Using Assessments to Improve Student Outcomes in Engineering Dynamics

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Abstract

Engineering Dynamics has historically been one of the most challenging courses in the engineering curriculum. At this institution, Dynamics is taken by approximately 400 students annually and the failure rate has hovered around 15-20% for the past 10 years. This rate has serious implications on program length and student retention. Numerous studies have been conducted that are aimed at improving these common statistics in Dynamics. These studies provide invaluable guidance on improving teaching techniques to address the diverse needs of learners in and outside of the lecture halls. The focal point of this study is on student assessments and their use to promote content mastery in Engineering Dynamics.

Although often met with controversy, proponents of second chance exams believe that when done properly, they have a significant positive impact on student learning and retention. This may particularly be the case for engineering dynamics, where students are lost in rigid body dynamics if they have not fully understood the foundational first part of the course, particle dynamics. In order to improve student learning, two significant changes were implemented in Fall, 2019. Firstly, students were given the ability to write two make up quizzes and one make up midterm exam. All make up quizzes and exams contained different questions, but were at the same level of difficulty as the originals. The details of the assessments, rules and constraints surrounding the reassessments, and a comprehensive evaluation of the effect of the reassessments on student outcomes and student experience are detailed.

1.0 Introduction

The Schulich School of Engineering (SSE) at the University of Calgary consists of five departments (Chemical, Civil, Electrical, Geomatics, and Mechanical Engineering) and offers specialized majors programs such as Oil and Gas. All students in the SSE take common engineering courses in the first year of their studies. At the end of the first year, students compete for a spot in their choice of program associated with a department or major. As there are limited spaces in each program, students are then offered admittance into a program based on their first year grades. This means that students may not be admitted to the program ranked as their first choice. The variance in popularity for the various programs, coupled with differences in program enrolment caps, leads to significant differences in the minimum entrance grades between the various programs. Currently, Mechanical Engineering requires the highest entrance grades.

Each program has a discipline specific curriculum and associated courses. Courses that cover material that is required across the various programs are normally taught in the “common core”. Engineering Dynamics (ENGG 349) is one such common core course, required in second year in

all of the five main programs except for Electrical Engineering, and has a typical yearly enrolment of 350-450 students.

Although based on elementary calculus and a single law of motion, Engineering Dynamics is considered to be one of the most challenging second-year courses. The course failure rate over the past 10 years has been around 15-20%. A student's failure in this course has serious implications on their overall success within the SSE. First, failure has implications on scheduling. If a student is required to repeat the course and it is a required prerequisite for their program, their studies must be extended at least half a year. Second, a failure reduces a student's overall grade point average (GPA) and this may affect their ability to continue on in the program or qualify for financial aid. Finally, if a student fails the course more than once, the student may be required to withdraw from the SSE.

Previous efforts to improve outcomes in this course at the University of Calgary have focussed on examining how the lectures could be better delivered in light of the vast array of learning styles of the students. In [1], Singh et. al. gave the index of learning style (ILS) survey [2] that is based on the Felder Silverman learning style model [3] to the 2015 dynamics class at the University of Calgary. After data analysis concluded that students would benefit from a more balanced approach to learning and that active learning opportunities should be regularly be provided to students. In fact, these results were as expected after similar results such as those in [4] had previously been obtained elsewhere. As a result of the study [1] itself, lecture demonstrations were designed, and lectures were delivered in a more engaging and interactive manner. Although these methods have improved the instructor course evaluations, their effect on overall student outcomes have not been significant. In [1] little attention was paid towards the assessment methods. In the previous course offerings, summative assessments were generally used as measurements of learning rather than vehicles to enhance learning. This shift in paradigm with respect to assessments formed the motivation for this research.

Fostering a mastery goal rather than a performance goal in the classroom can in part be supported by instructors by adopting assessment techniques associated with mastery learning. In Blooms philosophy of mastery learning [5], students must achieve a level of mastery of a given topic before learning subsequent information. If a student does not achieve mastery, then support is given to the student in learning the information before they are tested again. Regular assessments that incorporate feedback and second chance testing are simple tools that have been used in the implementation of mastery learning. A recent study [6] of second-chance testing in solid mechanics found that a majority of students report higher exam scores on the retake exams and the positive impact that frequent testing and retake exams has on student outcomes. Although this indicates positive outcomes for second-chance testing, there is little other published work on the effect of retake exams in Engineering Dynamics. Furthermore, the effect of retesting in other disciplines is often inconclusive regarding their impacts on retention of the course material as measured by final exam scores [7]. It should be noted that opponents of second chance exams suggest that overall learning of participants is not improved since students were less likely to study for a first exam, if they knew that they can take a second exam in the

future (e.g., [8]). This indicates that the method of retesting must account for this published limitation so that retesting may have a positive impact on student outcomes.

