



Challenge-based Instruction for a Civil Engineering Dynamics Course

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Introduction

This study evaluated the potential of challenge-based instruction for enriching a second year dynamics course. Problem based approaches to instruction are becoming more popular, but many of the models can be difficult to design and implement. The challenge-based approach used in this study enriched an existing active learning classroom setting with challenges designed to increase student comprehension and learning. The delivery of the course, offered primarily for civil engineers, initially followed a traditional lecture and homework model of instruction which equipped students to solve well-defined problems typically found in most textbooks. Students, equipped with prior experiences from calculus based physics courses, were trained to solve fundamental problems in kinetics and kinematics for both particles and two-dimensional rigid bodies. The course leveraged interactive classroom experiences (i.e. group problem solving and physical demonstrations) to support students' comprehension of the fundamental principles governing dynamic systems. A concern of the current implementation of the course was the loss of an opportunity to advance students transfer of knowledge to solve more complex engineering problems. This shortcoming, as noticed by the instructor, was exacerbated by the disconnection between the students' area of study (Civil Engineering) and the primary context of most textbook problems (Mechanical Engineering). Problem-based learning, as evident in prior research^[1,2,3], illustrates many methods for achieving these goals while still equipping students to solve well-defined analytical problems. Even specific to civil engineering, research has shown the benefits of engaging students in discipline specific problem solving contexts and suggests that students need more experiences in solving authentic challenges related to their discipline^[4]. Therefore, the implementation of the course was enriched by sequencing instruction around a series of challenge-based learning experiences following a proven learning cycle. This paper provides results from an initial study evaluating the prior implementation relative to the enhanced version of the course. The primary focus is to determine the impact of using small challenge projects to increase the effectiveness of learning and instruction with second year civil engineering students.

Background

Challenge-based instruction engages learners in complex problem spaces that require the coordination of multiple concepts to define an effective solution^[1,2,4,5]. That is, a challenge illustrates the context and conditions when knowledge is used. The central learning theory focuses on learners' ability to identify these conditions and transform what they know into information they can use in the current contexts. Challenge-based instruction serves as a mechanism for students to develop these skills and abilities by framing classroom instruction around a challenge or set of challenges. A challenge problem, introduced at the beginning of a course or topic, provides an introduction to the major concepts that will be presented as a part of

formal learning. The major concepts are then presented in a classroom setting with the challenge(s) serving as a focal point. Students are then required to identify the fundamental mechanics that are required to solve the challenge as the course progresses. This process engages students in high level problem solving tasks of design, trouble shooting and systems analysis which they will do during their profession.

Challenge-based instruction has been used successfully in multiple engineering contexts including bioengineering^[2], civil engineering^[6] and first year engineering to name a few.

Common to each of these efforts was the use of the STAR.Legacy learning cycle to guide the instructional design^[7]. STAR stands for Software Technology for Action and Reflection. Action and reflection define the primary pedagogical approach. The learning cycle, shown in Figure 1, illustrates a common sequence of learning phases used to guide students through an inquiry process. The cycle begins with presenting learners with a complex challenge and asking them to generate ideas and questions they have about the challenge. Next they can compare their ideas with other perspectives in a variety of ways such as reading expert opinions about how to approach the challenge. Research and Revise and Test Your Mettle provide iterative cycles where students learn about new concepts and strategies for using the concepts. The students then apply these concepts and receive feedback on their performance. In traditional tertiary settings, this would be participating in a lecture, completing homework and receiving feedback on the homework. Eventually learners must attempt to bring together all these lessons to synthesize a solution to the original challenge or solve a similar challenge. This final phase involves going public with what you know. This could be in the form of a report, presentation or performance on an exam. The learning activities associated with each of phases depends on the learning environment, available technologies and the instructor's pedagogical preference. The overall effectiveness will also depend on these variables as well.

