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A Multi-Instructor Study of Assessment Techniques in Engineering Mechanics Courses

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1. Introduction

The authors have conducted a three-year study to explore the effects of a new assessment model on student outcomes in a sophomore level Mechanics of Materials course. Preliminary results from the first two years were discussed previously [1]. The most recent set of results and conclusions are presented here, along with further discussion and lessons learned regarding its implementation. A key component of the latest phase of the study is the transition of the control instructor to the new method. For this instructor this paper includes a control / method comparison of student outcomes and observations on adopting the new method.

Based on the results of numerous informal classroom experiments and hundreds of informal discussions with students, it was determined that most students do not use effective study strategies to fully understand key concepts and to master problem solving techniques. Instead, the goal of their current studying and test taking strategies is to "maximize partial credit." These strategies work as follows.

1. Memorize problems from the homework, in-class examples, or previous exams.
2. Match each problem on the exam to one of the memorized problems that most closely resembles it.
3. Write down the memorized solution, making adjustments along the way so that the solution looks more relevant to the exam problem.

Because many grading models are based on a poorly defined concept of "correct approach," the above method is often very effective at getting a passing grade or better. After all, if the memorized problems have similarities to the exam problems, it is difficult for a grader to determine whether or not a student understands the correct approach. When partial credit is then awarded too generously, this flawed study approach is reinforced, and students do not feel the need to solve problems completely or correctly. Note that open-book exams or allowing students to copy solved example problems on personal formula sheets only exacerbates this problem.

Despite being effective at "getting through" a class, this learning strategy has very little value in terms of creating knowledgeable and capable engineers. It is known that pre-test cramming of example problems into short-term memory promotes almost no retention of the information [2,3]. More importantly, according to studies by cognitive scientists [3-6] (quote below from [3], page 156):

> "Example learners tend to memorize the examples rather than the underlying principles. When they encounter an unfamiliar case, they lack a grasp of the rules needed to classify or solve it, so they generalize from the nearest example they can remember, even if it is not particularly relevant to the new case."

Engineering requires an ability to apply key concepts to a variety of problems that have not been seen before (or memorized). Therefore, the approach of maximizing partial credit based on memorizing a few problems is counter to the goals of an engineering education. Furthermore, it can be said that the current partial credit grading model rewards students for pretending that they know how to solve a problem, even when they don't. This means our grading model is promoting behavior that is explicitly unethical for professional engineers, according to the National Society of Professional Engineers (NSPE) Code of Ethics for Engineers [7] (paragraphs II.5.a and III.1.a).

A second practice affecting learning is the copying of homework solutions from online resources. Collaboration on homework has occurred at some level since graded homework was introduced, but the practice of purely copying homework without even thinking about its substance is now so widespread that many have concluded there is no value in assigning course credit for homework. Even online products with randomized parameter values for homework problems have been compromised by shared spreadsheets that allow students to obtain solutions by substituting new values of the parameters. Traditional graded homework is now a high-cost, low-value activity.

In some cases, a passing grade in a class can now be obtained through a combination of copying online solutions to obtain a nearly perfect homework score and maximizing partial credit on exams by memorizing a few example problems. These approaches do not contribute in a positive way to the desired student learning outcomes.

The flawed studying strategies described above are not necessarily new, but their increased magnitude and widespread usage are relatively recent. They are enabled in part by the internet and social media tools, but also by certain types of grading models and course structures. Based on discussions with colleagues at other institutions, these increasing trends are observable across universities and disciplines.

With these ideas in mind, a series of experiments were conducted to measure the effects of a different assessment style on learning. This assessment strategy was implemented in a sophomore level Mechanics of Materials course (i.e., ME 222: Mechanics of Deformable Solids, at Michigan State University). We do not claim that the style of assessment used in the current experiments is unique, but it is uncommon in today's classrooms.

The new assessment model was influenced by a desire to:

- offer very little incentive for using the ineffective memorization strategy described above, while promoting the use of proven learning methods to achieve deeper learning, and
- remove the reward for copying homework solutions, while emphasizing the importance of spaced and varied problem solving repetition (practice) in the mastery of solution processes.

