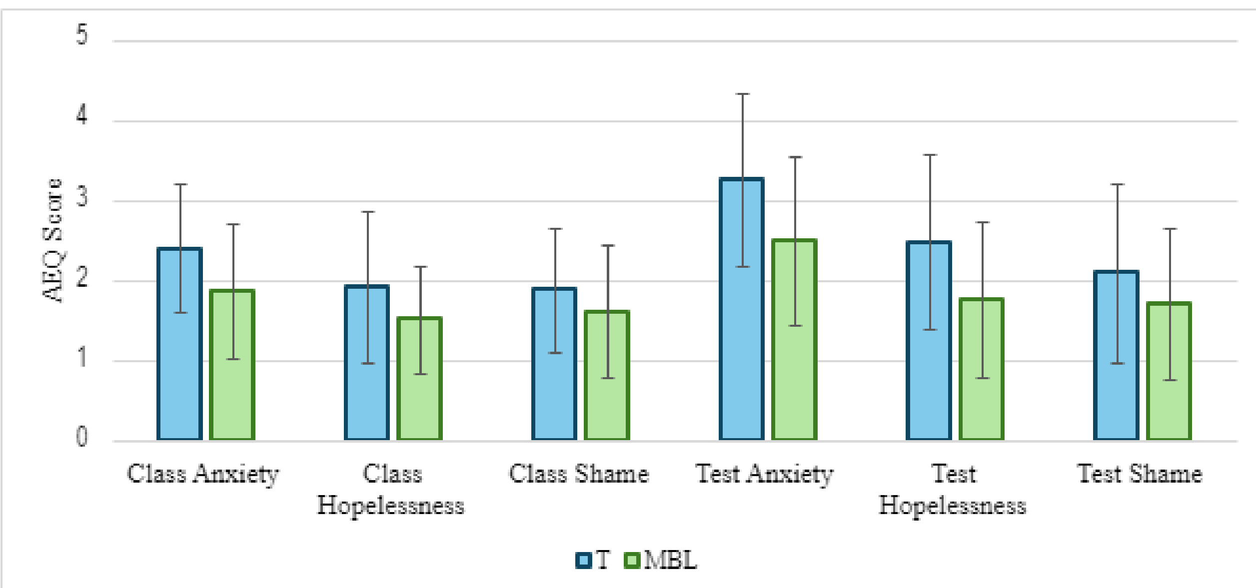

*Figure 4: Average student responses related to negative emotions for both traditional (T) and MBL course structures. Two-way ANOVA indicated that course structure had a significant effect in favor of MBL for all emotions except classroom shame (*mean ± stdev, *$p < 0.05$). Because five, three and one represent 'strongly agree', 'neutral' and 'strongly disagree' on the Likert scale, respectively, data suggest that students were generally in positive emotional states for both types of class structures.*