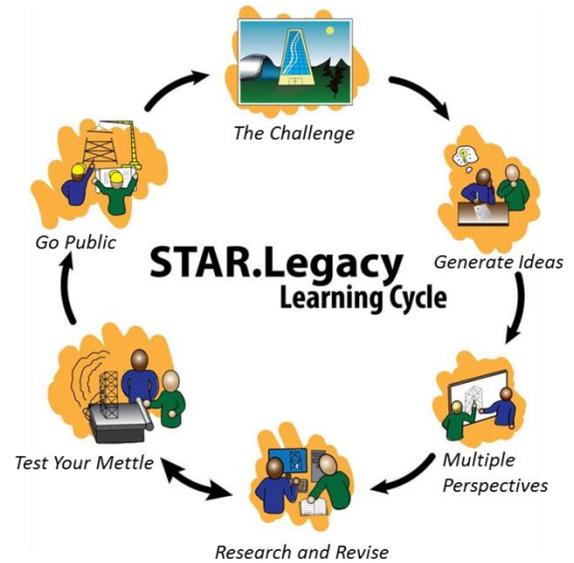


Figure 1: STAR Legacy Learning Cycle

Redesign of a Dynamics Course

A second year dynamics course provided for Civil Engineering majors combined lecture with interactive in-class learning exercises to enrich students' learning experience. The course content was organized around a taxonomic collection of critical concepts associated with the dynamics of physical systems. Topics included (1) two and three-dimensional particle kinematics, (2) two-dimensional rigid body kinematics, (3) the equation of motion, (4) the principle of work and energy, and (5) the principle of impulse and momentum. This taxonomy

of topics was based on the chapter sequence outlined in the course textbook^[8]. Each chapter contains many useful worked examples and practice problems based on fundamental principles. In past offerings, the students' performance on exams was adequate, but the variance was higher than desired. The exams assessed students' abilities to solve well defined problems, but there was no strong evidence this knowledge would transfer to more complex problems or be retained for an extended period of time. Also, the instructor believed students could develop stronger complex problem solving skills if put to the task.

The course was refined to capitalize on past successes of challenge-based instruction using a modification of the STAR.legacy learning cycle. The ten week course was divided up into six major units of study (free vibration was added to the previous five topics). Each unit lasted either one or two weeks. For five course topics, a challenge problem was defined to enhance the existing learning experiences. Each of the five challenge problems followed the same layout:

- A one page introduction stating the *Challenge* and associated context
- A one page *Generating Ideas* Section containing five consistent reflection questions
- A short section containing supplemental information and resources
- A description of the required deliverables.

Each of the 5 selected units began with the introduction of a challenge problem and an in-class reflection activity to help students orient to the major concepts of the particular topic. This Generate Ideas exercise provided students with approximately 15 minutes to record their initial thoughts about the challenge. The contents of the Generate Ideas section are shown below.

Generate Ideas: An exercise to help you think about and plan your approach to the problem.

Respond to the following items to the best of your ability. The reflection exercise will help you articulate your initial thoughts about the challenge and how you might solve it.

1. List in your own words what is the goal of this challenge:
2. List in your own words the relevant given information for this challenge problem:
3. List in your own words the major sub-problems you will need to solve to achieve this goal (i.e. the intermediate steps to achieve the goal of the challenge.)
4. At this time, what additional questions do you need to answer to solve this problem?
5. Briefly explain how you plan to approach and solve this problem:

Each Generate Ideas exercise was collected and copied. The instructor reviewed the students' responses to determine what concepts they knew and how well they could articulate this knowledge relative to the problem. The instructor provided brief feedback on the students' responses and usually returned them within one day. It is believed by the investigators that the repeated Generating Ideas activity and corresponding feedback serve to improve a student's

problem solving approach. This improvement would directly result in their ability to solve a wide range of fundamental problems and thus improve testing scores. The Generate Ideas activities were copied for a future, more in-depth analysis of the student's responses over several consecutive challenges. The investigators believe this may serve as an indicator of student improvement in defining a problem and ability to explain a course of action.