The study results strongly support the hypothesis that assessment style can be used to influence study practices and to promote the desired student learning outcomes. In fact, it may be one of the few ways, if not the only way, to do this.

2. Overview of the Experiments

During the period of fall semester 2016 through fall semester 2018, the authors conducted a series of experiments involving multiple sections of a course in Mechanics of Materials. These experiments are summarized in Table 1.

For each academic year during the period fall semester 2016 through spring semester 2018, two sections of the course used a modified assessment approach (model), while the remaining section (the control) used an assessment approach that mirrors the current standard. Briefly, the standard course design used by Instructor X employed graded homework, two midterm exams, and the use of partial credit based on “correct approach” in the grading of every assignment, while Instructors Y and Z implemented the modified assessment approach. These experiments accounted for the effect of the instructor on the student performance under the new model. The two versions of the new assessment model are described in Section 3.

Table 1. Summary of the course models used in each section during the study. Instances of the new model are shaded, while the control set sections are not shaded. The number of students in each section is provided in parentheses.

	Fall Semester 2016 (FS16)	**Fall Semester 2017 (FS17)**	**Spring Semester 2018 (SS18)**	**Fall Semester 2018 (FS18)**
Instructor X	Standard model used as control (53 students)	Standard model used as control (107 students)	NA	Version 2 of new model (100 students)
Instructor Y	Version 1 of new model (40 students)	Version 2 of new model (86 students)	NA	Version 2 of new model (91 students)
Instructor Z	Version 1 of new model (60 students)	NA	Version 2 of new model (125 students)	NA

In fall semester 2018, Instructor X, who previously taught the control sections, adopted the new assessment approach, so that both sections of the course were taught using the same course structure and assessment method.

To measure the effects of the different assessment approaches used during the semester, a common final exam was administered across all sections during each of the semesters. This final exam was developed and graded by the team. It contained different questions each semester, but the exams were consistent with respect to structure, types of problems and level of difficulty. The final exams were not returned to students, so it was presumed that previous versions of the exam were not available to students.

3. New Assessment Strategy and Course Structure

The course design had three primary features: Mastering, Variation, and No Graded Homework.

Mastering

The primary feature of the course design was to move toward a mastery model of grading. In this model, students receive credit only for correct solutions or solutions with minor errors, as described in Table 2. This means that any conceptual mistake made in the solution process results in no credit. The purpose of this grading method is to only give students credit for understanding how to solve a new problem completely, thereby reducing the possible benefits of memorizing example problems.

Table 2. Rubric used to grade each problem on exams.

Competency	Level	Score	Description
Meets Minimum Competency	I	100%	Correct answer fully supported by a complete, rational and easy to follow solution process, including required diagrams and figures
	II	80%	Incorrect answer due to one or two minor errors but supported by a correct solution process as described in Level I
Does Not Meet Minimum Competency	III	0%	Incorrect answer due to conceptual error(s)

In Level II scores described in Table 2, there are two necessary conditions for classifying an error as minor:

1. The mistake is a minor algebraic error, computational error, error in units or significant digits, or other human mistake such as misreading a value in the problem statement.
2. If the identified error had not been made, the final solution would have been correct.

When either of these conditions is not true, the error is assumed to be conceptual and the work does not demonstrate minimum competency. It thus receives no credit.

Grading appeals. In order to reduce the grading effort and increase the benefits associated with the rubric in Table 2, the initial round of exam grading only gave credit to correct solutions (Level I). With complete solutions in hand, students were encouraged to rework exam problems to locate their mistakes. If these mistakes fell into the category described in Level II of Table 1, then a written appeal could be submitted to obtain the partial credit defined in the rubric. More details about the rubric and the grading scheme are described in [8,9].

Locating, classifying and correcting errors on exams can be a very important part of the learning process. This is referred to as *reflection* by cognitive scientists [2], and we prefer that students rather than graders glean this benefit. We hope that this process leads to higher accuracy and grades in the future, all while developing an engineering mindset for checking work and locating mistakes.

