Course Learning Evaluation in MET Using MATLAB GUIs for Low-stake Assignment Feedback of Graphical Solutions

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Abstract

This paper describes the evaluation of learning that occurred in a mechanical engineering technology (MET) course when part of the learning process was implemented with MATLAB graphical user interfaces (GUIs). A strength of materials (SoM) course was used to implement the GUI tool for two SoM class offerings in different semesters. The learning of those two courses were compared to a SoM class offering that did not include the use of GUIs in any part of the course. The GUIs were used to provide try-again feedback on students' graphical low-stake assignment (i.e. homework) sketches of shear and moment diagrams. The GUIs provided numerical codes for correct answers that the students submitted to the learning management system (LMS) of the course to record and provide assignment credit. Individual GUIs with unique numerical codes were supplied to each student for two sketches in order to measure the amount of answer sharing within a class and between semesters. The results show that students that used shared answers received statistically significant lower average class scores. The results also show that the GUIs did not affect the students learning in sketching shear and moment diagrams, but the results provided the instructor with data about which students shared solutions, which students used shared answers, and that no answer sharing occurred between the courses of different semesters.

Introduction

In the learning process, instruction is provided to students through varying styles of teaching that fall under one of the many common learning models and theories [1], [2], [3]. The instruction provides students new information that needs to be assimilated into their understanding [1]. The retainment of that information is assessed through high-stake assignments (i.e. exams) and low-stake assignments (i.e. homework) assignments where students receive formative feedback [4]. The feedback provides students with information about their performance or understanding of new information [4] [5], [6], [7]. Feedback has been defined "…as the consequence of performance [7]," because feedback should encourage students to correct mistakes and therefore feedback becomes part of the learning dynamics [7], [8], [9]. But, what type of feedback is effective? The answer is dependent on the assignment.

There are numerous methods for providing student feedback with variables of the feedback related to amount, helpfulness, timeliness, and type [7], [10]. "The main purpose of feedback is to reduce discrepancies between current understandings and performance and a goal [7]." Numerous meta-analyses have reviewed feedback effects [7] where those results show that immediate feedback has a weak to moderately weak correlation on improving student learning over delayed feedback [6], [7]. Immediate feedback indicates that a student submits performance related to an assignment and assessment of the performance is provided to the student instantaneously. Delayed feedback indicates that the assessment of the performance is provided to the student during some time interval after student submission that can range from seconds to days. The comparison between immediate and delayed becomes difficult because of

the ambiguity of the delayed feedback temporal definition. Immediate feedback does satisfy a student's desire for knowing the correctness of performance without having to wait.

Try-again feedback is a form of immediate feedback where a student is able to submit performance for an assignment and retry the assignment when the feedback indicates incorrect solutions [6]. This type of immediate feedback is ideal for low-stake assessments because it allows a student the ability to try to answer an assignment, especially in a new subject area, without being penalized for initially poor performance [11], [12]. One issue with try-again feedback for non-proctored, low-stake assignments is that students may share solutions after the feedback verifies the correct solutions [13], [14], [15]. Learning management systems (LMS) can be programmed to provide try-again feedback (for equation derivations, fill-in the blank, matching, multiple choice, numerical, and some types of short answer problems) and automatically populate a gradebook with an assessment associated with the feedback [16], [17]. But, unless each student is provided unique questions, students may share the solutions.

Another issue related to try-again feedback is that most LMS do not incorporate immediate graphical solution feedback for submitted performance. Mechanics courses in engineering technology programs are one area where graphical solutions are required to obtain the correct solution for some problem types. Graphical solutions in mechanics courses include free-body diagrams [18], [19], shear and moment diagrams [20], [21], and vector addition [22]. Textbook publishers are working on filling this void of providing immediate graphical solutions feedback by including companion textbook material. But, companion textbook material adds an additional financial cost to students with the increasing textbook costs [23], [24] and removes the ability of instructors to tailor assignments. The use of graphical user interfaces (GUIs) is a method that can be used to provide immediate feedback for graphical solutions. GUIs have been implemented with LMS [25]. GUIs also remove extra student cost when developed and implemented by the instructor, and allow instructors to tailor assignments [25]. GUIs can be written in different high-level programming languages and have been used in the learning process with graphical solutions of models [20], [21], [22], [26], [27].