Over the past few years, the assessments in Engineering Dynamics have consisted of quizzes, a midterm, and a final exam. The quizzes make up 25%, the midterm, 25% and the final exam 50% of the course grade. It should be noted that in total, six to eight quizzes are given to the students that are based on weekly assignments. Each quiz contributes equally towards the final course grade. Although past student's comments on the course evaluations have strongly suggested that quizzes are a great opportunity for them to keep up to date with the course material, due to the heavy associated load, of the 8 quizzes, the two on which the lowest marks were obtained have not in the past been considered in the calculation of the students final grade. Although this is common practice when multiple quizzes are taken in a course, it does not give students the opportunity to learn from their mistakes. This is also true for the case of the midterm, where some students are left with a low mark, and therefore a poor understanding of the foundational material.

In order to improve student learning, two significant changes have been implemented in the Fall 2019 (F2019) Dynamics class. Firstly, instead of dropping a student's lowest two marks on the quizzes as done in previous semesters, students can rewrite any one quiz before the midterm, and any one of the later quizzes before the final exam. Secondly, with constraints, students can rewrite the midterm two weeks after the original date. The details of the assessments, rules and constraints surrounding the reassessments, and a comprehensive evaluation of the effect of the reassessments on student learning outcomes and student experience will be detailed in this work. In the second section, the course structure and the details of the assessment and reassessment methods are provided. In the third section, the results of the students on retake exams are compared to their original scores. In the fourth section, the results of a 5 point Likert survey that was completed by students to examine their perceptions of retake exams and their effect on their learning are analyzed. Finally, in the fifth section conclusions are drawn.

2 Overall course structure and assessment/reassessment methods

Course Structure

The Fall 2019 (F2019) Dynamics class consisted of a total of 405 students. Due to this large number of students, the course was offered in three different lecture sections by two different professors. Students in the same engineering discipline were enrolled in the same lecture sections, with the intent that example problems could be tailored to discipline specific examples. However, all students were evaluated based on the same material, i.e., they were given the same assignments, quizzes, midterm, and final exam.

Instructor A conducted one lecture section made up of Mechanical Engineering students (L01), while Instructor B conducted two sections (L02/03) made of students from the remaining disciplines. Both instructors conducted three weekly lectures and one weekly tutorial for their

students. The instructors met daily to discuss lecture content, classroom demonstrations, and delivery pace. Although the lecture notes were different between the instructors, both sets of digital notes could easily be obtained by all 405 students taking the course. The biggest difference in the lecture notes were in the solved example problems.

Each week, the instructors would post an assignment based on the lecture material covered. The assignment would consist of approximately 4-5 questions. Although these assignments were not for marks, they were necessary to complete in preparation for associated quizzes that were conducted in the tutorials. In order to optimize student learning objectives for each assignment, the instructors provided the numerical answers to each question on the assignment, but chose not to provide the solutions to the assignments until just hours before the quiz based on the assignment was scheduled to occur. It is a firm belief of the instructors that student learning in dynamics is afforded by the deep thinking associated with the complete engagement in solving problems. This level of learning cannot be achieved when students have the solutions to problems in front of them at the time they are attempting the problems. It should be noted at the time of posting the assignments on the course D2L site, two to four additional solved example problems were posted for the students to review. Additional resources for the students that were posted from the beginning of the term included a bank of old quizzes, midterms, and final exams. Finally, the instructors would post a set of additional problems for students to solve if desired after every major unit was completed.

There was more uniformity in the tutorial sessions. In these sessions, the instructors would first solve a problem (same problem for each section) that was specifically selected to highlight some of the difficulties that students encountered in the past in mastering the associated concepts. After a small break, the instructors would then deliver a quiz to the students. Since these tutorials were conducted at the same time of day and Instructor B's tutorial section was made up of students from both L02 and L03. This consistency in the timing of tutorials for all sections allowed for the professors to maintain consistency in assessments for all students (i.e., all students were able to write the same quizzes).

<u>Assessments Methods:</u>

Quizzes / Make Up Quizzes (25%)

Each of the six 30-minute quizzes was conducted in the tutorial sessions. Depending on the quiz schedule (which was posted on the course outline) each quiz covered concepts reviewed in either one or two assignments. Each quiz consisted of one free-response question. This free-response question, similar to the assignment problems, engaged students in solving problems that necessitated the application of the basic theory. Normally, the solution to each quiz, along with the draft marking rubric was posted on the course D2L site the day after each quiz. The students would receive their marked quizzes within a week of writing the quiz.

