# A New Assessment Model, Modified for Use in Dynamics

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## Abstract

This study builds on the development and implementation of a new assessment model called SMART. SMART was originally developed and studied in a Mechanics of Materials course at Michigan State University. The SMART method's new approach has been demonstrated to have very positive effects on learning in Mechanics of Materials, including an increase in final exam mean scores of approximately 30 points (out of 100) compared to a more traditional assessment model. These results were measured by a common final exam.

The second course to adopt the SMART assessment model is Introduction to Dynamics. This paper outlines the modifications to the assessment model and the course structure as well as student outcomes in this course. On a common, representative final exam problem, 68.5% of students in the SMART Assessment model met a rigorous level of minimum competency, while only 27.1% of students in the traditional model met minimum competency.

The goal of this paper is to discuss modifications to the SMART approach necessary to adopt the method in Introduction to Dynamics and provide initial evidence that the SMART approach improves student outcomes.

## Background

Teaching is challenging and consistently changing. Even after a professor has perfected their delivery and content, students with different study habits and backgrounds may require modifications to a faculty member's approach. Sometimes the observations about students leads to more effective delivery of content, like the move to active learning [1]. Sometimes observations lead to motivating a new generation of engineers, like the push for more rich examples and contextualizing [2,3]. Sometimes observations lead to the realization that what has worked in teaching for decades is no longer effective- not because the teaching has changed, but because the students have changed [4]. Students may approach the material, studying, and/or classes differently.

Engineering students are hard workers and have the potential to be great problem solvers. It appears from observations and discussions with students [5] that they have solved how to successfully navigate our current educational system. Not in a way that helps them learn, but in a way that helps them get the grades they want with the least amount of effort. Unfortunately, the solution they've developed is focused on methods that cognitive science says are ineffective [6,7]. More than ever, students are leveraging online solutions to complete homework assignments with only superficial thought about the concepts or the solution process. This means that they are improperly prepared for exams. However, through a combination of memorization and reliance on partial credit, these students are not only passing classes, they are getting good grades without learning or developing the necessary problem solving skills.

Grades are vitally important in education. Grades are the way professors tell students whether they have learned the material at a reasonable level. Grades are the single most motivating factor for students, especially when time seems short and pressure feels high. If students aren't learning at levels required for competency and professional success, then professors have a responsibility to assign commensurate grades. Not just because they haven't reached the bar, but because it tells the students where the bar is. And when engineering students see the bar, they can and will rise to the occasion and meet the expectations.

Several years ago, a faculty member at our University began to recognize these student changes. After interviewing students, looking at student data, and trying to understand the trends, they developed a method of assessment called SMART Assessment. SMART is short for Supported Mastery Assessment using Repeated Testing. This method uses aspects of mastery learning, frequent assessment through repeated testing, and a supportive problem solving framework, or Compass [8]. The method draws on cognitive science to create a set of best practices for student learning and builds a framework for grading based on motivating students to develop these practices as their study habits.

The method was developed and tested over a 3.5-year period in a Mechanics of Materials course. The results were very promising, with student improvements of at least one standard deviation when compared to their peers in traditional courses. The goal of this paper is to demonstrate that the method can be applied to more than just the original course. For this study the authors have adopted and implemented the SMART method for a different course, Introduction to Dynamics. While the course is still part of the engineering mechanics curriculum, it has several important features that make it worthwhile to demonstrate the versatility of the SMART method.

Before discussing what has been adapted, a summary of the SMART method is necessary.

**SMART Assessment**

The SMART method utilizes a synergistic set of "best practices" to challenge, inform, and support the learner.

*Mastering and Variation*

The primary component of mastery learning is correctness. In SMART learning, we define mastery of the material at two levels. Level 1 mastery requires a fully correct answer and a correct process that supports that answer. Level 2 mastery is mastery of concept, but with a minor error in execution. Mastery changes the grading paradigm by setting a clearly defined expectation for student capabilities. Mastery, as practiced in the SMART method, is defined not as perfection, but as competency, which means free from conceptual errors. Students who reach the correct answer or make non-conceptual errors are awarded a significant amount of credit. Table 1 shows a rubric used in the SMART method [5].

Mastery in teaching is not new [9,10]; it has been used effectively in Engineering schools across the country. The point of incorporating mastery in the SMART method is it moves grading away from a loosely-defined partial credit model that can be tricked by memorization to one that requires clear competency of the material.