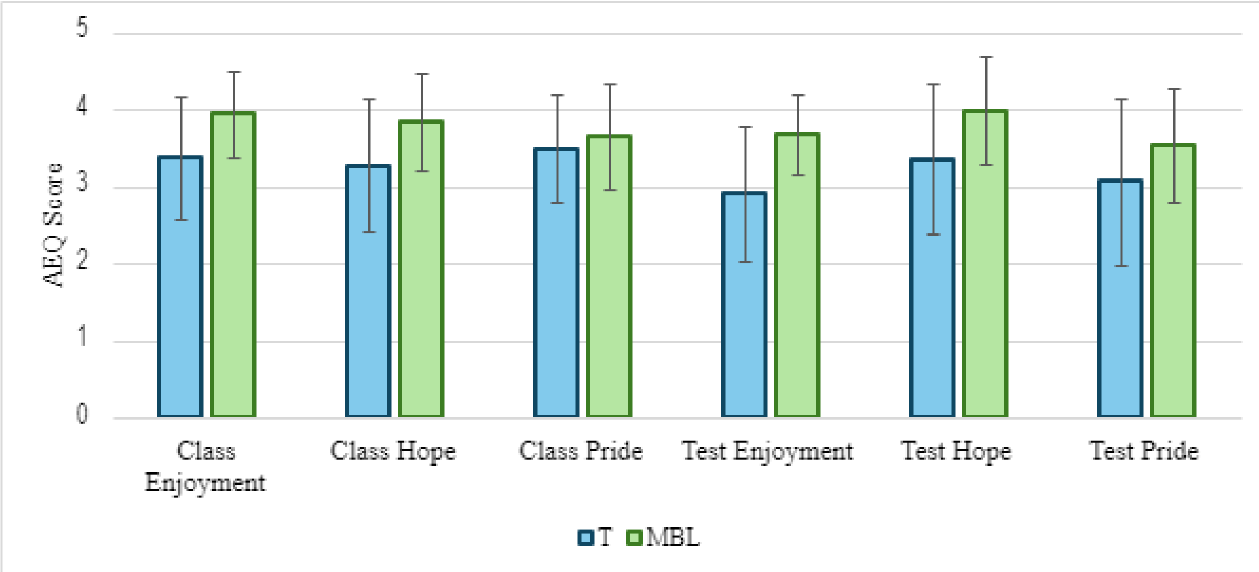

*Figure 5: Average student responses related to positive emotions for both traditional (T) and MBL course structures. Two-way ANOVA indicated that MBL course structure had a significant effect for all emotions except class pride (*mean ± stdev, *$p < 0.05$). Because five, three and one represent 'strongly agree', 'neutral' and 'strongly disagree' on the Likert scale, respectively, students were generally in positive or neutral emotional states for both types of class structures.*

Figure 6 shows that MBL may have reduced belonging uncertainty (less uncertainty is improved belonging; measured using the Belonging Uncertainty Scale), though the trend was not significant. However, students in both the traditional and mastery-based courses on average felt more belonging than uncertainty (ranged from 2.3 to 2.5 for MBL and 2.5-2.6 for traditional; score <3 corresponds to less uncertainty and more belonging).

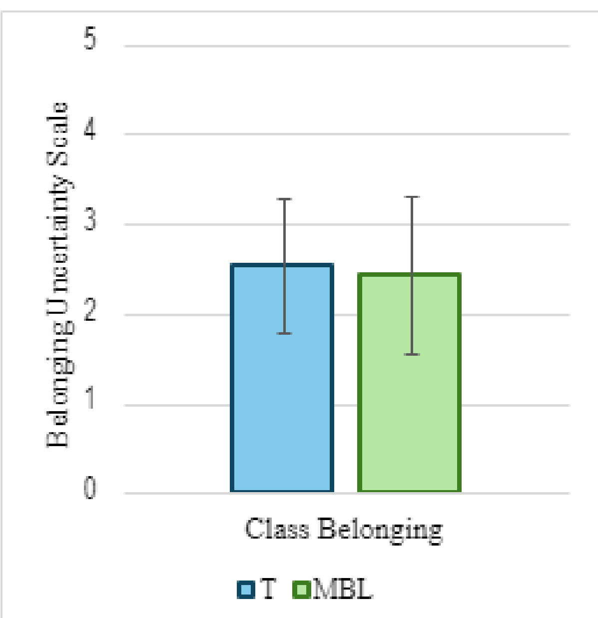

Figure 6: Average student responses for belonging uncertainty in traditional (T) and MBL course structures. A lower score indicates less uncertainty and, thus, more belonging. A five represents "strongly agree", a three "neutral" and a one "strongly disagree." While students may have felt more belonging with MBL, the effect was not significant. On average students felt more belonging than uncertainty in both version of the course (scores < 3).

Table 4 - Data collected from the AEQ-S survey and the Belonging Uncertainty Scale presented as mean +/- stdev for traditional (T) and mastery-based (MBL) course offerings. Statistics for two-way ANOVA are also presented.