Early and Frequent Assessment. In this new course design the timing and frequency of assessment is important. It is recommended that students get two or three early assessments during the first five weeks of the semester. If the assessments are left until later in the semester, students will not be able to adjust their study habits in time to complete the course successfully. If the early assessments are too few, students may chalk one or two bad exams up to "a bad day" and not recognize the need to modify their approach. Three exams sends a clear message that what they are currently doing is not working (or that it is starting to work). Frequent assessment also gives students repetition and practice. It is helpful for identifying errors and misconceptions early. It allows the exams to be reasonable in difficulty level.

Multiple exam attempts. We assumed that students had many years of experience working within the paradigm of maximizing partial credit. It could be unreasonable, then, to insert these students into a course that requires mastery. Among other reasons, it is likely that they have not developed proper study habits or the skills necessary to review and correct their work during an examination. To account for this, multiple opportunities were provided on each of the midterm exams. For each of the midterm exams, the final score was the sum of the best scores in each section (described below) from any of the exam attempts. There was only one attempt on the final exam, which had a similar structure as the midterm exams.

In version 1 of the assessment model, three attempts (A, B and C) at each exam were offered. There were four midterm exams, so a total of twelve exams plus the final exam were offered during the semester. With three chances to take each exam, we found that many students did not prepare adequately for the first exam (A), so the effort to create the exam was too high relative to the learning or assessment benefits. Also, twelve exams amounted to an exam almost every week of the semester, which caused a high level of exam fatigue among the students.

In version 2 of the assessment model, only two attempts (A and B) at each exam were offered. The number of midterm exams was increased to five, so a total of ten exams plus the final exam were offered during the semester. The schedule was arranged so that an exam was given in two consecutive weeks, and no exam was given the following week. This repeating pattern of [exam week / exam week / no exam week] provided a mental and emotional break every three weeks, which seemed to alleviate the stress observed in version 1. In addition, two chances to take each exam seemed to be plenty. Against the advice of instructors, some students continued to use the first exam (A) as a practice exam, but this effort was felt to be helpful by both students and instructors.

Reasonable test difficulty and time. Instead of solving a small number of lengthy problems, as was common practice in previous versions of this course, in the current model the exam was divided into 4 sections.

> Section 1: Conceptual questions – Short questions that require little or no calculation but address a fundamental concept in the course.
> Section 2: Simple problems – Questions that require very little time to solve and involve only 1-2 computations. These problems may be very simple cases or address a specific step in the solution to a more complex problem.
> Section 3: Average problems – Medium length problems that contain no avoidable complications.
> Section 4: Challenge problem – One problem that requires a student to demonstrate a complete solution process, often with multiple steps, for a problem that is more complex than those in Section 3.

Additionally, exams were designed with a goal that most students could complete them in about 2/3 of the allotted time. The remaining 1/3 was intended for students to review and correct their work. The total exam time was 90 minutes. For the final exam, the time limit was 120 minutes.

Variation

Each exam was created from scratch by the instructors to ensure that a variety of problems were used. Each version (A, B, C) of an exam covered the same concepts and solution processes, but with a reasonably broad variation in the specific problems that were used in the assessment. The purpose of this variation was to decrease the value of memorizing problems.

As the benefits of problem memorization were removed, students needed to be directed toward a more effective approach to learning. To this end, we created “The Compass.” The Compass is a detailed, step-by-step, problem solving process for each type of problem in the course [10]. Throughout the semester, we trained our students to use the Compass to map out their solutions. This is a key part of the current course design, as it gives students a way forward that is productive and helpful.

No Graded Homework

Homework was assigned but not collected or graded. While we did not collect homework, we did strongly emphasize practice. The goal here was to promote meaningful practice, not copying homework solutions for the sake of a homework grade. Students were provided with a list of suggested practice problems, many with fully worked solutions that followed the Compass. These problems were not collected, but students were told that success in the course depended on them using the practice problems correctly to prepare for exams.

In many classes, students do not complete homework assignments that are not collected. This behavior was also observed early in the semesters during our study. However, most (not all) students quickly realized that they would be unable to solve exam problems at the required level without sufficient and purposeful practice. It even became common for some students to request more practice problems.

In some sections we conducted a mid-semester survey to determine what types of study approaches were being used. This survey was primarily for feedback purposes, so the data is not appropriate for publication. Anecdotally, a meaningful number of students described how initially they did not read the textbook or do the homework, and they were able to significantly improve their test scores by adding these activities.