**Table 1. 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) |

Because no points are awarded for answers that are "conceptually wrong", students do not receive credit for memorizing and writing out the solution to a similar problem they have solved. Points are only given for correct answers with correct support (Level 1) or for answers that have a minor error (Level 2). For an error to be considered minor it must be 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. Additionally, the solution process must be correct, meaning that in the absence of the minor error, the student would have arrived at the correct answer. If these conditions aren't true, then the error is considered conceptual and the student receives no points.

The SMART rubric sets the bar for student success where it should be, at competency. Of course, this also means that the level of difficulty in the test problems must be appropriate. The expectation is that students who meet minimum competency in terms of understanding and applying key concepts can solve these problems completely and correctly.

The variation aspect of SMART is designed to further push students away from memorizing. Each exam is created from scratch (until a large enough problem pool is built) so the students see a wide variety of problems. This means that students need to develop a process for solving rather than relying on memorization.

So the bar is set high. Now the student needs to realize that they actually need to change their study habits to reach the bar.

### *Early, Frequent Assessment and Grading Appeals.*

The next components of the SMART model are designed to help the students identify that

1) their current study method isn't working (or maybe that it is),
2) they don't know the material as well as they thought, and
3) they can arrive at the correct answer with proper practice.

The first step in this is early exams. Often exams are given 4-5 weeks into a semester and by that time the student has little time to change their study habits. Additionally, students commonly believe that a single bad exam was due to a bad day, not a lack of competence.

In the SMART method the student takes 1-2 exams within the first 3 weeks of the semester. These are often exams on mostly review material, and most students believe that they know this material. After struggling through two exams graded with the SMART rubric over material they "know", students are often willing to consider instruction on best practices to learning and often change their approach to studying for the class. Continued frequent exams let the student know if the changes to their study habits are working or not. Since they are guided in 'best practices', the later exams often show a marked improvement, reinforcing the value of structured practice and learning.

The second step is grading appeals. Rather than providing a detailed breakdown of a student's errors, minimal marking is used. Students are graded on the 0% or 100% scale. They must review their work (with the help of detailed solutions), identify their errors, identify the type of error (conceptual or minor), and in the case of minor errors, rework the problem to obtain the 80% credit on the rubric. This structured reflection allows students to learn to assess their own work. It forces them to observe their errors and make changes. It also encourages them as they realize they CAN solve engineering problems.

These two pieces, early and frequent exams and appeals are key to informing students that their old method of studying is not actually effective and helping them make changes before it is too late. The next step is to guide them in making those changes.

### *The Compass, Multiple attempts, and reasonable exams.*

Once students understand that the expectation is correct problem solving, which requires varied and repeated practice instead of memorization, they need support and guidance in how to implement better strategies.

To this end the SMART method utilizes a "Compass" [8]. The Compass is a guided problem solving process. It is posted for students in mechanics of materials on the first day of class. In mechanics of materials most problems can be solved by following a single Compass that describes the steps to find the principal stress state at a point in a structure. A few additional topics require separate problem solving tips, but after using the Compass for much of the class, students are often able to build their own procedure for solving related problems.

The Compass is one of the hardest pieces of the SMART method to transfer because it is topic specific. It requires the professor to think critically about the types of problems they are solving and to build a systematic approach that solves the majority of those problems that has clear reasoning for "special cases". Most importantly, the professor needs to follow the Compass consistently when teaching and providing solutions. Only after students have become competent problem solvers using a robust method can the professor build on the intuition that the students have developed from using the Compass.

Besides learning support, students need to know that they have a reasonable chance of getting the problems correct. They need a grading model that encourages and rewards proper studying. To this end the SMART model gives students two attempts at each exam. The exams have completely different problems, but have a consistent structure and cover similar material. The second attempt allows students to learn from mistakes identified by the first exam without that first exam crushing their grade.

Finally, exams must be reasonable in difficulty and time. In the traditional partial credit model, the problem of excessively difficult or long exams was solved by more 'generous' partial credit. In the SMART model, this is not an option. Exams must have a reasonable selection of problems. Most of the exam, say 80%, should be problems that a C student is expected to solve. Only 20% of the exam should be intended to challenge A and B students. Exams must be tested to be sure they are not excessively long. Since students are required to get correct answers, they must have time to check their work. The exam should be designed to take up no more than 80% of the time allotted for a typical B student.

Additionally, exams should be written with 'reality' in mind. One goal of the problem solving process is to help students develop intuition. If exams have 'unrealistic' values, then students cannot do a sanity check on their answers to find mistakes, and they will not develop a meaningful engineering intuition.

## Modifications to the SMART Model for Dynamics

Any modification to the SMART model should be done carefully and with an understanding of the synergies involved. It is important to implement the SMART approach in a holistic manner consistent with its key principles, though some details of the implementation may necessarily vary from course to course. In the case of application to Dynamics, the goal was to change as little as possible. The rubric, exam schedule, appeals process, and exam structure all remained unchanged.

