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Driving Changes in Affect, Behavior, and Cognition in a First-year MATLAB Programming Course

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Abstract

This manuscript describes a curriculum overhaul for a required freshman programming course in the Department of Mechanical Engineering and Bioengineering at a small private midwestern university. While programming skills are essential for success in this field, many students showed negative attitudes toward programming and frustration with the programming course. In particular, the course evaluations from spring of 2019 suggested that substantial change to the course was necessary. Following research-based methods, discussed in the paper, several changes were implemented in spring 2020. To qualitatively assess student attitudes before and after the course revisions, the course evaluations from both the 2019 and 2020 semesters were evaluated based on their sentiment (e.g., positive/negative affect, affirmation of effective classroom practices, constructive critique to improve classroom practices, and positive/negative critique of course content). The most interesting finding from this analysis was the stark contrast between primarily affective statements in 2019 and primarily constructive statements in 2020. To assess the connection between student attitudes and course grades, a validated questionnaire was administered to the students who took the programming course in spring of 2019 and 2020. These scores and student grades in the course were analyzed using multiple linear regression, which showed that two dimensions of student attitude (affect and cognition) were significant predictors of final grade in the course. Finally, exam scores suggested that students were able to meet the course objectives in the new course format. Together, these findings suggest that student attitudes toward programming correlated with course performance in a freshman programming course, and the curriculum changes to that course helped improve student attitudes, which may ultimately help them succeed in their subsequent engineering coursework.

I. Introduction

"I hate programming," seems to be a common refrain among students in engineering disciplines that do not explicitly depend on software and hardware programming. For example, in spring of 2019, mechanical engineering and bioengineering students who took a first year MATLAB programming course showed negative attitudes toward programming, which seemed to create a barrier to learning. Furthermore, students who took the course in previous years frequently expressed negative attitudes toward programming, which created barriers to learning in subsequent course work. To help remove these barriers, we revised the course for spring of 2020 to incorporate teaching best practices, which included a change to tutorial- and video-based instruction instead of real-time note taking, improved alignment between course material and assessments, and a switch to mastery-based assessments. These types of changes have been shown to improve student attitudes and reduce failure rates in introductory programming courses

[1-3]. However, the link between course format, student performance, and student attitudes toward programming remained unclear. If we clarified this link, students could be better equipped to solve engineering problems and perform engineering analysis throughout their studies. Thus, in this study we analyzed course format, student attitudes, and student performance.

II. Review of Related Literature

A. Factors of Student Success

The factors that make students successful in and out of the classroom are incredibly complex with no fool-proof mathematical formula for success. We have begun to understand, however, that combinations of non-cognitive factors, such as grit, community engagement, identity, mindset, self-efficacy, and motivation are far more important predictors than traditional measures of test scores or intelligence measures [4]. Based on this premise, we posit the barriers to student success in programming-oriented courses could largely be addressed by focusing on promoting healthy student attitudes towards learning, and in particular, toward learning the computational skills required for successful programming within the students' vocational domain.

B. Student Attitudes Toward Learning Programming

For the purpose of this study, we operationally categorized *"student attitudes"* into three dimensions: affect, cognition, and behavior [5]. Within the domain of programming education, studies have shown that barriers to student success are often due to negative or undesirable student attitudes. For example, Rhamet et al. identified discernable barriers to student success in introductory programming courses, which included poor self-efficacy and motivation (affect), over-reliance on the instructor to provide all information and resources needed to solve problems (cognitive), and poor class preparation with limited revision based on feedback (behavior) [6]. Across each of these categories, Rhamet et al. found that student performance was correlated with student attitudes, however the measurement of student attitudes was still somewhat ambiguous.