We do not suggest that the details of the course design presented here are the ideal or only solutions to the observed student behaviors. Rather, we present them as an attempt to investigate what types of changes in course design might give rise to more beneficial student learning practices as well as improved overall performance.

4. Results

Data were evaluated using one-way ANOVA (analysis of variance) when comparing more than two groups, and using a Student’s t-test when comparing two groups. In this section data are presented only as median and mean $\pm$ standard deviation of the mean. Though the ANOVA indicated strong variations among some of the data sets, the details of these variations are not provided here in order to simplify the presentation. The authors felt that these variations, though mathematically significant, were not meaningful in terms of understanding the key effects being investigated.

Comparison of Student Groups Entering the Study

Student records were obtained and analyzed to determine if there were any significant differences among the students in each of the sections as they entered the course. In particular, we measured differences among incoming cumulative GPA's and the grades in the prerequisite course Statics (course code CE221 at Michigan State University). A summary of information for each of the three sections is provided in Figures 1 and 2 below. This data shows that, prior to each set of experiments, the variations in the incoming student populations among the various sections were not large enough to have a significant impact on the experimental results. The number of credits enrolled in by the students in each Section was also compared and showed no statistical difference (data not shown). The data provided in Figures 1 and 2 are based on a slightly smaller number of students than listed in Table 1 because this data was not available for all students.

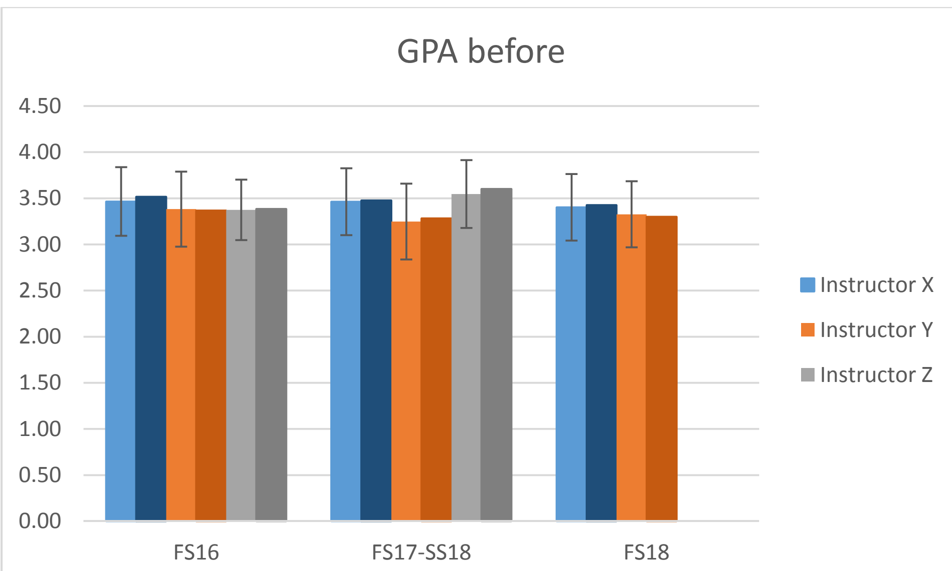

Figure 1. Cumulative GPA (on a 4-point scale) of the students attending ME222: Mechanics of Deformable Solids prior to entering the course. All data are presented as mean ± standard deviation of the mean (first bar in each set), and median (second bar in each set). Differences are found between Instructor X and Instructor Y (FS17), Instructor Z (SS18) and Instructor Y (FS17), and Instructor Z (SS18) and Instructor Y (FS18) ($p<0.05$).