Multiple Perspectives phase of the learning cycle was not used in this implementation. For future iterations of the course, we anticipate interviews with other faculty and practicing engineers to provide their perspective and share how their research or practice relates to the problem. Students would review these resources outside of class as a way to reflect and refine on what they produced during the Generating Ideas phase. This process will help them prepare for the in-class activities, homework and going public on the challenge.

The Research and Revise activity consisted of the traditional lecture and interactive team based exercises used in the prior implementation of the course. Other research and revise activities consisted of chapter readings and additional interactive classroom sessions. Students were also given links to relevant sources they could access as they perceived the need.

Test Your Mettle experiences took on multiple forms. As mentioned earlier, the instructor reviewed their initial ideas and provided simple feedback on concepts to consider as well as problem solving strategies (e.g. modeling the system with a free-body and kinetic diagram). Second, simple concept quizzes were given an average of every two days to the students. Students received prompt feedback on the quizzes which allowed the instructor to see if the class was keeping pace with instruction. Third, between classroom sessions they solved practice problems from the textbook and handed it in as homework. Students received feedback on these homework assignments and were given worked solutions to the problems. The review of these materials by the instructor provided important information on what students currently knew and how they were approaching these fundamental problems. This information informed the instructor on what and how to approach in the next interactive classroom session.

Going Public with their ideas was done by handing in a short report on their solution for the original challenge. Students needed to combine what they learned to generate a solution to the problem. They were asked to follow a specific problem presentation style based on guidance from the course textbook which included: 1) a clear statement of the problem to be solved, 2) modeling of the system (qualitative and quantitative), 3) a statement of assumptions, 4) the solution and 5) an evaluation the reasonableness of their results with a reflection on their problem solving process^[8]. These steps represent one method for presenting solutions to engineering problems. The main goal was to help students develop a consistent and effective method for communicating their thought process. These reports were graded and handed back to students with feedback on their approach and recommendations on how to improve their analysis strategies. Guidance was also provided on how to improve their ability to systematically display their problem solving process.

The ultimate goal for the course redesign was to develop a collection of interesting challenges that develop students' ability to model the dynamics of a physical system. The challenges were designed to relate concepts of dynamics to civil engineering and to be familiar enough for students to comprehend how the system works. Therefore, students could focus more on how the governing principles of dynamics would influence the behavior of the system. Table 1 outlines the current set of topics and associated challenges for this initial implementation.

Table 1: Summary of initial challenges used in a dynamics course

Topic Area	Details
Particle Kinematics	Title: <i>Post-Earthquake Analysis of the Ibis Hotel, Christchurch, New Zealand</i>
	Fundamental Principles: Rectilinear Motion, Relative Motion
	Description of Problem Context: Given a 10-story building that has recently experienced an earthquake, determine its inter-story drift by evaluating its response to an aftershock.
Equation of Motion for a Particle	Title: <i>Analysis and Modification of an Amusement Park Ride</i>
	Fundamental Principles: Curvilinear Motion of a Particle, Newton's Second Law for Particles
	Description of Problem Context: Given the current specifications of a spinning amusement ride, determine the change in the structural performance of the system if the rotational speed is increased.
Rigid Body Kinematics	Title: <i>Delirium Dispute</i>
	Fundamental Principles: Curvilinear Motion of a Rigid Body, Relative Motion
	Description of Problem Context: Patrons of an amusement ride have been fainting and/or getting sick. A class action lawsuit has been posted claiming the ride is not performing within the advertised specifications. As an expert witness, provide an analysis of the system to estimate its current performance relative to its specification.
Equation of Motion for a Rigid Body	Title: <i>Loop-O-Plane Loads</i>
	Fundamental Principles: Work of a force, Conservation of Energy, Moment of Inertia
	Description of Problem Context: Given an amusement ride with counter rotating cars, estimate the maximum rotation and load forces on the base of the ride.
Impulse and Momentum	Title: <i>Mission to Mars</i>
	Fundamental Principles: Impulse of a force, Conservation of Momentum
	Description of Problem Context: Estimate the thrust profile for controlling the descent of a capsule containing the Mars rover.