This paper evaluates the use of MATLAB GUIs in Strength of Materials (SoM) classes of a mechanical engineering technology (MET) program where the GUIs provide try-again feedback to students sketching shear and moment diagrams. The GUIs were used on low-stake assignments for two separate SoM offerings. The GUIs were used as a learning tool when the concept of sketching shear and moment diagrams was introduced in the class and the results of using the GUIs were subsequently compared to a control class that did not use GUIs. The GUI developer used the GUI and LMS to measure student answers and measure on some problems when students were using other students' solutions. The following research questions are addressed here:

1. How frequently did students share solutions on non-proctored low-stake assignments?
2. Did the students that used GUIs for graphical problems in their courses perform better on high-stake assignments than the students that did not have GUIs?
3. What was the student performance of those that accepted shared solutions compared to the students that did not use shared solutions?

GUI Development and Class Description

The GUIs used in this researched were programmed using MATLAB scripts. A script in MATLAB is a text file, also known as an m-file, that contains all of the code of the program [28]. MATLAB scripts are portable pieces of code that are easily transferred from computer to computer and can be run on any computer with MATLAB. MATLAB scripts are normally backwards compatible unless new functions or features are used in the scripts that were not available in previous editions of the software [28]. Each written GUI in this work allowed students to work on a single assignment where the assignment consisted of drawing both the shear and moment diagram of that assignment. Details of the development of these scripts can be found in reference [25] and limited details are provided here. Each GUI assignment produces a figure window with three separate plots in the figure. Figure 1 shows an example of the figure window with the three separate plots. The top plot contains the problem that consists of a beam with dimensions, applied loads with locations, and reactions with locations. The middle plot contains space for the student to sketch the shear diagram and the bottom plot contains space for the student to sketch the moment diagram. No additional files are required apart from the single MATLAB script to run the GUI assignment.
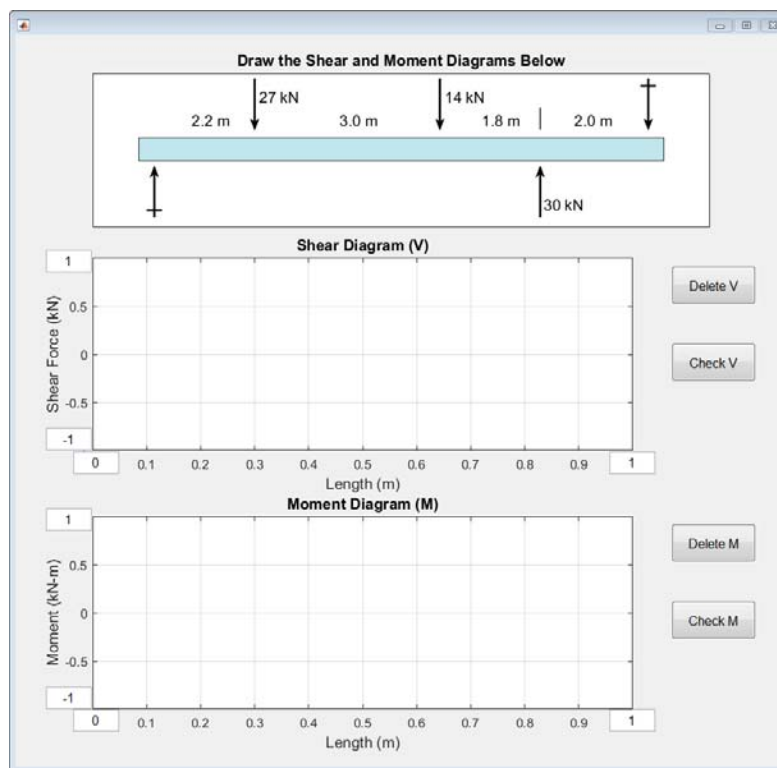

Figure 1. MATLAB GUI assignment figure window used to provide students with try-again feedback for shear and moment diagram sketches.