To better understand student attitudes in programming in a higher education context Cetin & Ozden developed the Attitudes Toward Computer Programming (ATCP) measurement scale [7]. The instrument has 18 self-reported items with a 5-point Likert scale. The internal reliability as measured by Cronbach's alpha of the three subscales ranged from 0.80 to 0.90, and 0.94 for the scale overall. The authors used confirmatory factor analysis to show three discernable constructs that align with the three dimensions of student attitudes previously defined by Aiken [5]. Items in the affective dimension focus on how students feel while programming (i.e., *I find programming* *frustrating* or *programming is boring*), items in the behavioral dimension focus on the actions of becoming a better programmer (i.e, *I take part in programming projects if I get the chance*, *I do research in order to be a good programmer*, or *I follow the developments in programming*) and items in the cognitive domain focus on the value of programming in solving problems (i.e, *programming makes human life easier* or *programming improves your problem-solving skills*). While self-reported scales do have some limitations in applicability, they allow for statistical comparisons across groups, across time periods (i.e., pre-post), as well as statistical correlations to other performance dimensions.

C. Best-Practices in Teaching and Learning Programming

Teaching programming is particularly challenging due to multiple contributing factors, including perceptions of assumed difficulty, disconnects from the authentic purpose and learning objectives, and student disengagement due to ill-matched pedagogical approaches. Within our own evaluation of the student comments from previous sections, instructor observations, and poor learning outcomes, the need to revise the instructional approach was evident. The instructional improvements employed in our research context were supported by best-practices researched and presented by Brown and Wilson, who present ten concise best-practices intended for a general audience engaging in programming-related education [1], and by Wells et al., who present a case example in the use of video tutorials to support learning and promote engagement within an engineering-specific context [3]. Most notable in Brown and Wilson's work was the emphasis on pushing students into active roles that require students to engage in and articulate problem definition, ideation and planning, and prediction. These core activities elevate the student activity in programming from lower-level cognitive skills (i.e., remembering, understanding) to higher-level cognitive skills (i.e., applying, analyzing, and evaluating). Wells et al. provide detailed guidelines that were particularly relevant to instruction in an engineering MATLAB course, and provided detailed guidance for structuring, producing, and sharing video tutorials. Together, both resources were well-aligned with the foundational objective of putting students in a more active and engaged role with more control and regulation of their learning.

D. Alignment of Content, Assessment, and Pedagogy

Streveler and Smith (2020) describe the Content-Assessment-Pedagogy (CAP) framework for course design that is centered on the ideal of strong alignment between these three domains [8]. Course content refers to what students are expected learn, the articulation of these goals into "SMART" objectives (from the acronym for specific, measurable, achievable, realistic, and timely), as well as the organization of learning objectives into groups three groups: 1) what is essential to the purpose of the course, 2) what is important, and 3) what is good to be familiar with [9]. The essential objectives, what Streveler and Smith refer to as "Enduring Outcomes," drive the remaining aspects of course design. For example, assessments that are well-aligned to the content will prioritize the enduring outcomes, giving students multiple opportunities for feedback and revision to build their mastery of these objectives over time throughout the course. Following the design of prioritized student learning objectives and corresponding assessment and feedback methods, planned learning activities will support student learning through active and interactive pedagogies, aligning activities that require the most effort to the objectives that are the most important for students to achieve.

Often when student satisfaction and course evaluations are low, it is because some part of this trifecta is out of alignment with the others. The authors used the student evaluations from the 2019 course to identify two key areas of misalignment, (1) content-assessment: curricular priorities were not well-articulated which made the alignment between the learning objectives and assessments seem disconnected or even arbitrary from the student perspective, and (2) assessment-pedagogy: the classroom activities did not adequately support the multiple iterations of a practice-feedback-revise cycle needed for students to feel confident that they could successfully complete the current assessments. The modifications to the course for 2020 described in the following section were motivated by correcting these alignment issues.

III. Research Methods

A. Research Questions

By revising the course, we aimed to improve student engagement and the overall student learning experience. We considered a semi-experimental study to provide a direct pre-post evaluation of the revisions planned and implemented between the 2019 and 2020 course offerings. However, many differences existed between the 2019 and 2020 terms, including multiple instructors, different course meeting days and times, altered instructional materials, as well as updated course assessments. The COVID-19 pandemic also introduced variation above and beyond normal course offerings that would further dilute meaningful interpretations of direct comparisons. Instead, the research design incorporated both quantitative and qualitative methods guided by the following two research questions:

1. How did instructional changes impact student performance and student attitudes toward programming?
2. To what extent were student attitudes toward programming related to student performance?