Participants

Two groups of second year engineering students participated in a dynamics course during the 2011 Fall quarter (43 students) and the 2012 Fall quarter (38 students). Students in both classes provided their consent to have their course materials used in the study. The instructor had no

knowledge of their consent before final grades were delivered; therefore, their participation had no bearing on their grade. To determine students' perception of the course, surveys were distributed to students mid-way through the course and upon course completion. Surveys were anonymous and course material was relabeled with identification numbers so that student responses could not be traced back to the individual.

Research questions and instruments

The central conjecture of this pedagogical approach is that students' ability to approach these complex problems will improve across the sequence of challenges. It is believed that this improved problem solving ability will result in better performance on exams that test their ability to solve well-defined problems. Therefore, the basic research questions are

1. How can a series of challenge-based learning cycles improve students' ability to analyze the behavior of dynamic (physical) systems?
2. How do students' abilities to define problems and generate solutions improve across a sequence of challenges during a term?

Multiple studies are planned to investigate these questions. This study focused on students' perception of the accessibility and the learning benefits of the challenge based approach as described in this paper. A student survey was presented as course evaluations at the middle and end of the quarter. The survey consisted of 20 items targeting benefits of the challenge-based instructional method and the effectiveness of the instructor. The items were worded as statements which the students could agree or disagree related to their experience in the course.

Additionally, a final exam with duplicate questions was given to students in both the 2011 and 2012 versions of the course. The exam was not returned to students; therefore, they were not accessible to students in future years. In the Fall of 2011, the presentation of the course followed a traditional model of instruction. In the Fall of 2012, the course was enhanced with a challenge based instructional approach as described above. A comparison of the two classes and their respective performance on the final exam is provided.

Results

The primary goal of this study is to evaluate the potential of the learning materials based on student satisfaction and a comparison of performance on a common final exam between the enhanced course (Fall 2012) and the no-intervention case (Fall 2011). The student survey items target students' perceptions of the challenge-based instruction relative to their learning, interest, motivation and the instructor. Students were asked to rate each statement (1-Strongly disagree, 2 disagree, 3 somewhat disagree, 4 somewhat agree, 5 agree, 6 strongly agree). Figure 2 summarizes students' responses to the survey.