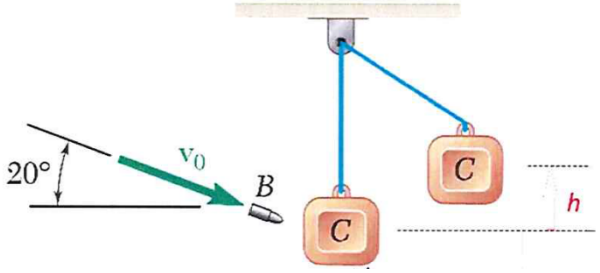
There were two sessions that were scheduled for make-up quizzes. One of these sessions was scheduled the week before the midterm exam. In this session, the students could choose to make up one quiz from quizzes 1-3. The second session was scheduled the week before the final exam. In this session, the students could choose to make up one quiz from quizzes 4-6. Scheduling constraints did not allow the students to receive their original quizzes 3 or 6 back before the two make-up quiz sessions. However, the students felt that they could learn from the mistakes that they made and make the decision on which quiz that they should retake based on the posted solution to these quizzes. Although the questions on the make-up quizzes were completely different than those on the original quizzes, they were designed to test the same body of knowledge tested in the original quizzes. Care was taken to ensure that the make-up quizzes were of the same level of difficulty as the original quizzes. . This was critical since it was felt that if the relative level of difficulty was a moving target, students would be less motivated to study for a make up exam if they thought that there was a possibility that it may be more difficult than the original. Additionally, comparing student results on two quizzes that were of different difficulty levels would not yield meaningful results. A sample original quiz and a make up quiz is shown below in Figure 1.

Block C (m_C= 4 kg) is suspended from an inextensible cord to form a pendulum. A bullet B (m_B=60 g) is fired with a speed of $v_0 = 500\ \frac{m}{s}$ and gets embedded in block C. The pendulum and bullet move together as one unit after impact

a) Draw the impulse and momentum diagrams for the system (pendulum and bullet) between the instants before and immediately after impact. Use these diagrams to determine the velocity of the bullet and block immediately after impact.

b) Draw the impulse and momentum diagrams for the bullet alone between the instants before and immediately after impact. Use these diagrams to determine the impulse that the bullet B exerts on block C upon impact.

c) Knowing the velocity of the bullet and block immediately after impact from part a), determine the maximum height h that the pendulum reaches.



Two smooth disks A and B each have a mass of 0.5 kg. If both disks are moving with the velocities shown when they collide, determine their final velocities just after collision in the **Cartesian coordinates**. The coefficient of restitution is $e = 0.75$.

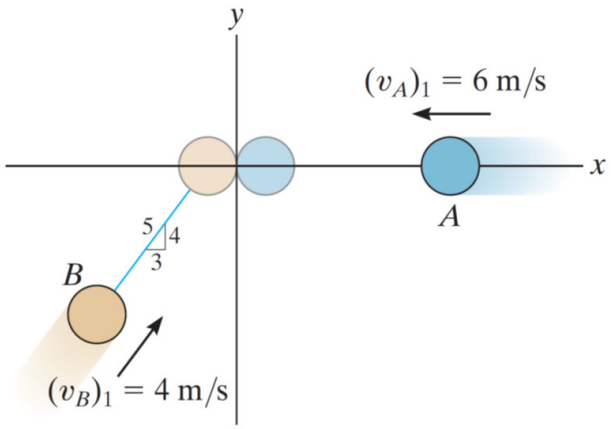


Fig. 1: Original Quiz 6/7 and make up Quiz 6/7

It was stated in the course outline that the purpose of make up quizzes was to accommodate any circumstance beyond the student's control, including illness, which may have resulted in an absence or undesirable grade on the original quiz. The decision to allow the students to make up only two of the six quizzes was made primarily since it was felt that if the students had the opportunity to make up all six of the quizzes, the students may perceive the make-up quizzes as being altogether too time consuming and they may decide at the beginning of the term to not take advantage of the learning opportunity that they may provide all together. Additionally, it was felt that the opportunity for procrastination afforded by the six-second chance quizzes may result in some students falling completely behind in the course. As stated on the course outline, only the best mark of the quiz and the corresponding make up quiz would count towards the student's final grade. It was felt recording the "best of" mark did not detract from the students' overall effort in studying since the students could only rewrite one out of three quizzes in each rewrite session. As stated, these make up quizzes were the only opportunity for students to make up quizzes that were missed due to illness and all other extenuating circumstances. Students were thus motivated to study for each quiz and save the make up quiz for such circumstances if necessary.

Midterm /Make Up Midterm (25%):

The 2-hour midterm exam consisted of four free-response questions and was conducted out of class hours. These free-response questions engaged students in solving problems that necessitated the application of the basic theory associated with the kinematics and kinetics of particles, and the preliminary concepts associated with the kinematics of rigid bodies. The midterm was designed such that the students could easily finish the exam in the 2-hour allotted time period.

A make-up midterm was scheduled for two weeks after the original midterm. It should be noted that the week after the original midterm was a scheduled reading break and so the university was closed. Although the questions on the make up exam were completely different than those on the original, they were designed to test the same body of knowledge tested in the original exam. Like for the make up quizzes, care was taken in the design of the make up midterm to ensure that it was of the same level of difficulty as the original exam.