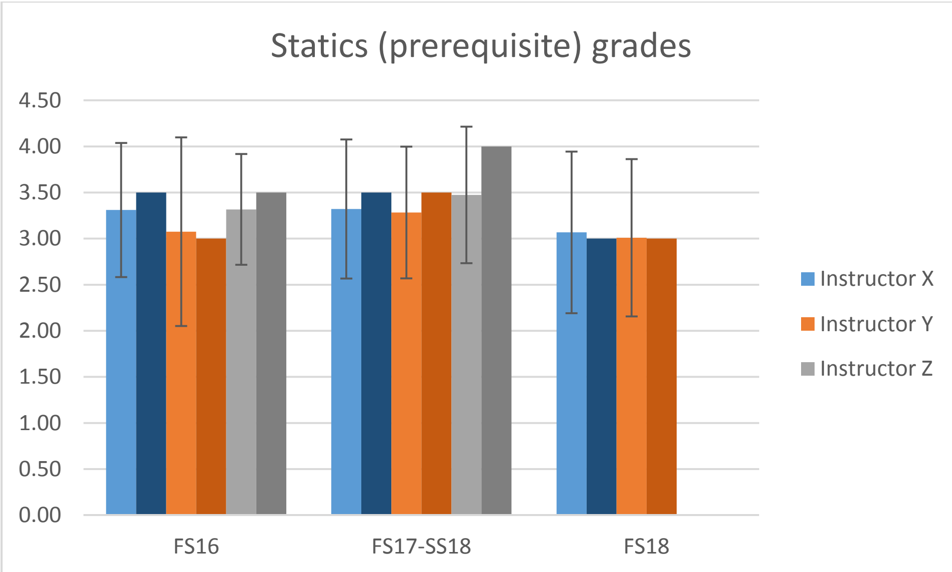

Figure 2. Grades in the prerequisite course CE221: Statics for the students attending ME222: Mechanics of Deformable Solids. All data are presented as mean ± standard deviation of the mean (first bar in each set), and median (second bar in each set). Differences are found between Instructor Z (SS18) and both Instructors X and Y (FS18) ($p<0.05$).

Final Exam Results

The common final exam was graded using the rubric in Table 2 for all sections, including the control sections. As described in Table 1, Instructor X taught the control sections during fall semester 2016 (FS16) and fall semester 2017 (FS17). Figure 3 shows the scores achieved in the final exam for each section of the course ME222: Mechanics of Deformable Solids.

During FS16 and FS17-SS18, the mean and median values of the grades achieved in the final exam by the students attending the control section (Instructor X) were significantly lower than those who attended the sections using the new assessment model (Instructors Y and Z). No statistical difference was found between the scores of Instructors Y and Z. Compared to the control section, the final exam mean scores in the sections using the modified assessment approach were approximately 15 to 30 points higher (out of 100), while the final exam median scores were 21 to 31 points higher. Under commonly used grading levels, this is a difference of 1.5 to 3 letter grades. These results suggest a high impact of the modified course model and grading technique presented here. Further, the data show that equal benefits were obtained for two different instructors.

Control instructor's implementation. During FS18, Instructor X adopted the new assessment model, so that both (all) sections of the course used the new model during this semester. The adoption proved to be very successful, with the mean and median scores in the section taught by Instructor X being statistically equivalent to those of Instructor Y during that semester. Considering only the results of Instructor X during the three semesters, the new assessment model resulted in a final exam mean score increase of 19 to 25 points (out of 100), while the median scores increased 21 to 25 points. This is a difference of 2 to 2.5 letter grades.