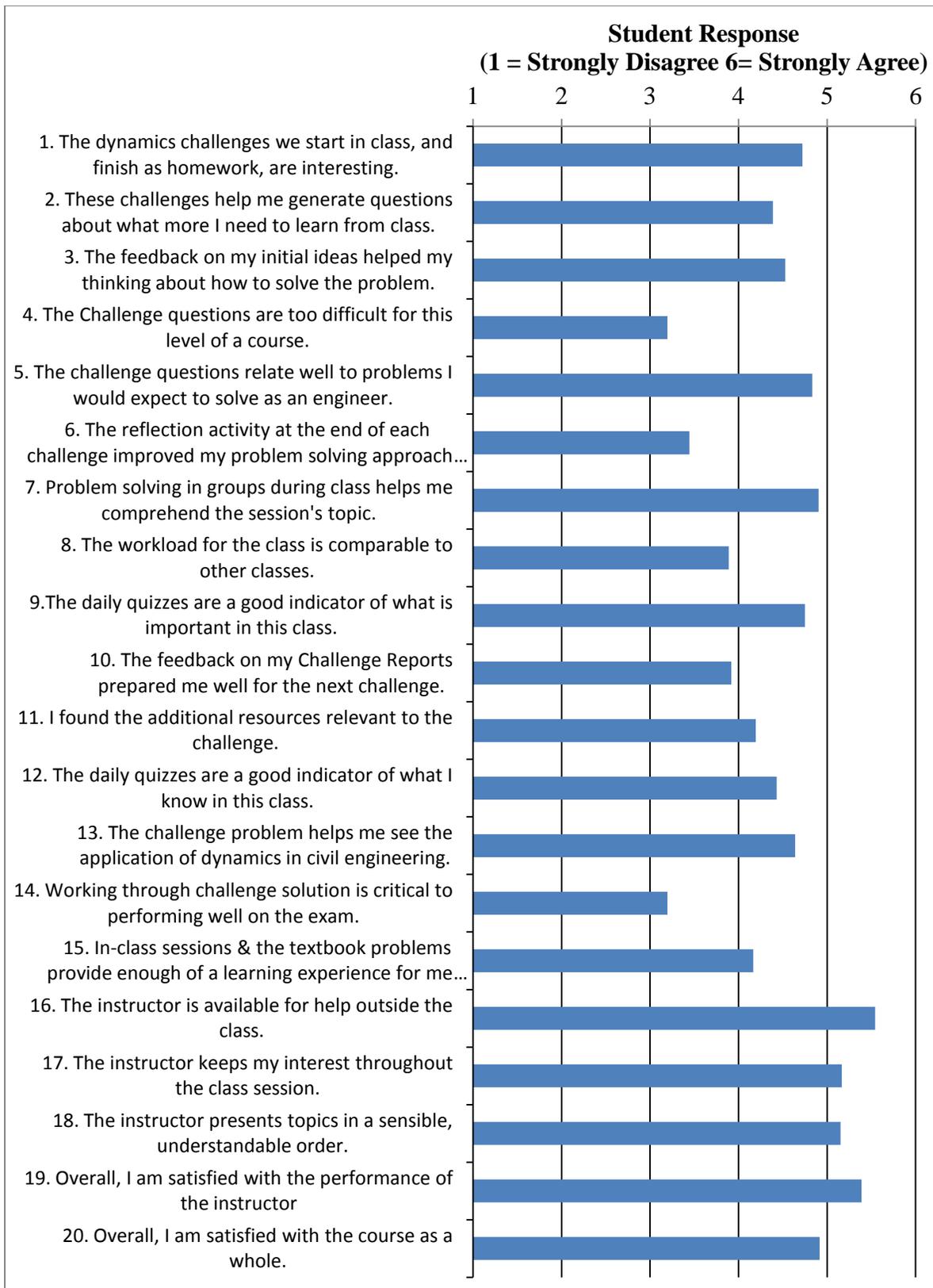


Figure 2: Student Survey regarding benefits of elements of challenge-based instruction

Analysis of the Survey Results

Overall, the results from the survey were extremely positive. Specifically, questions 1, 5, 13 and 17 indicate students agreed that the course and various challenges were interesting and authentic to the practice of engineering. Additionally, student responses indicate that the various stages of the STAR.legacy learning cycle improved their learning. For example, the Generate Ideas exercises helped to identify key course content for both in-class problems solving exercises and the challenge problems (questions 2 and 3). The Research and Revise and Test Your Mettle exercises helped students comprehend course material and perform well on exams (questions 7, 9, 11, 12, and 15).

The survey also indicated that the students believed that the challenges were not too difficult (question 4). Further, the students agree the workload of the challenges is appropriate for the course. On a related open-response item, students reported spending about 8 hours a week on course homework. This was in line with the instructor's expectations.

In question 6, students indicated that they were neutral on the benefit of the reflection activity at the end of each challenge problem with regard to their future performance on subsequent challenges. The investigators believe this is due to the order in which the reflection activities were conducted. Students, as a part of the final submission, included a reflection on their problem solving approach. This reflection was conducted before the final summative feedback was given. To improve the benefit of this activity in the future, a separate reflection activity will occur after feedback is received.

Questions 10 and 14 indicated that students were neutral regarding the benefit of the challenge problems and associated feedback with regards to future challenge problems and exams. Because the students appeared to improve over the quarter, it is unclear to the investigators why the students perceived a disconnection between these items.