It was stated in the course outline that the purpose of make up midterm was to accommodate any circumstance beyond the student's control, including illness, which may have resulted in an absence or undesirable grade on the original midterm. Also stated were the rules surrounding the make up midterm. Specifically stated was that if a student missed the original midterm and provided appropriate documentation, the makeup midterm would account for 100% of the midterm grade. If a student wrote the original midterm but wanted to rewrite it to improve their midterm grade, the makeup midterm would account for 70%, and original midterm would account for 30% of the midterm grade. If a student choose not to write the makeup midterm, then the original midterm grade would account for 100% of their midterm grade. The minimum of 30% of the final grade taken from the first exam was chosen instead the "best of" approach to overcome criticisms documented in, for example in [8], of second-chance exams. These criticisms are primarily associated with fairness and student effort. Specifically, opponents of the re-sit exams believe that they reward students who have made little or no effort and do a disservice to those who have studied for the original exam. Furthermore, they believe that students who have an opportunity to write a second exam, will invest less time in studying for the first. The 30%/70% make up / midterm contribution was intended to level the playing field on the fairness issue and encourage all students to study for the first midterm. More importantly, it was an effort to encourage all students to study for the first exam and if not successful, learn from their mistakes made on the first exam, and study again for the second.

Consistent with the quizzes, the midterm solutions and tentative marking rubric were posted on the course D2L site the day following the exam itself. The exams were marked and handed back to the students within a week of writing. In total the students had one week from the time that their midterm was handed back, to the time that the make-up midterm was implemented. In this time, the students had the opportunity to compare their solutions to the instructor's solutions and learn from their mistakes. It should be noted that all students were encouraged to meet with the instructors or teaching assistants to discuss any particular concerns that they may have with the material covered on the midterm.

Final Exam (50%):

Consistent with the format of the final exam in Engineering Dynamics for decades, the 3-hour final exam in F2019 was scheduled by the Registrar's office and consisted of five free-response questions. These free-response questions engaged students in solving problems that necessitated the application of the basic theory. From early in the term, and as evidenced by posted old final exams, the students knew that the final exam consisted of one question from before the midterm, and four questions from material covered after the midterm. The emphasis of the final exam was

thus rigid body kinematics and kinetics. This exam was in fact considered a cumulative exam since the understanding of particle dynamics is critical to the understanding of rigid body dynamics. Unfortunately, the final exam in the F2019 was scheduled on the earliest possible day in the two weeks of available final exam times. Specifically, the last dynamics class was on a Friday, and the final exam was on the Monday morning. To help the students with the limited available study time, the instructors decided to hold a review session on the Saturday before the final exam. In the 3-hour review session, the instructors reviewed all of the lecture material and solved problems that covered the lecture material studied after the midterm. Only students absent from the exam due to documented circumstances were permitted to apply to write a deferred final exam.

Consistency in Marking:

In all quizzes, midterms, and in the final exam, students were required to show all of their work. The marking rubric was designed by both instructors with the philosophy that emphasis should be placed on the demonstration of correct conceptual understanding (e.g., correct free body and kinetic diagrams), and little marks were removed for mathematical errors. The marking was supervised by the instructors, but conducted by the teaching assistants. For the most part, whichever the assessment, two teaching assistants were responsible for marking one question for the entire class. The instructors would first meet with the teaching assistants after the assistants had an opportunity to solve the problem and think through the multiple ways that the problem could be correctly solved. With the associated preliminary understanding already in place, the instructor would demonstrate the application of the marking scheme by marking a set of exams with the assistants. The teaching assistants would then mark another segment of exams and the instructor would then go through each of these exams with the teaching assistant and would correct marking errors. This process would repeat until the instructor was confident that the marks obtained by both teaching assistants were in strict accordance with the marking rubric and were consistent.

3. Results of the student exams and make up exams

The results of the student's quizzes and make up quizzes are shown in Table 1 for L01, and in Table 2 for L02/03. It should be noted that at the time of writing of this paper, due to technical difficulties, quiz 3 results were not available (NA). Immediately apparent from this table is that there is little difference between the class averages on all quizzes when comparing section results. It can also be seen from both tables, that students who obtained marks significantly below the class average took the opportunity to rewrite them. This is evidenced in quiz 1 where the class average of both lecture sections was approximately in mid-eighties on the original quizzes and students who choose to rewrite the quiz had obtained an average around 40% on the same quizzes. This first quiz is perhaps the easiest as it is associated with the basics of the kinematics of particles and the students have seen parts of the material in high school physics. The fact that students were obtaining grades of 40-50% on this preliminary material indicates that they would likely have difficulties with subsequent material if corrective action was not taken. On average, for both lecture sections, the students grades increased by 31% on the make-

up quiz 1. Similar pattern is found for quiz 2, but the increase in results, particularly for L01 was not as high. Student grades from both sections increased over 20% on make-up quizzes 4 and 5 when compared to the original quizzes. The increase in grades between the original and the make up quiz 6 was very small for both sections. However, the overall class average was the highest for this quiz and the differences between the class average and the rewrite students average on the original quiz was also the lowest for this quiz. Overall students performed on average 18% higher on make up quizzes than they did on the original quizzes.