The axes of the shear and moment diagram of the GUIs are adjustable by the user. This adjustment allows students to change the axes to the required values for the problem and allows the students to zoom into specific sections of the sketch that may require more sketch details. In this version of the GUIs, the units are static and defined in the figure window as shown on the axes for the beam length, the shear force, and moment of Figure 1. Once a student updates one

of the axis values, the entire plot is updated and maintains any sketch produced by the student that even may not be viewable in the new window. Buttons on the side of the GUI allows the student to delete any current sketches or check the sketch plot against the known solution with some predefined error boundaries. Each sketch can be checked individually.

Both diagrams of each GUI had a separate 5-digit numerical code defined in the script for correct answers. Once a sketch was correct, the GUI provides the student with the numerical code that the students enter into Blackboard for assignment credit. For one shear diagram and one moment diagram each student was provided an individual script that had a unique 5-digit numerical code different from those of every other student. Blackboard was programmed to accept all numerical codes for all students as correct. This process allowed the instructor to assess which students were accepting shared solutions from other students. To keep the students from searching the MATLAB scripts for the numerical credit code, all MATLAB scripts were provided to the students as p-codes. P-codes are obfuscated codes that are difficult to view using text reading software or programming editors.

Two SoM classes used MATLAB GUIs to provide try-again feedback to students sketching shear and moment diagrams. The SoM class is only offered in the fall semester of the research location and the use of GUIs were used in the 2016 and 2017 classes for a single week when the instruction introduced shear and moment diagrams. Therefore, the SoM offering of 2015 is used here as the control group. All three classes were taught by the same instructor using an inverted pedagogy [12], [29] with try-again feedback for all homework assignments. The instruction for the control group consisted of interactive pdf files with imbedded videos [12]. The homework assignments were administered on the LMS Blackboard where the strictest numerical error bounds for homework solutions were set at plus and minus 10 percent of the third significant figure of the solution. The instruction for the experimental groups consisted of online videos developed from the material content of the interactive pdf files of the control group. Again, the homework assignments were administered on the LMS Blackboard with the same error bounds as the control group [11]. The homework assignments for all three classes were similar and all assignments within a single class were identical. The class time for all three SoM offerings were used to answer and work on homework questions, work one on one with instructor assistance, or to work in groups on laboratories associated with the learning content. The distribution of the grades for the classes is shown in Table 1. The number beside the lab reports and homework indicates the total number of those types of assignments given during the semester. Therefore, the table shows that the homework assignments are low-stake assignments because each assignment was worth less than 1 percent of the total course grade.

Table 1. Grade distribution of the control class and the two experimental classes.

	2015 Class (%)	2016 Class (%)	2017 Class (%)
Exam 1	25	15	15
Exam 2	25	15	15
Exam 3	N/A	15	15
Final	30	30	30
Lab Reports (8)	10	13	13
Homework (15)	10	12	12

Results and Evaluation

The 2015 class (referred to as "Class 0") had 10 students as the control group. The experimental 2016 class (referred to as "Class 1") had 18 students and the 2017 class (referred to as "Class 2") had 21 students. Only 17 of the Class 2 population were used in statistical analysis because 4 of the students either failed for plagiarism or stopped attending class and missed at least one high-stake assignment. Therefore, the data from those students were seen as outliers in the statistical calculations, but their data is included in graphs that compare the use of numerical codes obtained from the GUIs.

The course final grades were used to compare the populations since the same instructor taught the courses with similar instruction methods and similar grading calculations and the GUIs were only used for a small part of the course instruction. The instructor did not normalize the grades or apply any curves in the data shown. A two-tailed f-test was performed on the variance of the course grades between the control group and both experimental groups. The p-value for equal variance between Class 0 and Class 1 was $p = 0.86$ and between Class 0 and Class 2 was $p = 0.94$. Therefore, the t-test used equal variance calculation methods in the statistical calculations. Table 2 shows the averages and standard deviations for the grades of these three classes. The equal variance two-tailed t-test was performed between Class 0 and Class 1 ($p = 99$) and Class 0 and Class 2 ($p = 96$) shows that there is a high probability of the students being from the same population.

Table 2. Sample size and grade statistics of the control class and two experimental classes.