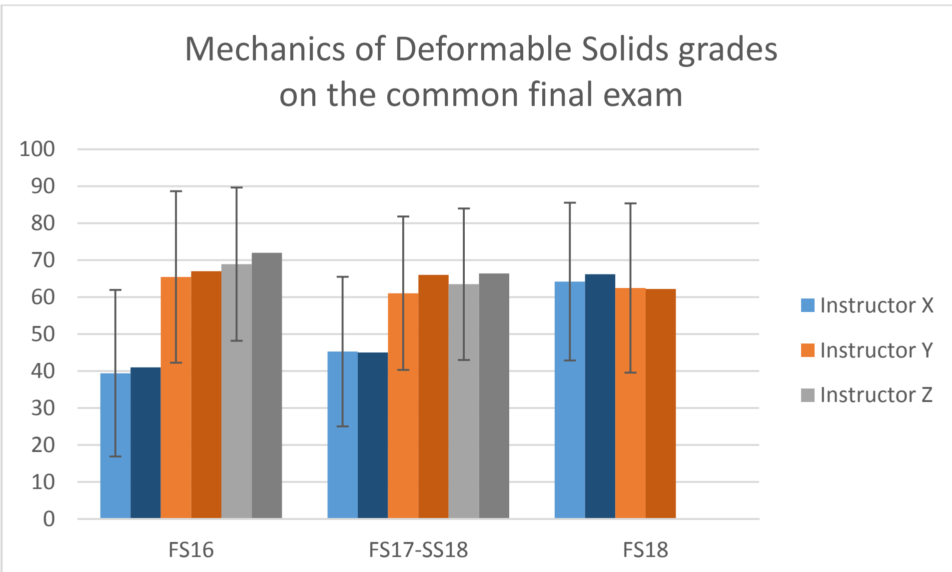

Figure 3. Grades for the final exam of the course ME222: Mechanics of Deformable Solids. All data are presented as mean ± standard deviation of the mean (first bar in each set), and median (second bar in each set). Differences found between Instructor X (FS16 and FS17) with respect to every other class, namely Instructor Y (FS16, FS17, FS18), Instructor Z (FS16, SS18), and Instructor X (FS18) (p<0.05).

The curving of final grades is inconsistent with the current assessment model, though it is not unreasonable for this more rigorous assessment model to be paired with a pre-determined modified grading scale. Curving grades has the unintended consequence of obscuring a student's standing in the course throughout the semester. More importantly, students who expect a curve to raise their grade are less motivated to use effective study methods or to exert the required effort to learn new concepts and solution approaches.

Nonetheless, the students in our study did not have the benefits of taking previous courses that use a "defined partial credit model" of assessment as in Table 2. As a result, their knowledge of prerequisite material was lower than expected and their initial study approaches were generally not very useful. So in addition to learning the course material in the current course, it was necessary for students in the study to significantly improve their prerequisite knowledge and to adjust to new learning strategies. We observed substantial improvements in both of these throughout the semester.

If the current model were used in all courses, the expectation is that these deficiencies would be minimized and the study strategy adjustments would be unnecessary. Based on these justifications, a very small curve (about 5%) was applied uniformly to the final course scores before assigning final grades. We believe this curve will become unnecessary if students are exposed to this assessment model in prior courses.

5. Keys to Implementation

Based on surveys and direct interactions with students, as well as the results described above, the following principles are believed to be key to the success of the proposed assessment model.

Holistic Approach. When making significant changes to a course design, it is important to take a holistic approach. As the above modified course design was developed, we tried to anticipate issues that might result from any particular change and address them in a way that gave students the best chance of success in the new system.

Our experiences confirm that implementing a stricter partial credit structure by itself would send a shock wave through the system that would certainly cause other problems to flare. This is inadvisable. The various pieces of our implementation worked together to alleviate many of these issues.

Changing the mindset. This principle applies in several distinct ways. First, because the “correct approach partial credit model” is used so widely, the “defined partial credit model” presented in Table 2 is difficult for students to understand. Many students have never been required to completely solve a problem in order to get a good grade. As a result, many of them have never worked to obtain the level of knowledge and skill necessary to solve problems other than trivial ones. Despite attempts to clearly explain the grading approach in lecture and in the syllabus, it generally takes a few low scores on exams and subsequent discussions with the instructor for many students to realize what is expected under the new rubric.

When this realization begins to take shape, the second part of the mindset change must begin. In the “correct approach partial credit model,” students receive very little penalty for making conceptual errors and almost no penalty for computational and other simple mistakes. This grading culture has established an attitude among many students that solving a problem completely is unnecessary, and getting the right answer is too much to expect, even for simple problems. The result of this attitude is that many students do not take a careful or methodical approach to problem solving, and there is little attention given to checking work for errors. In short, these students are not developing an engineering mindset to problem solving. The only way to establish this mindset is to enforce it within the assessment model, an example of which is described in the previous sections. This must be reinforced, however, with occasional classroom discussions and frequent problem solving sessions that illustrate proper solution techniques and strategies for checking work.

Perhaps the most unfortunate consequence of the “correct approach partial credit model” is that some students believe they are not capable of solving problems correctly. This is not the intended interpretation, of course, but it is a common one. For this reason, students need frequent doses of encouragement along with step by step instructions.