Since students were only permitted to rewrite one quiz from quizzes 1-3, and one quiz from quizzes 3-6, the total percentage of students that took the opportunity to rewrite the quizzes can be found by summing the percentages of students that wrote either set of the makeup quizzes. Since quiz 3 data is currently not available, only the percentage of those who wrote quiz 4-6 can be calculated. Examining quizzes 4-6, it can be concluded that 74% of students in L01 and 81% of students in L02/L03 participated in writing the makeup quizzes.

Table 1: Quiz and Make Up Quiz Results for L01 (Mechanical Engineering Students)

	Quiz 1	Quiz 2	Quiz 3*	Quiz 4	Quiz 5	Quiz 6
Subject Tested	Kinematics of Particles-Curvilinear	Relative motion of particles	Kinetics of particles	Impulse and momentum	Kinematics of rigid bodies	Kinetics of rigid bodies
Overall Class Average, First Sitting (N_1 + N_2 = 191)	83.6%	87.0%	NA	68.7%	65.1%	93.5%
% of Students Who Wrote the Make Up Quiz, (N_2/191)×100	11.5%	9.4%	NA	28.8%	39.8%	5.0%
Class Average of N_2 on their First Sitting	39.2%	52.7%	NA	47.7%	48.7%	90.0%
Class Average of N_2 on their Make Up Quiz	75.0%	53.9%	NA	78.0%	73.0%	94.4%
Change in Average of N_2 from their First Sitting to their Make-Up Quiz	+35.8	+1.2	NA	+30.3	+24.3	+4.4

Table 2: Quiz and Make Up Quiz Results for L02/L03 (Other Engineering Students)

	Quiz 1	Quiz 2	Quiz 3*	Quiz 4	Quiz 5	Quiz 6
Overall Class Average, First Sitting ($N_1 + N_2 = 214$)	85.4%	86.3%	NA	73.7%	59.3%	91.9%
% of Students Who Wrote the Make Up Quiz, $(N_2/191)\times100$	12.1%	12.6%	NA	23.8%	52.3%	5.0%
Class Average of N_2 on their First Sitting	39.7%	48.9%	NA	54.8%	45.8%	82.7%
Class Average of N_2 on their Make Up Quiz	66.9%	64.9%	NA	77.1%	68.0%	82.7%
Change in Average of N_2 from their First Sitting to their Make-Up Quiz	+27.2	+16	NA	+22.3	+22.2	+0

The results of the midterm and make up midterm are shown in Table 3. The class average for the original midterm was 7% higher for L01 compared to L02/L03. This was expected as L01 is comprised of mechanical engineering students, who obtained the highest grades in first year engineering and who should have a higher aptitude for the content. In total, 24% of L01 students and 32% of L02/03 students wrote the make up midterm. These students obtained grades 14.5% (L01) and 12.7 % (L02/03) below their class average on the original midterm. Their average grades increased by 23% (L01) and 22.9% (L02/L03). In fact, as can be seen in Table 3, the students received an average grade that was 8.5%, (L01) and 10.2% (L02/L03) higher than the class average in the original midterm. It should be emphasized that although both midterms had different questions, they were carefully prepared by the instructors to ensure that they were of the same difficulty level and would take the same amount of time to complete.

Table 3: Midterm and Make Up Midterm Results for All Students

	Section L01 Mech Eng (N = 191)	Section L02/L03 All other Eng (N = 214)
Overall Class Average, First Sitting	71.7%	64.8%
Number of Students Wrote Make Up Midterm (N_2)	46	69
% of Students Who Wrote the Make Up Midterm, $(N_2/N)\times100$	24.1%	32.2%
Class Average of N_2 on their First Sitting	57.2%	52.1%
Class Average of N_2 on their Make Up Midterm	80.2%	75.0%
Change in Average of N_2 from their First Sitting to their Make Up Midterm	+23.0	+22.9

The results of the final exam have been tabulated in Table 4. Consistent with the midterm result, the class average on the final exam was higher for L01 (71%) than it was for L02/L03 (65%). This is a significant difference since it represents a change in an overall letter grade. Of more significance is the final exam average of those students who wrote the make up midterm. Like the midterm, these students scored below the class average, but their averages were significantly closer to the class average then they were on the original midterm. Of only those students who wrote the make up midterm, the students scored 4.3% (L01), 2.9% (L02/L03) below the class average. This is a significantly less gap then was achieved on the original midterm where these students scored 14.5% and 12.7% less than the class average. This indicates that these students may have significantly benefitted from the knowledge they gained rewriting the midterm or they did not put as much effort into the original midterm, knowing that they had a second midterm in spite of the grading scheme provided. However, it is believed that these students also may not have put in a significant effort into the final exam since it was held only two days after the end of classes. It is therefore believed that it is more likely that the make up midterm student's knowledge of the final exam material (predominately rigid bodies dynamics) was more grounded by their better understanding of the midterm material (particle dynamics).