Comparison of Final Exam Scores

A final exam with common questions was given to two separate dynamics classes. The Fall 2011 group of students were taught following a traditional instructional model, and the Fall 2013 course was enhanced with challenge-based instruction. The GPA and SAT scores of the two groups were considered statistically equivalent with a 95% confidence. In 2011, the final exam consisted of 6 separate questions. In 2012, the final exam reused 5 of the previous year's questions and added a 7th question covering vibration. The exams were given over the same period of time and graded following similar rubrics. Table 2 illustrates the topics for each question and the aggregate performance of each of the student groups.

Table 2: Final Exam Scores for Fall 2011 and Fall 2012

Topics	2012 (n = 38)		2011 (n = 43)		Improvement	Statistically Significant ($\alpha=0.05$)
	AVG	STD	AVG	STD		
P1 - 2D Rigid Body Kinetics (<i>Dependent Motion</i>)*	81.8%	19.4%	75.0%	19.6%	X	
P2 - Particle Kinematics (<i>Variable Acceleration</i>)*	79.2%	17.2%	77.2%	21.1%	X	
P3 - Principle of Impulse and Momentum (<i>Impact</i>)	70.2%	24.0%	78.0%	22.0%		X
P4 - Conservation of Energy	59.5%	21.8%	76.3%	14.2%	NA Diff. Prob.	X
P5 - Principle of Impulse and Momentum*	74.9%	12.4%	64.1%	15.4%	X	X
P6 - 2D Equation of Motion for a Rigid Body*	80.5%	14.5%	69.5%	15.9%	X	X
P7 - Vibration	63.7%	14.5%	-	-	NA	NA

*Challenge-based instruction was used for the content for these questions

In four of the five repeated questions, the Fall 2012 group of students showed improvement in their aggregate scores. Statistically significant improvement ($\alpha = .05$) was seen for Problem 5 and Problem 6. Additionally, the improvement for Problem 1 was borderline significant ($\alpha = 0.06$). Problem 2 did not show a statistically significant improvement in the average score; however, the variance in scores was reduced. For each of these final exam questions (Problem 1, 2, 5, and 6) a challenge problem was used to frame the instruction for the fundamental concepts. Problem 3 showed a statistically significant reduction in the score between the Fall 2011 and Fall 2012 scores. This is especially interesting because the topic of impact was not a fundamental concept for any of the challenge problems. Finally, Problem 4 showed different scores but for two different problems. The problem given in 2012 was much more difficult than the corresponding problem from 2011, as might be inferred based on the extreme differences in scores.

Conclusions

Students expressed a very positive response to the use of challenge-based instruction and the various learning experiences used to support instruction. The majority agreed that the challenges were interesting and relevant to engineering practice. Students were neutral regarding if the challenges were too difficult and the appropriateness of time the course demanded. To achieve the goals of the project, the challenges needed to be difficult in order to engage the students in authentic practice. Some students with little prior knowledge may find the challenges too difficult; therefore, a great variance among the responses may occur on items related to

performance. The students also appreciated the classroom learning experience and instructor. Students reported these experiences prepared them for their engineering career, but were neutral about how well the challenges prepared them for the exam. This finding was not too surprising, because the objectives of the exams were more focused on replication of solving well defined problems which were more like the classroom and homework activities (Research and Revise). The exams did not include questions similar to the Generate Ideas exercises. There were also no multi-factor analysis or synthesis tasks similar to what is needed to Go Public. In the future, additional assessments will be added to the exam to measure students' ability to approach more open-ended problems.

Students' performance on exams between the two versions of the class indicates that the challenge-based instruction had a significant positive impact on the performance of the students. For two topics that were enhanced by the challenge-based instruction, students performed significantly better. Two additional topics enhanced by challenge problems also indicated moderate improvement. Additionally, the three lowest average scores from the 2012 enhanced course were based on topics not associated with any challenges. It is very clear, however, that these results are based on a small sample size and are only comparing two aggregate data points. Future research studies will investigate the retention of knowledge after completing the course, as well as adding subsequent classes to the data set. Also, detailed analysis of the Generating Ideas exercises throughout the progression of the quarter would help to evaluate if the students improve in their problem solving approach.

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