B. Research Context

This study was conducted on a required first year programming course in the mechanical engineering and bioengineering program at a small midwestern private university across two academic years. The course included 43 students across the author’s (BL) two sections in 2019 and 49 students across the author's two sections in spring 2020. In 2019, 81% of the students were male and 86% were white, and in 2020, 80% were male and 82% were white. The course was designed to equip students to use MATLAB to solve problems within mechanical engineering and bioengineering using techniques such as plotting, loops, conditional statements, and array operations.

C. Course Changes from 2019 to 2020

The first-year ME-125 MATLAB course is a 1-credit course that helps students develop basic programming skills for engineering problem solving, including use of arrays, plotting, conditional statements, loops, and basic statistical analysis. The broader structural changes to the course aimed to address two key areas of misalignment: assessments that were not well-aligned with curricular priorities, and classroom activities that were not well-aligned with assessments. To address these misalignments based on best practices [1,3], the following changes were made for the 2020 spring semester:

a. The assessments of student learning were changed from a traditional midterm and final to three competency quizzes with a cumulative final.
b. The primary mode of content delivery was changed from real-time demonstrations during class with out-of-class homework to more of a flipped modality with out-of-class tutorials supported by in-class review and practice.
c. The distribution of course meetings through the semester was changed from meeting once per week for 50 minutes over the full semester to meeting twice per week for 50 minutes over half of the semester However, the total contact hours and student workload remained the same (Table 1).

The competency-based approach can be considered the primary intervention, while the other changes were made in service of that intervention to promote alignment between instructional methods and assessments. The changes to the distribution of course meetings and content delivery were intended to facilitate mastery of course content, which was then measured using the competency-based approach. The overarching goal of the changes was to provide every student the tools to master the course content by creating alignment and this goal required multiple changes simultaneously.

The decision to redistribute the course meetings was made to decrease the time lag in between course sessions where students were actively engaged in the content and able to receive real-time instructor feedback. Other logistical factors (i.e., relative timing of other 7-week courses offered in the curriculum) played into this decision as well, but are not discussed at length here.

Table 1

Timing and weekly workload comparison between 2019 and 2020

Timing within Semester	2019 Weekly Workload	2020 Weekly Workload
First seven weeks	One 50-minute class period	No class meetings
Second seven weeks	One 50-minute class period	Two 50-minute class periods

To support alignment of the course content with the assessments, extensive changes were made for the content delivery. In 2019, the content was delivered using real-time note taking and demonstrations during the class meetings and readings from the textbook [10]. In 2020, the content was primarily delivered through written tutorials where the students created MATLAB programs by following the instructions. The tutorials were supplemented by five- to ten-minute videos that showed additional examples of the concepts in each tutorial. These videos showed the instructor's MATLAB window as the examples were worked out, giving the students the opportunity to see the same concepts from the tutorials in the format they would be expected to use for their homework, quizzes, and exams. The tutorials and videos were designed to be completed by each student mostly outside of class meetings. The class meetings were used for short (less than ten-minute) reading quizzes, short PowerPoint presentations (less than ten minutes) that reviewed the reading material, and in-class work time where the students could ask the instructor questions about the tutorials and homework assignments. Due to COVID-19, the entire 2020 course took place online, which resulted in some unintended changes. The live sessions were held on a video chat platform where the instructor was able to screen share and communicate with the students using audio, video, and text chat.

Assessments were altered to focus on the most important concepts from the course and to more overt student preparation for these prioritized topics. In 2019, the students took a midterm over array operations, built-in functions, and plotting halfway through the semester, and a final exam over logic, conditional statements, and loops at the end. The new assessment plan, implemented in 2020, replaced the midterm exam with three competency quizzes that each focused on a single skill (i.e, plotting, conditional statements, and loops). The students were given a single attempt on each of the competency quizzes. A comprehensive final exam was still included that also tested concepts from the competency quizzes among other concepts introduced throughout the course. Table 2 summarizes the overall changes in assessment plan per concept.