Emotion Type	T			MBL			Structure (MBL vs T)		Time (week 6, 11,15)		Interaction	
	Week 6	Week 11	Week 15	Week 6	Week 11	Week 15	F	Prob > F	F	Prob > F	F	Prob > F
Class Anxiety	2.1 +/- 0.5	2.3 +/- 1.0	2.4 +/- 0.8	1.9 +/- 0.7	2.0 +/- 0.7	1.9 +/- 0.8	7.44	p = 0.007*	0.418	p = 0.660	0.300	p = 0.742
Class Enjoyment	3.5 +/- 0.7	3.6 +/- 0.8	3.4 +/- 0.8	3.9 +/- 0.6	3.7 +/- 0.6	3.9 +/- 0.6	8.52	p = 0.004*	0.009	p = 0.991	1.08	p = 0.343
Class Hope	3.4 +/- 0.7	3.5 +/- 0.8	3.3 +/- 0.9	3.7 +/- 0.6	3.5 +/- 0.6	3.8 +/- 0.6	4.97	p = 0.028*	0.068	p = 0.934	1.22	p = 0.299
Class Hopelessness	1.6 +/- 0.6	1.8 +/- 0.8	1.9 +/- 1.0	1.3 +/- 0.5	1.7 +/- 0.7	1.5 +/- 0.7	4.07	p = 0.046*	2.13	p = 0.124	0.295	p = 0.745
Class Pride	3.6 +/- 0.7	3.6 +/- 0.7	3.5 +/- 0.7	3.6 +/- 0.7	3.5 +/- 0.8	3.7 +/- 0.7	0.00003	p = 0.996	0.001	p = 0.999	0.492	p = 0.613
Class Shame	2.2 +/- 1.0	2.0 +/- 0.9	1.9 +/- 0.8	1.7 +/- 0.8	1.8 +/- 0.8	1.6 +/- 0.8	3.86	p = 0.052	0.520	p = 0.596	0.399	p = 0.672
Test Anxiety	3.4 +/- 0.8	3.6 +/- 1.0	3.3 +/- 1.1	2.5 +/- 1.0	2.5 +/- 1.0	2.5 +/- 1.1	25.93	p < 0.001*	0.227	p = 0.797	0.198	p = 0.821
Test Enjoyment	3.1 +/- 0.7	3.0 +/- 0.7	2.9 +/- 0.9	3.4 +/- 0.7	3.1 +/- 0.6	3.7 +/- 0.5	8.82	p = 0.004*	0.943	p = 0.393	2.19	p = 0.117
Test Hope	3.4 +/- 0.9	3.2 +/- 1.0	3.4 +/- 1.0	3.8 +/- 0.8	3.6 +/- 0.7	4.0 +/- 0.7	8.48	p = 0.004*	1.21	p = 0.301	0.320	p = 0.727
Test Hopelessness	2.1 +/- 0.9	2.2 +/- 1.1	2.5 +/- 1.1	1.6 +/- 0.7	2.1 +/- 1.1	1.8 +/- 1.0	6.07	p = 0.015*	0.978	p = 0.379	0.764	p = 0.468
Test Pride	3.1 +/- 0.9	3.0 +/- 1.1	3.1 +/- 1.1	3.7 +/- 0.8	3.2 +/- 0.8	3.6 +/- 0.7	6.68	p = 0.011*	0.837	p = 0.436	0.492	p = 0.613
Test Shame	2.0 +/- 1.0	2.1 +/- 1.1	2.1 +/- 1.1	1.5 +/- 0.7	1.8 +/- 0.9	1.7 +/- 1.0	5.03	p = 0.027*	0.329	p = 0.720	0.147	p = 0.863
Class Belonging	2.6 +/- 0.7	2.5 +/- 1.0	2.5 +/- 0.8	2.3 +/- 0.7	2.5 +/- 0.7	2.4 +/- 0.9	1.22	p = 0.271	0.055	p = 0.947	0.227	p = 0.798

*Statistical significance ($p < 0.05$) denoted with an Asterisk**

Discussion

We found student anxiety, enjoyment, hope and hopelessness improved regarding how students felt about the MBL classroom and tests. In addition, student shame and pride related to testing in the MBL course also improved. We confirmed our hypothesis, and existing literature, that student anxiety would decrease in the MBL course. While students may have felt a greater sense of belonging (less uncertainty) with MBL course structure, this effect was not statistically significant. However, increased pride, reduced shame, and increased enjoyment suggest that student belonging may improve if a more sensitive measure of belonging was used.