The final exam averages for the previous year (F2018) are also provided. In F2018, the students did take regular quizzes and a midterm, the same two instructors taught the course (but for different sections), did have a final exam review tutorial, but make up exams were not available. As a result of the assignment of different lecture sections for the instructors, a direct comparison between lecture sections is not possible and results are presented as an entire class average for F2018. A comparison of the final exams between the F2018 and F2019 (prepared by the same instructors) indicates that they were of the same difficulty level. As can be seen from the table, the mechanical engineering students in F2019 did 6.7% better on the final exam than did the class in 2018, while the others (L02/L03) only achieved a 0.7% higher average. A better comparison would be the overall class average of the two combined sections between subsequent years, where the F2019 students achieved a 3% higher average than the F2018 students. This 3% increase in the overall average does have significant effect on class grade point average, but it is felt that since the change is small, more data is required to fully understand the effect of the make-up quizzes and midterms on the final exam results.

4. Student evaluation of the make up quizzes and exams

As previously mentioned, on the weekend before the final examination, a review session was held. In a break between two problems, a survey was distributed to the students with aim to evaluate the student's perception of how the second chance midterms/quizzes influenced their learning. The survey asked the students to use a 5-point Likert scale ((1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree)) in their responses to all (but one) of the questions. A total of 189 students provided valid responses to all of the survey questions. The questions, and their mean scores are tabulated in Table 1 below. A Likert plot of

the data is given in Figure 2. It should be noted that the first question on the survey (not reflected in the results below) asked the students if they participated in one or more of the make-up quizzes/exams. There were 5 students who did not participate in any make up quiz or midterm and therefore those surveys were discarded (5 surveys).

Table 4: Final Exam Results

	F2019, Section L01 (N = 191) Mech Eng	F2019, Section L02/L03 (N = 214) All other Eng	F2019, All Sections (N=405)	F2018, All Sections (N=467)
Overall Class Average on Final Exam	71.0	65.0	67.8	64.3
Number of Students Who Wrote the Make Up Midterm, N_2	46	69	NA	NA
Final Exam Average for the Students Who Wrote the Make Up midterm	66.7%	62.1%	NA	NA

Table 5: Student Survey Data on the Effectiveness of Second Chance Exams (N = 189)

Question	**Mean**
Q1: You wrote one or more make up quizzes because you were sick or could not make it to the quiz on the day of the original quiz.	1.46
Q2: You studied **less** for the **original** quizzes/midterm knowing that you had an opportunity to rewrite them.	1.97
Q3: Overall, you perceived that the make-up quizzes/midterm to be: (Circle) (1) Much Easier (2) Slightly Easier (3) About the Same (4) Slightly Harder or (5) Much Harder than the original quizzes / midterm.	2.73
Q4: The make-up quizzes / midterm formed a good motivation to learn material that you did not originally have time to when you wrote them the first time.	4.27
Q5: Overall, you put ***more*** effort into the course because of the make-up quizzes / midterm than you would have in their absence.	3.56
Q6: You felt ***more prepared*** for the make-up quizzes / midterm than the original ones.	3.78
Q7: Overall, you learned ***more*** in the course because of the make-up quizzes/midterm.	4.09
Q8: You wish that you could have the opportunity to rewrite exams in all courses.	4.73