Table 2

Summary of Changes to Assessment Strategy in the 2019 and 2020 Term

Concept	2019 Assessment	2020 Assessment
Array operations & built-in functions	Midterm Exam	Competency Quizzes 1, 2, & 3, Final Exam
Plotting	Midterm Exam	Competency Quiz 1, Final Exam
Conditional statements & logic	Final Exam	Competency Quiz 2, Final Exam
Loops	Final Exam	Competency Quiz 3, Final Exam

D. Assessment of Student Performance

Performance was assessed using two exams in 2019 and using three quizzes and a single exam in 2020. The scores from the 2019 exams were averaged for each student to give one overall exam score. These scores were binned into regions of ten percentage points to show the distribution of grades on the exams. All grades below 60% (i.e., failing) were grouped into a single bin. The final course letter grades for both years were binned in a similar fashion to create histograms. The three competency quizzes from 2020 were categorized into pass or fail where passing was defined as a score greater than or equal to 80%.

E. Quantitative Analysis of Attitudes Toward Programming

The ATCP questionnaire developed by Cetin and Ozdin (2015) was administered to the students in the author's course sections from both years. The questionnaire consisted of 18 Likert scale questions and measured attitude along three subscales: affect, cognition, and behavior. Scores were summed from these three subscales to generate an overall score. Note that in the ATCP scale, some items were negatively worded and others were positively worded, so the negative items were reverse coded to have strongly agree equal 1 on the 5-point Likert scale and strongly disagree equal 5. The positive items were coded such that strongly disagree was equal to 1 and strongly agree was equal to 5. In addition, to better align with the research context, all variants of "programming" were replaced with variants of "MATLAB" or "MATLAB programming."

Changes to the course structure were made, in part, to improve student attitudes and learning outcomes, so significant differences in student attitudes were anticipated between the 2019 and 2020 student groups. Changes in student attitudes toward programming between groups were investigated using an independent sample t-test for a comparison of means across each of the ATCP subscales. In contrast, no theoretical reason existed to assume significant differences would exist in the relationships between student attitudes and student performance. These relationships were assessed using multiple linear regression, with the 2019 and 2020 cohorts treated as a single group. The independent variables were the ATCP subscale scores and the dependent variable was the final course grade in percent with a significance level of 0.05. In the initial model, behavior was not a significant predictor of final grade ($p>0.05$), so it was omitted from the final model presented in Section IV.

F. Qualitative Analysis of Attitudes Towards Programming

Student comments from open-ended questions on the 2019 and 2020 course evaluations were analyzed using an abbreviated content analysis protocol. The questions used in the analysis were: 1) “What were the most effective aspects of this instructor's teaching?” 2) “In what ways could this instructor improve his or her teaching?” and 3) “Please feel free to share any further comments you have for this instructor.” Coding categories were developed based on the tri-dimensional attitude framework (Aiken, 2002) so qualitative results could be quantified and compared to the ATCP survey results [5]. The coding categories included (a) affect dimension: “positive affect” and “negative affect;” (b) behavioral dimension: “affirmation of effective classroom practices” and “constructive critique to improve classroom practices;” and (c) cognitive dimension: “positive critique of course content” and “negative critique of course content.” Given a relatively small data set and a two-person research team, codes were assigned to text-strings using a negotiated coding procedure for the three free response questions. First, the researchers worked individually to identify “sentiments” as strings of text used to communicate a single idea, and then code each sentiment according to the established a priori codes. The researchers then compared and discussed results to reach consensus on the meaning and intention of each sentiment. Frequency counts of the total number and category of sentiments were reported for each year.

IV. Results

A. Assessment of Performance

In both the 2019 and 2020 semesters approximately 90% of the students passed the course, while 10% of students fell below the threshold of a passing grade (60%). In general, students who did not pass the course did so as a result of sustained disengagement, including missed classes and several missing assignments. A notably higher percentage of students earned an A or B in the course in 2020 compared to the previous term (Fig. 1).