Amazingly, several surveyed emotions improved while the average grade in the course dropped considerably from a B to a C+. The large drop in average grade is likely a result of several factors, including because it was the first time we taught a course in this manner, and we likely had unrealistic expectations with the difficulty of the testing problems for the Fundamental skills. Calibrating a new assessment standard presents its own challenge. The data from this first offering will allow us to adjust the benchmarks for some of the skills leading to a grade distribution closer to the traditionally assessed course. This, in turn, may lead to larger effect sizes than reported in this paper.

A common concern with MBL is that instructors will not be able to cover all the material they currently cover. This is a valid concern. As described, we lost about 1 class period due to the increased testing (and we would have liked more coaching time too). For this course, that meant that we did not cover the topic of superposition, and we labeled the mesh analysis approach as an advanced skill that the high-achieving students could quickly learn by watching the flipped classroom video (which they easily did, in part because they had already mastered Kirchoff's Voltage Law and node voltage, a similar analysis method). In the end, we were comfortable removing the topic of superposition from the course because we felt there were other topics that were more important for our student's success. Fundamentally, MBL is a paradigm shift from providing students limited understanding of many topics (breadth) to mastering the essential topics (depth)—it's a tradeoff.

A limitation of the MBL approach is that students may attempt to memorize the steps of solving the homework problems instead of truly learning how to approach novel problems. Including more design skills (e.g. skill A1 in Table 2) could help address this shortcoming. However, in an introductory class like circuit analysis, only several types of variations are appropriate for these introductory learners anyway, so making the problem banks large enough (20+) to capture multiple problems associated with these variations ensures students are well prepared to use them in the future (and if they complete every problem in the problem bank they likely complete more problems for a given skill than the instructor of the course did when they were an undergraduate student). Many students completed every problem in a problem bank, which likely helped reduce anxiety—students know that if they are comfortable doing every problem in the bank they should excel on the test for that skill.

Another limitation of this study is that we compare two different semesters (fall 2022 and fall 2023) which means two different groups of engineering students at different times, and this could account for some of the observed differences. However, we did control for other variables by keeping the same instructor; offering the courses during the same time-of-day for the same length-of-time; using the same flipped instruction format, videos and other course resources; and covering nearly all the same topics. Because we offer two sections of the course each fall, we originally considered teaching one section in the traditional manner, and the other with mastery; however, because our students are very socially connected to each other, we feared students in one section of the class might influence student perception in the other section, so we decided against that approach.

Conclusion

Anxiety and belonging are major barriers for student success, especially for underrepresented students in demanding degree programs such as engineering. MBL gives students more autonomy, offers more flexibility and focuses the course on building students' foundational skills. Even though the grade distribution shows that it was more difficult for students to achieve high grades in the course, the students emotional experience in the MBL course improved in areas that could reduce student anxiety and improve a sense of belonging.

References

[1] R. C. Kessler, M. Petukhova, N. A. Sampson, A. M. Zaslavsky, & H. Wittchen, "Twelve-month and lifetime morbid risk of anxiety and mood disorders in the United States," *International Journal of Methods in Psychiatric Research*, vol. 21, no. 3, pp. 169-184, Sept. 2012, https://doi.org/10.1002/mpr.1359.

[2] Center for Collegiate Mental Health (CCMH). (2017, January). 2016 Annual Report (Publication No. STA 17-74).

[3] P. A. Lowe, "Should test anxiety be measured differently for males and females? Examination of measurement bias across gender on measures of test anxiety for middle and high school, and college students," *Journal of Psychoeducational Assessment*, vol. 33, no. 3, pp. 238-246, 2015, doi: 10.1177/0734282914549428.

[4] Cizek, G. J., & Burg, S. S. (2006). Addressing test anxiety in a high-stakes environment. Thousand Oaks, CA: Corwin Press.