Class	sample size	Average Grade	Grade Standard Deviation
Class 0	10	77.44	11.75
Class 1	18	77.36	11.35
Class 2	17	77.20	11.67

Shear and moment diagrams were presented to Class 0 during week 8 of the semester. The questions asked for numerical values found on the diagrams without requiring the students to submit sketched diagrams. These numerical values can be found without drawing the diagrams by solving for the shear and/or moment of that specific location on a beam. All questions for each student in Class 0 were identical and therefore answer sharing could occur within the control group without instructor knowledge or verification in these low-stake assignments.

Shear and moment diagrams were presented to Class 1 and Class 2 during week 7 of the semester. The MATLAB scripts were provided to the students by download through Blackboard. All of the assignments were identical and all of the numerical codes for the solutions in Class 1 were identical ore each student except for the shear and the moment diagrams where each student had a unique code. Each student was assigned a student number from 1 to 18 in integer increments for Class 1. The unique numerical codes for the shear diagram were between 96481 and 96498 in integer increments and between 39221 and 39238 in integer increments for the moment diagram. Blackboard was programmed to accept all of these numerical codes as correct for the associated problem in order to measure which students were receiving homework answers. Review of the submitted numerical codes for these problems provides data to answer the first research question: *How frequently did students share solutions*

on non-proctored low-stake assignments? This data was not extracted and reviewed from Blackboard until after the final grades were submitted to keep the instructor from being biased in grading future high-stake assignments. Figure 2 shows this data graphically for both the shear and moment diagrams for the assignments with unique numerical codes. If every student submitted their assigned numerical code, the data points would all fall on the straight, dashed lines shown. All values that do not fall on that line indicate that the student used a numerical code assigned to another student. Viewing the data from the y-axis provides the frequency that each numerical code was used. For example, code 96491 of Figure 2a was used by 5 different students; code 96489 of Figure 2a was used by 3 different students; and code 96494 of Figure 2a was used by 2 different students. Some student numbers do not have an associated submitted numerical code because these students did not submit a numerical code to get assignment credit. The two sets of data shown in Figure 2 indicate that for Class 1, 7 students on the shear diagram problem and 8 students on the moment diagram problem used a numerical code that was not supplied to them through their individual Blackboard assignments.
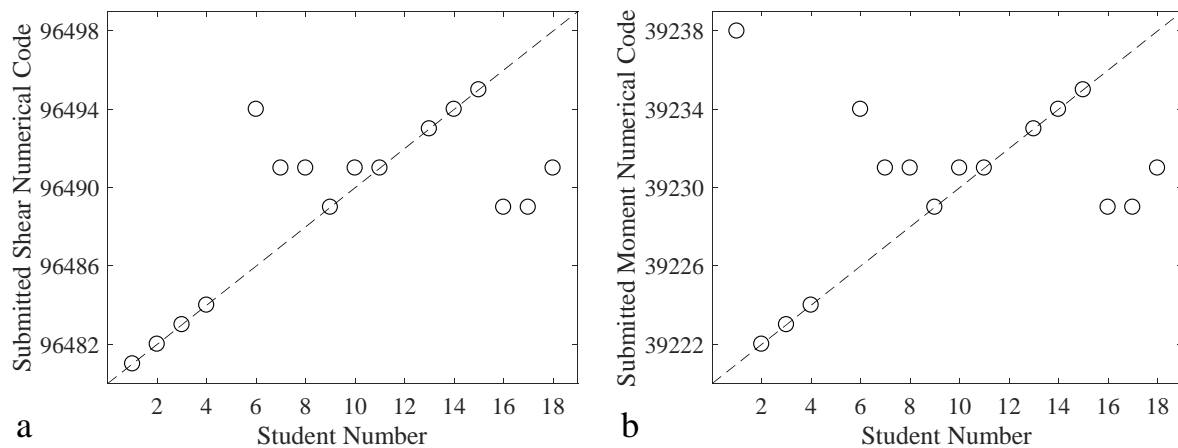

Figure 2. Unique numerical codes submitted to the LMS from each student of Class 1 for a) the shear diagram with unique numerical codes and b) the moment diagram with unique numerical codes.