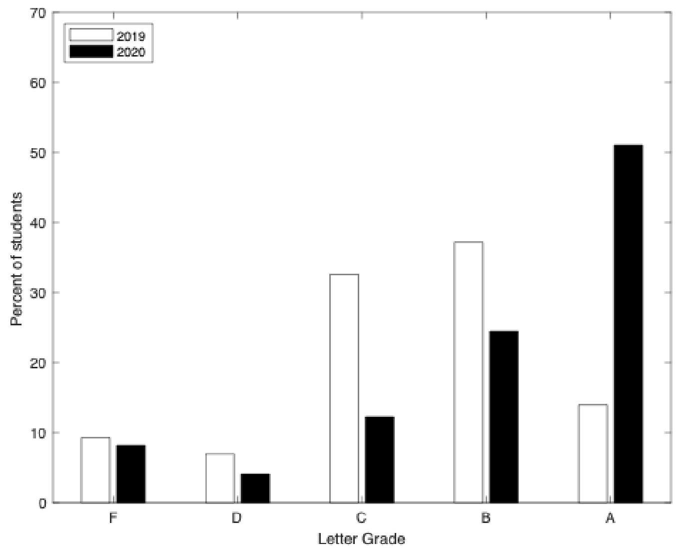

Figure 1: Histograms of final course letter grades for 2019 and 2020.

Additionally, a higher percentage of students earned passing exam grades in 2020 (94%) compared to 2019 (80%; Fig. 2) and 81% of students earned either an A or a B on the exam in 2020, while only 30% of students earned an A or B average on the 2019 exams.

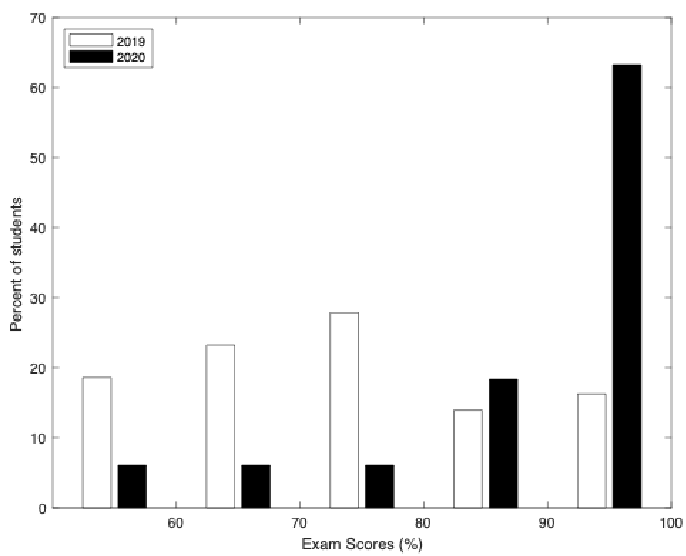

Figure 2: Histograms of exam scores for 2019 (averaged) and 2020.

More than 85% of students passed (earned above an 80%) the first two competency quizzes in 2020, while only 50% of students did so on the third competency (Fig. 3).

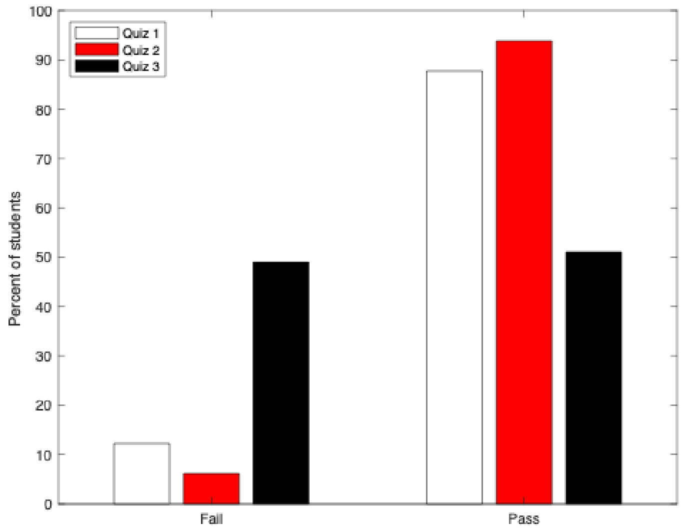

Figure 3: Histograms of scores on 2020 competency quizzes.