[6] K. M. Kieffer, C. Cronin, & D. L. Gawet, "Test and study worry and emotionality in the prediction of college students' reasons for drinking: An exploratory investigation," *Journal of Alcohol and Drug Education,* vol. 50, no. 1, pp. 57-81, Mar. 2006.

[7] K. J. Jensen & K. J. Cross, "Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclusion," *Journal of Engineering Education*, vol. 110, no. 2, pp. 371-392, Apr. 2021, https://doi.org/10.1002/jee.20391.

[8] M. Henri, M. D. Johnson and B. Nepal, "A review of Competency-Based Learning: Tools, Assessments, and Recommendations," *Journal of Engineering Education*, vol. 106, no. 4, pp. 607-638, Nov. 2017, https://doi.org/10.1002/jee.20180.

[9] T. R. Guskey, "Lessons of Mastery Learning," *Educational Leadership,* vol. 68, no. 2, pp. 52-57, Oct. 2010.

[10] K. M. DeGoede, "Competency based assessment in dynamics," *2018 ASEE Annual Conference & Exposition*, Jun. 2018.

[11] K. M. DeGoede, "A mastery-based learning model for an upper-level vibration analysis course," *2020 ASEE Virtual Annual Conference Content Access*, Jun 2020.

[12] D. B. Oerther, "Using Modified Mastery Learning to Teach Sustainability and Life-Cycle Principles as Part of Modeling and Design," *Environmental Engineering Science*, Feb. 2022, https://doi.org/10.1089/ees.2021.0385.

[13] Hui Ma. "Mastery Grading Approach in a Calculus Course". 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland, 2023, June. ASEE Conferences, 2023. https://peer.asee.org/43548.

[14] P. Armstrong, "Bloom's Taxonomy". Vanderbilt University Center for Teaching, 2010. https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/ (accessed 02/01/2024).

[15] M. Bieleke, K. Gogol, T. Goetz, L. Daniels, R. Pekrun. “The AEQ-S: A short version of the Achievement Emotions Questionnaire,” *Contemporary Educational Psychology*, Jan. 2021. DOI: 10.1016/j.cedpsych.2020.101940.

[16] G. M. Walton, G. L. Cohen, G. L. (2007). A question of belonging: Race, social fit, and achievement. Journal of Personality and Social Psychology, 92(1), 82-96. (tool available online: https://sparqtools.org/mobility-measure/belonging-uncertainty-scale/; accessed 04/01/2024)

Supplemental Material 1 (S1)

Emotions Questionnaire Administered to Students

Supplemental Material 1 (S1)

Emotions Questionnaire Administered to Students

Emotions Questionnaire: EGR 210 - Fall 2022_1

This questionnaire refers to emotions you may experience as part of this class (EGR 210 - Electric Circuits). It is divided into three sections: **(a)** your emotions related specifically to testing in this course, **(b)** your emotions related to Circuits class in general, and **(c)** your experience as part of the larger Engineering program. Please reflect on your experiences during this semester as you answer the questions below.

* Required

Unique Identifier

1. Copy and paste the unique identifier you received in your email: *

Emotions during Electric Circuits testing and exams

Attending college classes can create different feelings. This part of the questionnaire refers specifically to emotions you may experience *during exams* in EGR 210 - Electric Circuits. Before answering the questions below, please recall your experience during the most recent exam this semester.

2. Indicate your recent experience during the most recent exam *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
Because I enjoy preparing for the test, I'm motivated to do more than is necessary.	◯	◯	◯	◯	◯
I am optimistic that everything will work out fine.	◯	◯	◯	◯	◯
Before taking the exam, I sense a feeling of eagerness.	◯	◯	◯	◯	◯
I get so nervous I wish I could just skip the exam.	◯	◯	◯	◯	◯
I think about my exam optimistically	◯	◯	◯	◯	◯
I worry whether the test will be too difficult.	◯	◯	◯	◯	◯
My confidence motivates me to prepare well.	◯	◯	◯	◯	◯
I enjoy taking the exam	◯	◯	◯	◯	◯
At the beginning of the test, my heart starts pounding.	◯	◯	◯	◯	◯