It should be mentioned that the current course structure for dynamics at MSU necessitated that exams be given during class periods. This means that exams are 50-minutes long. In this version of the course a total of 10 class periods out of 40 were reserved for examinations. This means that in-class instruction is reduced by 20% over a traditional course. To achieve this, the lecture material was modified to be more efficient and worked example problems were provided to students outside of class. Additionally, a strong focus was given to the development of free body diagrams. Thus, free body diagrams were considered an integral component to obtaining a conceptual understanding of the problem. Although, in theory, students should have learned how to develop a free body diagram in statics, this was not true.

The biggest challenges were writing reasonable exams that covered the material in non-trivial ways. Early exams required a lot of solving and editing by the professor to achieve a reasonable level. However, it was found that the multiple exam attempts allowed a large variation in topics. Rather than two exams and a final, students took nine exams and a final, so the breadth of questions they saw was much greater.

As mentioned previously, the Compass is one of the hardest parts of the SMART method to transfer. Building a Compass for dynamics was not trivial, but there are a many resources. A conversation with another faculty member was helpful in reorganizing the content of dynamics to be Newton first (i.e., F=ma). Better stated, kinetics followed by kinematics. While the opposite approach is used in many dynamics books, it allows the Free Body Kinetic Diagram to motivate the kinematics. The Free Body Kinetic Diagram and equilibrium become the backbone of the Dynamics Compass and drive the problem solving process.

Dynamics is also challenging because it has multiple solution methods. In addition to Newton, Work-Energy and Impulse-Momentum are also used and students struggle with which method to apply. The Compass needs to give them insight on how these methods link to Newton's approach and give guidance on how to choose one method over another. In this implementation of the SMART method, the instructor used the Free Body Diagram as the fundamental unifier of the methods and created a process for problem solving in each of the three cases: Newton, Work-Energy, and Impulse Momentum.

A third challenge with translating the Compass to Dynamics was the possibility of different motions. In Mechanics of Materials, the beams are fixed and there is a single load case to analyze. In Dynamics, the Compass had to have a clear process for assuming a type of motion (e.g., slip or tip), a step for checking the assumption, and then a contingency step if the assumption failed.

A final change made between the SMART implementation in Mechanics of Materials vs. Dynamics was homework. In Mechanics of Materials, homework was assigned, but not collected or graded. In Dynamics, a regular homework schedule was maintained. Homework was graded based on process (not correctness) and contributed to the final grade, but at a much lower level than previously.

**The Study**

In the Fall 2019 semester, two instructors taught separate sections of Dynamics. Both instructors have taught dynamics on a regular basis for more than 5 years. The instructor of section B initially used the SMART method in dynamics in the fall of 2018 and had used the SMART method in Mechanics of Materials.

Section A was taught by traditional methods. There were two midterm exams (50 minutes each) and one final (120 minutes). Quizzes occurred during weeks without exams. Homework was collected weekly, graded, and returned. Exams were graded based on standard partial credit practices.

Section B was taught using the SMART method. There were nine exams (50 minutes each) offered during the semester and a two-hour final exam. Homework problems were regularly assigned, and feedback was given on the students' process rather than answers.

Section A and Section B had different final exam times. The instructors decided to offer an identical problem on each their final exams and compare the results. This study looks specifically at a rigid-body problem solved by Newtonian mechanics.

**Student Outcomes**

A single problem was compared between the two sections. It is a rigid-body problem where the system is in pure rotation. The problem had two primary aspects:

1) A Free body kinetic diagram (FBKD).
2) Equilibrium
   a. $\sum F_x = ma_x$
   b. $\sum F_y = ma_y$
   c. $\sum M_{@G} = \bar{I}\alpha$

Additionally, the problem required students to

3) Use relevant kinetic friction laws.
4) Identify two-force members.

In both classes the exam was graded using their normal methods. Section A was re-graded using the Mastery rubric so the results could be compared. Students were grouped into four main categories.

a) Incorrect FBKD.
b) Correct FBKD but incorrect equilibrium equations.
c) Correct FBKD and correct equilibrium equations, but wrong answer due to minor errors.
d) Correct FBKD and correct equilibrium leading to a correct answer.

Note that levels a) and b) do NOT meet minimum competency, while levels c) and d) DO meet minimum competency in terms of the SMART evaluation approach.

In terms of grading, in the mastering rubric the categories were scored 0, 5, 25, 30 out of 30, respectively. In the traditional partial credit approach, scores had a relatively wide range. Students in category a) could receive 90% if they missed a single force and did everything else correctly. Only students in categories c) could score as high as 95% and d) students were awarded 100%.