Generally speaking, the student attitudes and behaviors described in this paper are not due to laziness or lack of ability. Students today are capable and willing to work hard. If their grades are any indication, they are doing what is expected of them. If we wish for them to reach a higher level of performance, then we need only to raise the expectations and provide the necessary support for them to reach those expectations.

Compass. If we expect students to solve problems correctly, then we must teach them a clear process for doing so. For each type of problem, we provide a problem solving process called a Compass [10]. Students are encouraged to follow this approach when solving practice problems, and all problems solved in class or provided as examples follow this approach consistently.

A Compass is a written guide, or a set of suggested steps, for solving a certain class of problems. It is not usually a detailed process because the nature of each problem is unique and requires some creativity in the application of the relevant concepts. Enough detail is provided so that students know the order of the steps to take in solving a problem. Key assumptions may also be provided.

Here is an example Compass for drawing a FBD of a beam, truss or frame structure:

1. Create a *new* drawing of the structure, representing each member as a line.
2. Represent internal connections as either pinned or welded.
3. Define a global coordinate system (GCS) that is convenient for the current problem.
4. Replace all boundary icon symbols with the reaction forces and moments that these boundary supports impose on the structure.
5. Draw all external loads.
6. Include all key dimensions, including units.
7. Label all points corresponding to boundaries, joints, load discontinuities and key sections.

The word Compass is appropriate here, because its role is to suggest what direction to go next rather than which detailed steps to take. The details of each step may depend on the particular problem, and these are left to the problem solver to determine, though a Compass may recommend a few options.

Rather than limiting creativity, a Compass facilitates it by reducing the mental load associated with developing an overall solution process. With practice, the solution steps in a Compass become habitual. This consistency frees the mind to focus on the unique aspects of a problem that do require some creativity of thought, or to concentrate on performing accurate computations.

A Compass eliminates many common questions such as, “Where do I start?” or “I’m stuck, what do I do next?” Further, by emphasizing the order and the role of each step in the solution process, it discourages the skipping of steps, a common reason many students get stuck when trying to solve problems.

It should be noted that using the Compass is a pedagogical choice to teach process before, or along with, teaching intuition. Intuition is developed through experience, and should not be confused with guesswork. There may be a concern that students might become overly dependent on a Compass. In the beginning, this is considered to be an acceptable result because we do want to mold behavior and build healthy problem solving habits. But in the long run, observations of student behavior suggest that a Compass is like training wheels on a bicycle. They enable you to ride without falling when you first get started, but you shed them quickly when you gain confidence in your own abilities, along with greater intuition.

The Compass is one of the so-called Seven C’s of problem solving that are described in [11]. Introducing students to these components of problem solving provides a framework for learning and a way to categorize skills. This also helps learners to better appreciate the broad set of skills and knowledge needed to be a good engineer.

How to Study. When it becomes clear to students that previous study approaches are ineffective, they begin to seek new study strategies that are more productive. Fortunately, the work of cognitive scientists has converged toward a reasonably complete model of how learning happens [2,3]. Some students, especially those who are experiencing failure for the first time, are quite accepting of study advice based on science instead of that from peers. We have found it helpful to spend a few minutes at the beginning of the semester and again about mid-semester discussing study strategies that work.

Exam Problems. Considering the amount of information available on the internet and how easy it is to add new content, it is essential to spend the time and effort to develop new examination questions for each and every exam during the semester and from semester to semester. Questions should not be difficult or tricky in any way, but they should test a student’s ability to apply a robust solution process and correctly use key concepts in a way that does not benefit from memorizing the solution to other problems. Variations in exam problems encourage proper study habits, and problems at the proper level of difficulty help to increase students’ confidence while making the grade meaningful. We noticed an occasional tendency, on our part, to increase the level of difficulty in exam problems. This creep toward more challenging problems should be monitored carefully.