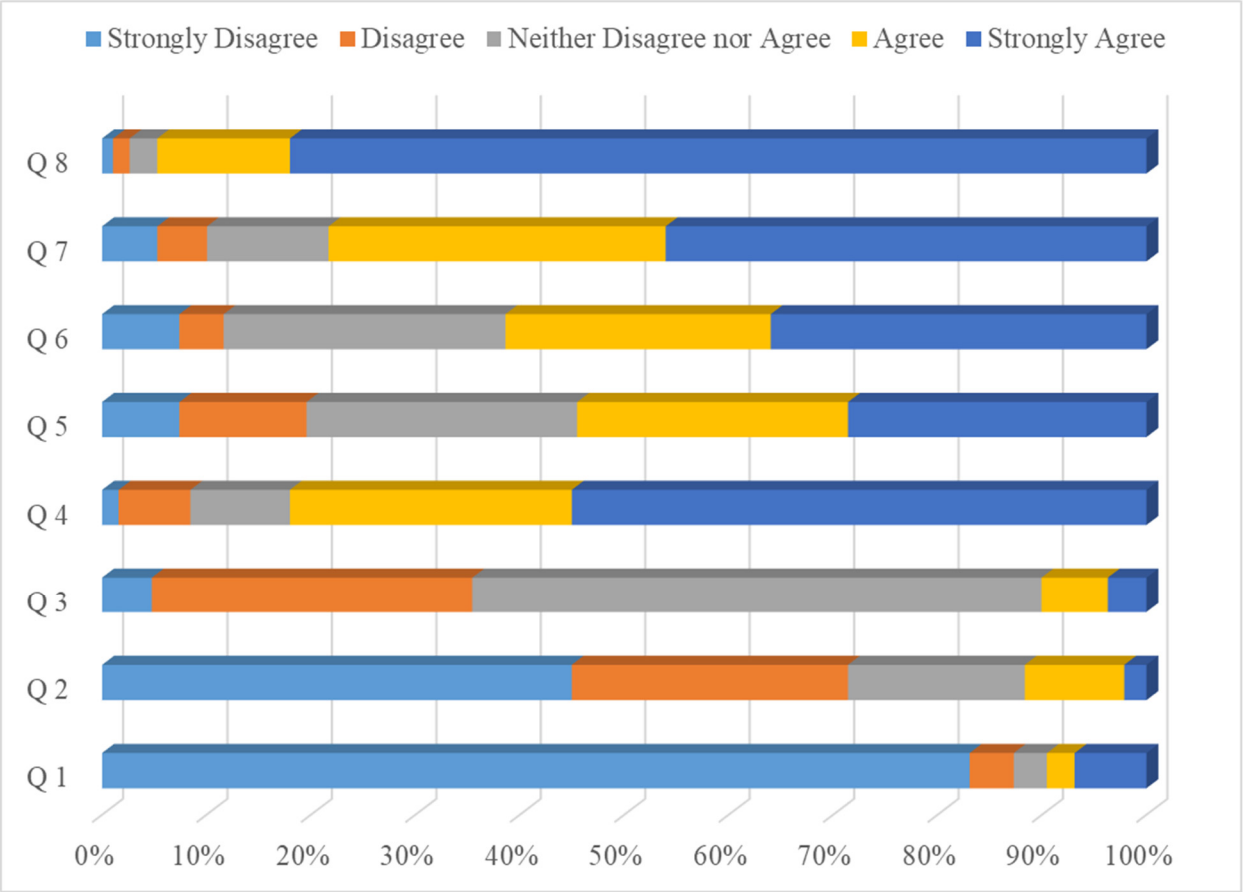


Fig. 2: Likert Plot of Survey Data

Interpretation of the Survey Data:

The response to question 1 indicates that the majority of the students wrote the make up exams not solely because they had been absent from an exam due to illness. This indicates that the students saw the perceived value in rewriting their exams to improve their learning outcomes. Similar to question 1, question 4 was aimed at understanding the reasons why the student's chose to rewrite their exams. With the high workload in engineering, students often are forced to make choices to master concepts in one course at the expense of another. This is often unavoidable when multiple exams/quizzes/assignments are due in the same week. The strong response to question 4 (mean=4.37) indicates that students felt motivated by the fact that they benefited from the extra time for full content mastery afforded by the make up exams. However, results from question 2, where the students, on average (mean=2) disagreed with the statement that they studied less for the original exams knowing that they had an opportunity to rewrite them, indicate that the students did not rely solely on the make up exams to improve their grades. It should be noted that, as can be seen from the Likert Plot (Figure 2) that approximately 9.5% of the students agreed and 2% of the students strongly agreed that they studied less for the make up exams knowing that they had the opportunity to make up the exams in the future. This suggests that approximately 10% of the students felt that the opportunity to make up exams did not increase their overall effort in the course. This is also evidenced from the response to question 5, which

was inserted into the survey to complement question 2. Specifically, the response to question 5 suggested that in total 18% of the students either strongly disagreed (6%) or disagreed (12%) with the statement that they put more effort into the course as a result of the make up exams.

As previously mentioned, care was taken in the design of the make up quizzes and exams to ensure that they were of the same level of difficulty of the original quizzes/exams. This was critical since it was felt that if the relative level of difficulty was a moving target, students would be less motivated to study for a make up exam if they thought that there was a possibility that it may be more difficult than the original. On average, the student's response to question 3 indicated that the students perceived the make up quizzes and exams to be the same level of difficulty as the original ones. Although about 10% of the students did perceive the make up exams to be harder than the originals, it is felt that this percentage is low relative to the expected response from students. Specifically, in the instructors' experience, students' perception of dynamics problems that they have not seen before is that they are always more difficult than ones that they have seen. This is attributed to the fact that the simple laws of dynamics can be applied in a vast number of physical situations, and if students do not have a previous experience with a specific situation, they find the analysis difficult. It is by independently engaging in difficult problems without easy solutions in front of them, can students truly master the concepts in dynamics and be able to apply them in any physical situation. The fact that the students found that the make up questions were on average the same level of difficulty than the original one suggests that the students did have the opportunity to master the material before they wrote the makeup questions.