All of the shear and moment diagram assignments for Class 2 were identical to Class 1 except different numerical codes were used. The same problems with the unique numerical codes were used, except a different set of answers were programed in the GUIs. Each student was assigned a student number from 1 to 21 in integer increments and the unique numerical code for the shear and moment diagrams were 96499 to 96514 and 39239 to 39259 respectively. These numerical codes follow integer increments from the numerical codes of Class 1 because the LMS was programmed to accept all of the codes from Class 1 and Class 2 as correct for the associated problem. This data provides additional insight in answer sharing between semesters for the first research question because the data allows review of solution sharing between Class 2 students and allows review of solution sharing from Class 2 students using answers from Class 1 students. Figure 3 shows the data graphically for both the shear and moment diagrams of Class 2. No students from Class 2 used numerical codes from Class 1 and therefore the submitted numerical codes on the y-axis are limited to those assigned to Class 2. Again, if every student submitted their assigned numerical code, the data points would fall on the straight lines shown. The four outliers are included in this data as well for completeness to show those additional points where

numerical scores were shared. Again, this data was not extracted from Blackboard until after the final grades were submitted to limit instructor bias on the high-stake assignments. The two sets of data indicate that for Class 2, 10 students used a numerical code that was not supplied to them through their individual Blackboard assignments.
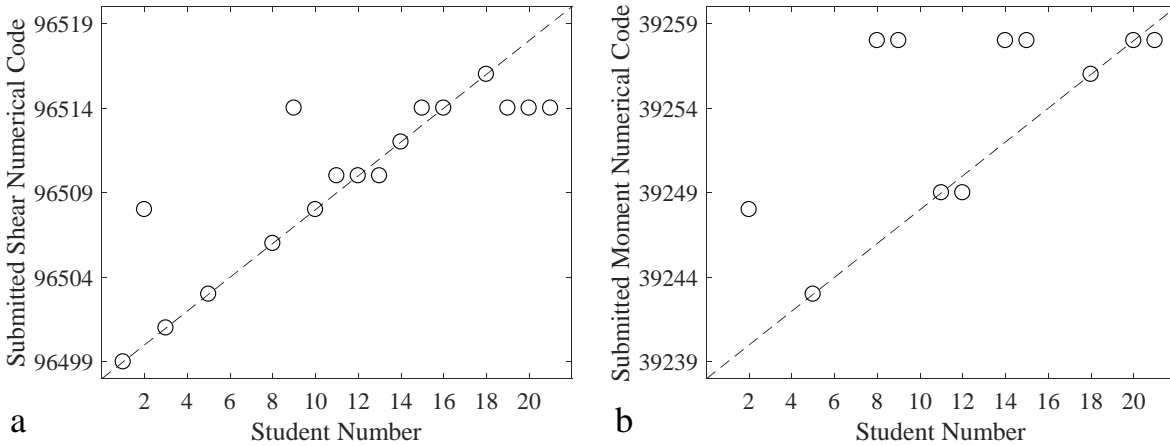

Figure 3. Unique numerical codes submitted to the LMS from each student of Class 2 for a) the shear diagram with unique numerical codes and b) the moment diagram with unique numerical codes.

The final exam (administered in week 17 of the course) was used to evaluate the students' competence at drawing shear and moment diagrams. The high-stake final exam was used to answer the second research question: *Did the students that used GUIs for graphical problems in their courses perform better on high-stake assignments than the students that did not have GUIs*? The final exams of each of the courses contained a problem that required the construction of both a shear and moment diagram. Figure 4 shows the problems used in each class on the final exam that required these diagrams. The problem for Class 0 was a statically determinate cantilever beam in US customary units, the problem for Class 1 was a statically indeterminate cantilever beam in US customary units, and the problem for Class 2 was a statically indeterminate cantilever beam in SI units. The problems for Class 0 and Class 1 stated in the problem statement that the shear and moment diagrams were required as the solution. The problem for Class 2 requested a design factor calculation based on the bending stress in the beam. This problem required a shear and moment diagram to determine the location and the magnitude of the maximum moment that would define the maximum bending stress.