Frequency of Exams. As noted previously, the frequency and volume of exams is a key principle in the current approach, especially early in the semester. Early and frequent feedback is crucial for students to make the necessary changes in mindset and study strategies to be successful under the current rubric. In addition, in the current model exams serve as intense forced practice sessions. During exams, students sit uninterrupted for up to 90 minutes once a week to work on course problems. The repetition and spacing of these sessions likely plays a large role in improved learning due to increased levels of retrieval practice [2,3,12,13].

Early Exams. It is recommended that students experience two or three early assessments (during the first 5 weeks of the semester). If the assessments are too late, students will not be able to adjust their study habits in time to complete the course successfully.

These early exams are an excellent opportunity to test pre-requisite knowledge. This serves two purposes. First, students see how they are graded on material that they should already know. This distances the instruction from the grading technique, and students see that the standard is higher than they have previously experienced. Secondly, the instructor can identify any shortcomings and take steps to correct them before they are compounded by new material.

Lectures. The greater amount of class time devoted to testing means that lecture time is typically reduced under the new model. In our studies described above, this made it necessary to focus on the most important topics and example problems in class, and to assign readings and additional practice problems for out of class work. It is notable that the measured improvements in performance occurred despite the significant reduction in lecture time compared to the control group.

To create additional lecture time as well as a common exam time for multiple sections of the course, a new course model is currently being implemented. Instead of two 80-minute or three 50-minute lecture times per week, with one of these often used for examinations, we are moving toward a model of two 50-minute lecture sessions per week plus one common 110-minute laboratory time per week. The laboratory time will be used for examinations during most weeks, and for extended problem solving sessions or other active learning during the weeks with no exam. The common exam times in this course model also reduce the total amount of time that instructors must spend developing new exams (by a factor of two if there are two course sections).

Implementation by early career faculty members (comments by Dr. Roccabianca). The successful implementation of the new assessment model requires some significant adjustments not only by the students, as discussed above, but also by the instructor. For example, crafting a new exam during most weeks requires the instructor to invest a significant amount of time and energy throughout the semester. Secondly, the significant reduction of lecture time means the instructor must restructure much of the class material that may have been prepared in previous years, another investment of time and energy. These "energy bumps" become less severe as the semester progresses and especially in subsequent years, but the additional upfront effort could discourage some young faculty from implementing the new model. These concerns are partially, though not completely, alleviated by the new course structure proposed in the previous paragraph.

Some tips for ease of implementation:

1. Plan ahead. The number one tip is to strategize and prepare in advance as much as possible. From choosing the software one feels more comfortable with to design the exams with, to having handouts prepared in advance (during previous semester or over the summer), to having the schedule of the teaching modules and the syllabus ironed out ahead of time. Anything that can be achieved before the semester starts will be of great help.
2. Mentoring. It is very important to have a good mentoring structure that will be able to support you and help you throughout the implementation. Specifically, having the guidance of a senior colleague was of great importance and I often relied on this support throughout my first implementation.
3. Departmental support. As mentioned before, students are initially shocked by the mastery model of grading. They have not likely experienced that before, therefore they feel they will not be able to achieve the level of expertise required and this insecurity leads them to think this grading model is "unreasonable". As the data showed, most of the students are absolutely capable of achieving great results, and a lot of them eventually feel absolutely empowered by the new model. However, the initial weeks could be tough on them and this might lead to increased complaining and might be reflected in course evaluations at the end of the semester. For these reasons, to have Departmental, and possibly College, support while navigating the first implementation is key to the success of the methodology.

With respect to the student course evaluations, my average score decreased only slightly throughout the three years of this study (i.e., FS16 3.67 ± 0.56, FS17 3.47 ± 0.65, FS18 3.26 ± 0.89, on a 4 point scale). However, the scores remained within departmental average each year and remained within the standard deviation range of the first year.

6. Conclusions

The results of this study strongly support the hypothesis that students will adapt their study habits to changing assessment strategies. Compared to students in a control group that used conventional assessment methods (i.e., partial credit on exams based on "correct approach"), students in sections that used a defined partial credit assessment model scored approximately 1.5 to 3 letter grades higher on a common final exam. This was repeated in multiple semesters with multiple instructors. These results suggest that establishing higher performance standards in conjunction with increasing practice using a compass-guided solution process can lead to significantly higher student performance on exams.

7. References

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