Table 2 shows student performance for the two sections. In section A (traditional approach), only 48.2% of the students were able to correctly draw the FBKD and 27.1% demonstrated full problem competency (categories c and d). In Section B (SMART approach), 95.5% of students correctly drew the FBKD and 68.5% of students were able to demonstrate full problem competency.

Students in the two sections were not identical, Section A had 6 students who were repeating the course. Section B had only 1 repeat student. Students entering the two sections had close, but not identical GPAs. Section A's students had scores in Statics that were 1/3 of a standard deviation below those in Section B. Section A's students had scores in Mechanics of Materials that were also 1/3 of a standard deviation below those in section B. Grades in Mechanics of materials are for students who took the course, before or during the semester they took Dynamics. All but 6 students in Section A had a grade for mechanics of materials, all but 2 for

section B.  A comparison of incoming GPA and scores in Statics and Mechanics of materials is shown in Table 3.

**Table 2** – Section competencies on a Newtonian Mechanics problem.

|  | Section A (Traditional) | | Section B (SMART) | |
|---|---|---|---|---|
| **Grading category** | # students | % students | # students | % students |
| a) Incorrect FBD | 44 | 51.8% | 4 | 4.5% |
| b) FBD | 18 | 21.2% | 24 | 27.0% |
| c) FBD + Equil. | 10 | 11.8% | 38 | 42.7% |
| d) FBD + Equil. + Correct | 13 | 15.3% | 23 | 25.8% |
|  |  |  |  |  |
| Total | 85 | 100% | 89 | 100% |
|  |  |  |  |  |
| **Meets Minimum Competency [(c)+(d)]** | **23** | **27.1%** | **61** | **68.5%** |

**Table 3** – Student preparedness indicators.  This table shows the average grade (standard deviation of grade) for incoming cumulative GPA, Statics course grade, and Mechanics of Materials grade.  All numbers are on a 4.0 scale.

|  | GPA | Statics | Mechanics of Materials |
|---|---|---|---|
| Section A Traditional | 3.4166 (0.3601) | 3.0618 (0.8077) | 2.7000 (1.108) |
| Section B SMART | 3.4996 (0.2995) | 3.3222 (0.7469) | 2.9833 (0.8851) |

**Conclusions**

Previous work on the SMART method in a Mechanics of Materials course demonstrated an increase in final exam mean scores of approximately 30 points (out of 100) compared to a more traditional assessment model.

In the current paper, adjustments necessary to use the SMART method in Introduction to Dynamics are discussed.  Data on student problem solving during the final exam (compared to a control section) indicate that these modifications resulted in a significant improvement of student learning outcomes, in spite of a 20% reduction in overall in class instruction time.

A key limitation of this study was the inability to give a common final exam.  This limits the current study to the comparison of a single problem.   Additionally, incoming student indicators (GPA and prerequisite grades) could not be properly controlled for since they were anonymized.  Additionally, this study contains small numbers and is by no means identified as a complete research study on this approach.  However, this work does show the potential benefits of

refocusing the grading approach away from traditional partial credit to one with a well-defined rubric. Further work, with a larger number of students, instructors and the same graders across all sections will permit a more complete analysis, including a statistical evaluation.

While the comparative data for Dynamics is more restricted than the Mechanics of Materials data (comparative key question vs full final exam), the results do show a greater than 40% difference in minimum competency scores (on a 100% scale). This is a significant result and warrants further study.

One benefit of the SMART method being used in Mechanics of Materials was that many students had some familiarity with the teaching approach. Some because they took Mechanics of Materials with the SMART method and some because their friends had taken the course using that model. Some students in both Dynamics sections were also concurrently enrolled in the SMART implementation of Mechanics of Materials. The benefit was that student buy-in was much easier to achieve than when the SMART method was first introduced at Michigan State University.

The success of the SMART method in Mechanics of Materials and now Dynamics has resulted in significant faculty interest. The method is now being adopted by the faculty teaching fluid mechanics, with notable early success. The method was initially used by two instructors at Michigan State and as of Spring semester 2020, 4 more instructors have adopted the method for teaching their courses. However, the increased number of exams with the SMART approach could provide significant stress on students if they are taking several classes that are taught with the approach. By developing more useful study habits early in their curriculum while taking core courses, it is hoped that these habits would stick and prove beneficial throughout their undergraduate career.

This paper provides other new instructors with a summary of the basic premise of the SMART method and an example of modifications that allowed it to be successfully adopted in a new course.

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