B. Quantitative Assessment of Student Attitudes

A total of 21 students from 2019 and 30 students from 2020 responded to the ATCP questionnaire. The relationship of student attitudes to final grade was studied for all students as a whole, with the total N = 51. The multiple linear regression showed that affect and cognition were significant predictors of final grade (Table 3).

Furthermore, the average scores for each dimension of attitude were compared across years and no significant differences were observed. The average score for the affect dimension was 3.21 (S.D. = 0.19) in 2019 and 3.67 (S.D. = 0.73) in 2020 ($p = 0.06$), the average score for the dimension was 2.83 (S.D. = 0.47) in 2019 and 2.65 (S.D. = 0.39) in 2020 ($p = 0.15$), and the average score for the behavior dimension was 3.13 (S.D. = 0.72) in 2019 and 2.78 (S.D. = 0.60) in 2020 ($p = 0.06$).

Table 3

Results of multiple linear regression, showing relationships between final course grade (%) and questionnaire scores.

	Estimate	SE	95% CI	p-value
Intercept	44.2	8.62	[38.0, 50.4]	<0.001
Affect	7.32	1.32	[6.3, 8.3]	<0.001
Cognition	5.84	2.58	[5.0, 6.7]	0.028

Note. N=51. CI = confidence interval.

C. Qualitative Assessment of Student Attitudes

Student sentiments on the course evaluations appear to differ between 2019 and 2020 (Table 4). In 2019, a total of 17 students responded to the survey and expressed a total of 36 sentiments, which represents an average of 2.1 sentiments per respondent. In 2020, a total of 31 students responded to the survey and expressed a total of 86 sentiments, an average of 2.6 sentiments per respondent. Note that some respondents may have expressed several sentiments, while others may have expressed none.

For the 2019 survey two-thirds of the sentiments expressed were negative (24) and half were expressions of affect (18). The predominant categories were in the behavioral dimension "negative/constructive logistical critique (12), and the affective dimension "negative affect" (12). In 2020, nearly two-thirds of the sentiments expressed were positive (52), and expressions of behavioral or cognitive attitudes (52). In the 2020 term, the number of sentiments expressed per respondent increased, the total number of negative affect sentiments was reduced from 37% of the total sentiments expressed to 6% of the total sentiments expressed and the proportion of purely affective statements decreased from 50% to 37%. Most notably, students in 2020 expressed 5 cognitive sentiments in their evaluations, while the 2019 students did not express content related sentiments at all.

Table 4

Frequency of sentiments in each category from course evaluations.

Sentiment Category	2019	2020
Positive logistical affirmation	6 (17%)	26 (32%)
Positive content affirmation	0 (0%)	1 (1%)
Positive affect	6 (17%)	25 (30%)
Negative/constructive logistical critique	12 (33%)	21 (26%)
Negative/constructive content critique	0 (0%)	4 (5%)
Negative affect	12 (33%)	5 (6%)
Total sentiments expressed	36	82

Note. N=17 for 2019; N=31 for 2020

V. Discussion

A. Observed Impact on Student Performance

The research design for this study did not include a quasi-experimental analysis to test the effectiveness of the course improvements because the changes implemented (i.e., distribution of course meetings, shift in primary content delivery approach, and alterations to the overall assessment plan) were too numerous to directly compare the student outcomes of the 2019 term to the 2020 term. Nonetheless, the shifts in final grade and exam score distributions suggest that the changes implemented in the 2020 term had an overall positive impact on student performance. Despite an abrupt shift to a fully remote modality approximately one week before the course began, we did not formally investigate the potential impact of the COVID-19 pandemic on this course. However, the overall increase in student performance on exams, in particular, occurred despite the disruptions caused by the pandemic.

Looking more closely at the distribution of exam scores, 81% of students achieved an exam score of a B or better in 2020 compared to only 30% of students in 2019. This improvement could, in part, be attributed to variations between the assessments themselves (i.e., different question styles, number of items, etc.) rather than a direct measure of improved student learning. We argue, however, that the addition of the competency quizzes allowed students to more effectively focus their practice and revision on the core topics that are most critical for satisfying the course learning objectives. Across the three competency quizzes about 90% of students achieved passing scores (80% or better) for plotting and conditional statements, and about 50% for loops. Overall these scores suggest that students received adequate support to prepare for the assessments. The content analysis of students' comments on course evaluations also addressed student performance on loops, and will be discussed further below.