All three problems required the students to first calculate the reaction loads. Class 0 was able to use two static equilibrium equations and Class 1 and 2 required deflection formulas to determine the reaction loads. Therefore, the assessment here eliminated the reaction load calculations and assessed the shear and moment diagrams based on each student's calculated reaction load. Each diagram was graded on a six-point scale for a total of 12 points between the two diagrams. For the shear diagram; the points were based on the starting and end points (1 pt) of the diagram, the lack of slope between the shear force change discontinuities (1 pt), and the different shear force magnitudes across the length of the diagram (4 pts). For the moment diagram; the points were based on the starting and end points (1 pt) of the diagram, the different slopes of the diagram between the locations of the applied loads (3 pts), the maximum moment location and value (1 pt), and the minimum moment location and value (1 pt). Table 3 shows the average score and
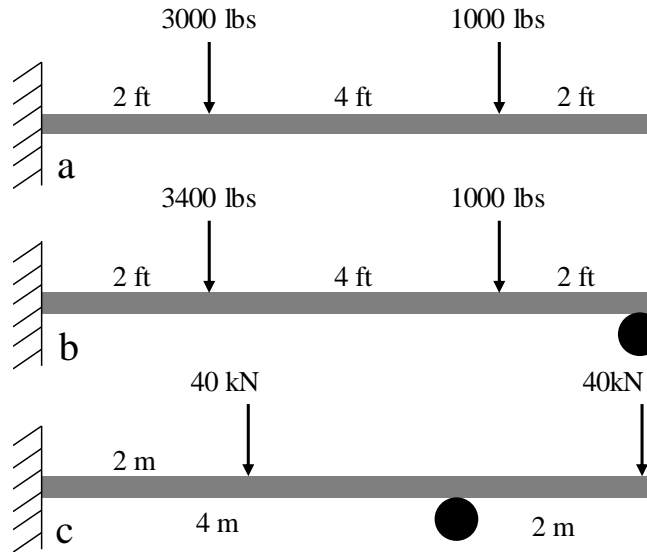
Figure 4. Final exam shear and moment diagram associated problem for a) Class 0, b) Class 1, and c) Class 2.

standard deviation for each class after the problems were assessed as described. Since the Class 2 problem statement did not specifically state the requirement of the shear and moment diagram, 2 sets of statistics are shown for Class 2. The score with the lower average includes the students (n = 5) that did not attempt to draw a shear and moment diagram because they did not understand the application of the diagrams in this problem. The other score is for the students that understood the requirement of drawing a shear and moment diagram and attempted that solution.

Table. 3. Final exam shear and moment diagram evaluation for the control class and the two experimental classes.

	Class 0	Class 1	Class 2 (all students)	Class 2 (diagram attempt)
Average	11.4	11.44	7.47	10.58
Standard Deviation	1.26	1.46	5.22	1.93

The two-tailed f-test was performed on the variance of the shear and moment diagram evaluations between Class 0 and Class 1 (p = 0.67) and Class 0 and those that attempted the diagrams in Class 2 (p = 0.22). These values did not indicate a statistical difference in the variance and again, the t-tests were performed assuming equal variances. The two-tailed t-test was performed between Class 0 and Class 1 (p = 0.94) and Class 0 and those that attempted the diagrams in Class 2 (p = 0.27). These values indicate that having the students sketch the shear and moment diagrams with the GUIs in low-stake assignments has no statistically significant change on the students' ability to draw shear and moment diagrams in the high-stake assignment (i.e. final).

The final evaluation was used to answer the third research question: *What was the student performance of those that accepted shared solutions compared to the students that did not use shared solutions?* This evaluation consisted of comparing the average final grades of the students in Class 1 and Class 2 between those that copied (n = 18, defined here by the variable

"copy") at least one numerical code in the low-stake GUI assignment and those that did not copy any (n = 12, defined here by the variable "no copy") numerical code. The students that left both problems blank were not used in this evaluation. The two-tailed f-test (p = 0.18) indicated no statistical significant variance difference between the copy and no copy student averages and therefore an equal variance two-tailed t-test was performed on the averages. The results of the t-test (p = 0.10) indicated that there is a 90 percent probability that a student that copies a numerical code will receive a lower grade than a student that does not copy a numerical code. The confidence interval of the t-test indicates that a student that copies may have a final class grade that is up to 16 points lower on a 100-point scale than students that do not copy any numerical codes.