The response to question 5 indicated that the students in general felt more prepared for the make up midterm / quizzes than they did the original one. This result is expected as there was no motivation for the students to rewrite the exams if they did not feel more prepared for the make up exams. The students did not have to sign up to rewrite any of the exams and could make their decision to rewrite any exam up until the moment that the exam started. The fact that the results of this question do not suggest that all students strongly agree with statement that they felt more prepared for the make up exams (mean=3.78) may speak more towards the students general confidence level in the material in general, which is still in its infancy stages until their knowledge matures in subsequent courses.

The results of question 6 indicate that the students perceived that they learned more in the course because of the make up quizzes/midterm. This strongly suggests that the students perceive that they benefitted from the make up exams. This is evidenced also by the strong response to question 8 which indicated that the students strongly agree (mean=4.73) that they wish that they could have the same opportunities for making up exams in other courses.

Other evidence of impact that the make up exams had on the students were given in the section of the survey where students could add comments. Although only a small percentage of students provided comments, some common comments included:

- *Thank you for providing us with a chance to improve our marks*
- *The make-up quizzes made the course less stressful*
- *Doing well on the rewrite gives students motivation to keep working hard because they have a second chance to get a good grade*
- *The make-up exams helped me understand concepts that I previously did not.*
- *The instructors should allow students to rewrite all of the quizzes*
- *The weighting of the make-up midterm should be the better mark of the two.*

In short, these comments indicated that make up exams lowered student stress, were motivating, and positively impacted student understanding. On the implementation side, students wanted more make up opportunities and did not like the aforementioned 30/70 split in the midterm marking scheme.

5. Conclusions

With the intent to implement mastery learning techniques and improve student outcomes, two significant changes have been implemented in the Fall 2019 Engineering Dynamics class. Firstly, instead of dropping a student's lowest two marks on the quizzes as done in previous semesters, students were allowed to rewrite any one quiz before the midterm, and any one of the later quizzes before the final exam. Secondly, with constraints, students were permitted to rewrite the midterm two weeks after the original date. Care was taken to ensure that all retake exams were of the same difficulty level as the original exams and that there was consistency in the marking of the exams. It should be noted that the authors tried to provide motivation for the students to study for the first midterm and not use the retake as a procrastination tool by making the first midterm mandatory and count 30% towards the overall midterm grade regardless of the mark achieved on the retake exam.

One of the most common difficulties associated providing make up exams that prevents instructors from implementing them are the additional resources required to do so. Specifically, extra time is required of the instructors for developing the retakes, providing the marking rubrics and training the teaching assistants on marking. The extra teaching assistant hours are needed for invigilating, marking and entering the marks of the retake exams. In this course, the retake quizzes necessitated the development of 6 additional questions, and the retake midterm four. Given that two instructors were teaching these 405 students, this actually translates into each developing 5 additional exam problems. The associated effort is not that significant for seasoned professors who have a bank of exam problems from previous years. It was estimated that the additional teaching assistant hours were more significant. Specifically, to complete the additional work associated with the make up exams, 60 additional teaching assistant hours were required. This translates into 1 additional teaching assistant. The authors believe that given the improved outcomes, one additional teaching assistant can easily be justified.

The results obtained showed that approximately 75% of class took the opportunity to rewrite the quizzes and 25% of the class rewrote the midterm exam. This is expected as the midterm exam is a much larger commitment than any individual quiz. The results showed that student's outcomes improved on the retake quiz and on the midterm exam over the original sitting. . The positive impact of students retaking the midterm on overall outcomes was evidenced by the fact that the retake students scored very close to the class average on the final exam, whereas they were originally 14.5% (L01) and 12.7% (L02/L03) below the midterm class average. This is a significant result as the material covered in the final exam was significantly more difficult than the midterm material. The students achieved a 3% higher final exam average, and a 2% decrease in the overall failure rate (F and D grades) than the class of fall 2018 where retakes were not offered. This is a small positive result, but more data from previous and future class offerings may yield results that are more statistically significant.

The 5-point Likert survey results echo the positive impact that the retake exams had on the student outcomes. The results of the survey indicated that although some did, the majority of the students did not agree that they put less effort into the first exam, knowing that the retake was available. The survey also indicated that students perceived that the make up exams were of the same level of difficulty as the original exams. Although the authors are both extremely experienced in teaching and doing research in dynamics, the validation from the students that the difficulty level was constant was welcomed. In general, the students strongly agreed that they learned more from the course as a result of the make up exams and that they wished they had the same opportunities in other courses. Apart from suggestions with respect to implementation, student comments at the end of the survey indicated that make up exams lowered student stress, were motivating, and positively impacted the students understanding of dynamics.

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