Curiously, in both semesters about the same percentage of students (10%) did not achieve the minimum threshold to pass the course. In all cases, students had multiple signs of disengagement with the course activities (i.e., missed classes, incomplete or missed assignments), though some differences seemed to exist between students in the different years. In 2019, the students who did not pass regularly attended class, turned in most of their homework and project assignments, and took their exams. The students that did not pass the course in 2020 did not submit most or all of their homework and tutorial assignments, mostly did not attend live class sessions, and did not take the competency quizzes in some cases. Additionally, we made multiple attempts to contact and help students at risk of failing in 2020, while we did not systematically make these attempts in 2019. These differences may be explained by the added external stressors caused by COVID-19 during the 2020 semester, though future versions of the course should include careful monitoring of and early intervention for students who may be at risk of failing.

B. Observed Impact on Student Attitudes

No significant differences were observed between years for any of the attitude subscales measured by the ATCP questionnaire, though the differences for the affect and behavior subscales approached significance ($p=0.06$). Oddly, the behavior and cognition scores were higher for the 2019 students than the 2020 students. The 2020 students scored slightly higher on the affect subscale, which indicates more positive attitudes that seem to be echoed in their sentiments on the course evaluations, discussed below.

In addition to self-reported attitudes measured by the ATCP questionnaire, we analyzed student attitudes expressed in student responses to the open-ended questions included in their end-of term course evaluations. The comments were broken down into "sentiments," or a string of text used to convey a single thought or idea, then each sentiment was categorized as positive or negative, and belonging to one of the three attitudinal dimensions. In our analysis, we grouped the term "constructive" as a negative sentiment, despite its generally positive connotation. At a minimum these sentiments communicated some aspect of the course that could be improved, if not something that had a real or perceived negative impact.

Affective sentiments were comments that expressed feelings with no specific examples that tied into a course policy, assignment, or event. In general, these statements communicated feelings of satisfaction or dissatisfaction, but did nothing to offer any actionable feedback. For faculty who rely on student responses to evaluate and plan course improvements, purely affective comments offer little value. Behavioral and cognitive sentiments were regarded as high value because even if they were "negative" (i.e., a critique) they referenced some specific aspect of the learning environment or experience that could be improved. Including such examples and descriptions takes more time and effort to produce as a more careful reflection of the student's learning experience, and thus could be seen as an indicator for student engagement.

We expected that if the course improvements increased the level of student engagement, two things would happen in the course evaluation comments: (1) sentiments would discernibly shift from primarily negative to primarily positive; and (2) sentiments would discernibly shift from affective to behavioral and cognitive. As expected, with better alignment between course learning objectives, pedagogical methods, and assessments, the overall attitudes expressed in course evaluations shifted from predominantly negative (67%) to predominantly positive (63%). More importantly, the nature of the sentiments expressed in the course evaluations by the 2020 students were more focused on relevant aspects of the course. For example, only 50% of students passed the competency quiz on loops, and students commented regarding the lessons on loops ("*...spend more time on loops in general. Maybe make that tutorial shorter so we can have two separate tutorials on loops*"). Not only is this feedback more valuable to the instructor for course improvement, it exemplifies a level of reflection on their learning process that was not observed in the 2019 cohort.

C. Relationships Between Student Attitudes and Performance

To evaluate the relationship between student attitude and student performance, we asked all students from the 2019 and 2020 semesters to complete the ATCP questionnaire. The survey provides a measure of student attitudes towards programming across three subscales: affect, behavior, and cognition. As expected, both students' affective and cognitive attitudes were found to be significant predictors of their overall performance.