I start to think

I start to think that no matter how hard I try I won't succeed on the test.	○	○	○	○	○
I am very nervous during exams.	○	○	○	○	○
I feel like giving up.	○	○	○	○	○

3. Indicate your recent experience during the most recent exam (continued) *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
I am very confident.	○	○	○	○	○
Pride in my knowledge fuels my efforts in doing the test.	○	○	○	○	○
I feel so resigned that I have no energy.	○	○	○	○	○
I get so embarrassed I want to run and hide.	○	○	○	○	○
For me the test is a challenge that is enjoyable.	○	○	○	○	○
I feel hopeless.	○	○	○	○	○
Because I am ashamed my pulse races.	○	○	○	○	○
I get embarrassed because I can’t answer the questions correctly.	○	○	○	○	○
I feel ashamed.	○	○	○	○	○
I’m proud of how well I mastered the exam.	○	○	○	○	○

After the exam I feel ten feet taller because I’m so proud.	◯	◯	◯	◯	◯
I am proud of myself.	◯	◯	◯	◯	◯

Emotions during Electric Circuits course

The following questions refer to emotions you may experience as part of this course, EGR 210 - Electric Circuits. Before answering the questions, please recall some situations *in class* and then please reach each statement below and indicate how you *typically* feel when being in class.

4. Please indicate how you feel, typically, when in class.
*

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
Even before class, I worry whether I will be able to understand the material	◯	◯	◯	◯	◯
Being confident that I will understand the material motivates me.	◯	◯	◯	◯	◯
I am looking forward to learning a lot in this class.	◯	◯	◯	◯	◯
Because I'm so nervous I would rather skip the class.	◯	◯	◯	◯	◯
I am confident when I go to class.	◯	◯	◯	◯	◯
I am full of hope.	◯	◯	◯	◯	◯
I am motivated to go to this class because it's exciting.	◯	◯	◯	◯	◯
I feel nervous in class.	◯	◯	◯	◯	◯
Because I've given up, I don't have energy to go to class.	◯	◯	◯	◯	◯

I enjoy being in class.

I enjoy participating so much that I get energized.

When I say anything in class I feel like I am making a fool of myself

5. Please indicate how you feel, typically, when in class (continued)
*

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
I get tense in class.	○	○	○	○	○
I am confident because I understand the material.	○	○	○	○	○
After I have said something in class I wish I could crawl into a hole and hide	○	○	○	○	○
I get embarrassed.	○	○	○	○	○
I feel hopeless.	○	○	○	○	○
Because I get embarrassed, I become tense and inhibited.	○	○	○	○	○
I have lost all hope in understanding this class.	○	○	○	○	○
When I do well in class, my heart throbs with pride.	○	○	○	○	○
I am proud of myself	○	○	○	○	○
I think that I can be proud of what I know about this	○	○	○	○	○

subject

I feel so hopeless all my energy is depleted.

Because I take pride in my accomplishments in this course, I am motivated to continue.

6. Please indicate how you feel, typically, when in class (continued)
*

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
Sometimes I feel that I belong at Electric Circuits class, and sometimes I feel that I don't belong.	○	○	○	○	○
When somethin g bad happens, I feel that maybe I don't belong at Electric Circuits class.	○	○	○	○	○
When somethin g good happens, I feel that I really belong at Electric Circuits class.	○	○	○	○	○
Taking Electric Circuits builds my confidence that I can graduate with an engineering degree	○	○	○	○	○
I feel very different than most other students in this class	○	○	○	○	○
I am discouraged because the pace of the course was too fast	○	○	○	○	○

I am happy with the speed at which I learn the course material	○	○	○	○	○
My proficiency with the concepts in Electric Circuits exceeds that of my peers	○	○	○	○	○
In Electric Circuits class, I feel I am part of a community of learners.	○	○	○	○	○
When I work on Electric Circuits, I feel mostly alone/isolated.	○	○	○	○	○
When I am struggling, I feel there are others in my class I can count on to help me.	○	○	○	○	○
When I consider my experience in Electric Circuits class, I feel more confident.	○	○	○	○	○