Discussion

The learning process requires that students implement new knowledge in some form where formative assessment can be employed to provide feedback about the new knowledge. With feedback, students can correct misunderstandings and therefore, create an education loop. Try-again feedback is a tool that allows students to implement this education loop without time delays because the student is able to immediately receive feedback on submitted performance. This work shows that GUIs can be used to provide that immediate feedback for low-stake graphical assignments. The results here answer the second research question: *Did the students that used GUIs for graphical problems in their courses perform better on high-stake assignments than the students that did not have GUIs*? and show that there is no statistical significance in improvement or degradation of the performance over a course between a student using the try-again feedback of graphical solutions with the GUI compared to try-again feedback requesting specific numerical values from the graphical solution. The use of these GUIs may have an immediate effect in the learning process. Therefore, other high-stake assignments (i.e. exams prior to the final) may be better data points to measure the effectiveness of the GUIs on initial student learning. These measurements and analysis are left for future work.

The GUIs were used to measure answer sharing of low-stake assignments between students and answer the first research question: *How frequently did students share solutions on non-proctored low-stake assignments*? Figures 2 and 3 shows that 44 percent and 48 percent of students from Class 1 and Class 2 respectively, used shared answers for low-stake assignment credit. These figures also show that 22 percent and 19 percent of students from Class 1 and Class 2 respectively, share answers for low-stake assignment credit. Unfortunately, try-again feedback allows students first attempting an assignment, to get the correct answers for the assignment from that feedback and potentially share with other students in the class. The number of students that used a shared numerical code was higher than expected, but the results are not able to distinguish between students that copy and students that work in groups to complete these low-stake assignments. For example, the course instructor noticed that students 9, 16, and 17 of Figure 2a were always working in a group on these assignments and therefore each of those students used the numerical code assigned to student 9. But, the instructor never saw any of the 5 students that submitted the numerical code of student 11 working together. This type of issue is common in academic settings for low-stake assignments because little to no proctoring is available, the students proctor their own learning, and students are encouraged to work in groups. The LMS submission data may provide additional information to determine the

difference between group sharing and individual coping and is left for future work and evaluation. These results may be an indication of the work ethic of different students in the class. Students with a high work ethic perform better and work harder to learn the material and submit their own work. Students with a lower work ethic will request answers when learning becomes difficult, rather than working harder to understand the material.

Another important point observed from the data is that no numerical codes from Class 1 were used in Class 2. Reports have been submitted regarding issues with answer sharing, online solution banks, etc. where answers are obtained from outside of the class without students having to complete the work. The results of this work are unable to measure online solution sharing because the instructor developed the GUIs and problems, but this work can measure the sharing between semesters. The data did not show answer sharing for any of the assignments related with shear and moment diagrams between semesters. All solutions between Class 1 and Class 2 were changed by at least one numerical digit and the LMS of Class 2 was programmed to accept all the answers of both classes as correct. No answer sharing between semesters was recorded in Class 2 even though one of the students from Class 1 was retaking the class in Class 2. Solution sharing between different semesters may be a larger problem at larger universities with larger class sizes. The GUIs developed and used in this work could be used as well to directly measure solution sharing in and between semesters of a large course.

Conclusion

The use of MATLAB GUIs to provide try-again feedback on graphical assignments does not offer any advantage over using try-again feedback requesting specific numerical values of the graphical assignments when the graphical assignments are assess during high-stake assignments at the end of a semester. The GUI was able to provide the student try-again feedback and therefore allow the student to make mistakes during the learning process. Students are able to perform equally well on high-stake assignments at the end of a course independent of the tool used with the try-again feedback on the graphical assignment. These GUIs may assist some students in the short term in practicing graphical solutions, but additional research needs to be performed to support that assumption.

Try-again feedback offers an avenue for answer sharing with classmates, even when assignments are instructor developed. The results of this work show that answer sharing on low-stake assignments has a negative impact on student performance. The development of the MATLAB GUI with the use of individual numerical codes for individual students provided a means for measuring the impact of answer sharing on student performance. These measurements showed that 46 percent of the students in the experimental sample used shared answers. Some of this sharing was probably groups of students working together to complete the assignment, but the statistics indicate that there is a 90 percent probability that a student using a shared answer will have a lower grade than a student that does not use a shared answer. More research is needed to measure how try-again feedback with the GUIs assist in initial student learning and not just how GUIs can measure the effects of answer sharing in low-stake assignments on overall performance.

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