Contrary to expectation, behavioral attitudes did not significantly predict performance. This observation was particularly surprising since behavioral attitudes translate to action, which one might expect to have the strongest correlation to performance outcomes. One possible explanation for this finding is that the behavioral items in the ATCP questionnaire were not as broadly applicable to students outside of computer science as the other subscales. In the context of an introductory programming class for engineering students, students are not expected to spend a significant amount of time researching programming tools, reading about new developments in programming, or seeking out opportunities to work on programming projects outside of class. Even highly engaged students who might typically perform in the top 25% of their class would respond negatively to all or most of these items, and still perform well in the course. While the correlation between these activities and being a successful programmer is easily explained through clear intrinsic interest, that degree of interest may be above and beyond what is needed to develop basic functionality and skill. A behavioral scale that focused more on utilitarian actions of entry-level programmers such as independently searching help libraries, revising program scripts, incorporating feedback, and/or persistence in finding solutions may have produced different results.

Through the content analysis, we found that the attitudes expressed in the open-ended responses to student evaluations were consistent with the quantitative measures of student attitudes toward programming. We believe that the combination of course improvements (i.e, less time between course meetings, tutorial-based instruction, and competency-based assessment) improved overall student engagement, which propagated to improved attitudes and improved performance. This claim is further supported by the change in student evaluation comments that were primarily affective sentiments when observed student engagement was low, but shifted to more contextualized behavioral and cognitive sentiments when observed student engagement was high.

D. Study Limitations and Future Work

This study has several important limitations. First, the 2019 students experienced the class entirely in-person, while the 2020 students were forced to take the course entirely online due to COVID-19 restrictions. Not only did the course format differ substantially between years in unintentional ways, many external stressors were introduced or amplified during the pandemic. Second, the 2019 students were not surveyed until one year after they took the course, while the 2020 students were surveyed almost immediately after they took the course. This difference may be important because the 2019 students may have changed their attitudes toward programming with MATLAB after using it extensively for practical purposes in their second year engineering courses. Third, student attitudes were only measured after each year without pre-assessments, which may limit the conclusions that can be drawn from this study. Future work should include pre- and post-assessment of student attitudes to further analyze the extent to which attitudes are affected by the revised course delivery as opposed to other factors.

The course revisions were planned prior to the COVID-19 pandemic and will be retained once fully in-person learning resumes, but the abrupt shift to online learning may have had an impact on student experiences in the course due to forced, unintended changes in the course. The largest unintended change in 2020 was a lack of “over-the-shoulder” guidance. The course was structured to allow abundant free work time during class to allow students to ask questions as they were working on assignments. This type of guidance can reduce frustration and help students overcome challenges in the course. However, students did not remain in the online meetings as the instructor expected, which reduced the spontaneous interactions between students and the professor. This issue was addressed in 2021 by placing students in breakout rooms during the online sessions and instructing the students to work on their assignments with their small groups as the instructor circulated through the breakout rooms. During fully in-person learning, a similar approach will be taken, though the groups will be more organically formed instead of assigned and instructor monitoring will be performed by listening to conversations within groups and walking around the room instead of entering and exiting breakout rooms. Future work may examine whether student outcomes in the course differ between online and in-person settings after COVID-19.

Following this work, several questions about this particular course remain. Why, for example, did the failure rate not change between years? Despite a higher proportion of students who earned an A or a B in 2020, the same proportion of students failed in 2020 and 2019. Future investigations should seek ways to reduce the failure rate. Additionally, future versions of the course should address the failure rate for the competency quiz on loops. Students in 2020 mentioned loops specifically in their course evaluations as a topic that was particularly difficult, so steps should be taken to improve their comfort level on this topic.

On the basis of this work, future research could address several follow-up questions. One of those is: how does success in a first-year course programming course impact student performance in subsequent coursework that uses programming? For example, would overall performance improve in a second-year course (e.g., Dynamics) that uses programming if a student could improve their performance in their first-year MATLAB course? Other follow-up questions could include: what can be done to improve attitude and performance for the students who fail? How does prior experience with programming impact student ability to master the topics in the first-year MATLAB course; does every student need to reach the same minimum proficiency by the end of the semester? If these questions were addressed, students may feel more confident using programming as a problem solving tool and be more successful in their subsequent coursework.

VI. REFERENCES

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