Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47239

Assessing the Impact of Teaching Style on Problem-Solving Skills and Conceptual Understanding in Undergraduate Dynamics

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Assessing the Impact of Teaching Style on Problem-Solving Skills and Conceptual Understanding in Undergraduate Dynamics

This paper presents the results of a study investigating the influence of teaching style on student performance in undergraduate Dynamics. Building on our previous work, which explored the differences in problem statement, solution, and evaluation methods among three instructors with distinct teaching approaches, we now report on the outcomes of student assessments. The study examined student performance on both fully-worked-out problems and concept inventory dynamics problems, allowing us to explore the relationship between problem-solving skills and conceptual understanding.

The three teaching styles examined in this study are: (A) a flipped, recitation-based classroom with a mastery-based derivation approach, (B) a lecture-style class using the SMART (Supported Mastery Assessment through Repeated Testing) approach, and (C) a lecture-style class with three levels of student participation to engage both reflective and active learners. We analyzed student performance data from exams and concept inventory questions to address the following research questions: (I) Do problem-solving skills differ among students taught with different approaches? (II) How does conceptual understanding vary among students in different teaching environments? (III) Is there a relationship between problem-solving skills and conceptual understanding, and if so, how is it influenced by teaching style?

This study contributes to the discussion on effective pedagogical practices and the implications of teaching styles for fostering a range of problem-solving skills in students. Specifically, this paper presents a comparison of the teaching styles highlighting the results for both fully worked out problems and concept inventory problems. Our findings provide insights into the differences of each teaching approach and the impact it can have on problem-solving skills, conceptual understanding, and the complex relationship amongst these two skills.

Introduction

Concept inventories like the Dynamics Concept Inventory (DCI) or the proposed Rigid Body Dynamics Concept inventories (RBDCI) have been shown to be effective at identifying student misconceptions and guiding instructor efforts [1,2]. In their 2020 paper on the propagation of the use of concept inventories in Mechanical Engineering [3], Cornwell and Self et. al. suggest that instructor adoption of concept inventories depends on a variety of factors including the institutional context, learning context, and the instructor's interaction with the concept warehouse community.

In other work, researches have explored the role of institutional and learning contexts on student success [4], student perceptions [5,6,7], and student self-efficacy. Additionally, by changing the learning contexts, instructor's outlooks have also been affected [8].

In this paper the authors explore the role of institutional context and learning context (or instructional style) on student performance on exams. These two contexts play an important role in how students learn a subject, develop processes for solving problems, scaffold material, create conceptual hierarchies, and the time it takes them to develop an intuitive grasp of the key ideas [9,10,11]. Because of this the authors hypothesize that there should be measurable differences in student capabilities on concept inventories and longform problems as a result of different instructional and institutional contexts.

Given the breadth of pedagogical approaches and diversity of institutional contexts, it is not possible to exhaustively explore this question and that is not the goal here. The goal here is to build on previous work on instructional differences [12] to explore the impact of those differences on student success on longform and concept inventory questions.

Research Questions

The purpose of this paper is to explore the relationship between teaching style and students' success with longform and concept style questions. The three related questions are:

(I) Do problem-solving skills differ among students taught with different approaches?

Each instructor has expectations for how students will approach problem solving in his/her class. These problem-solving approaches are embedded in the classroom structure and instruction. Students adapt to or adopt these methods to varying degrees of success, often syncretizing new methodologies with their own approach. The research question explores how well these problem-solving skills translate into successfully solving long form problems.

(II) How does conceptual understanding vary among students in different teaching environments?

Each instructor has a different approach to instruction and learning. The use of derivations, worked examples, active learning, testing, and grading approach all influence the student's ability to grasp key concepts. Does the environment reward intuitive thinking on problems that can make them easier to solve? Does a process-based classroom that uses a robust but brute force approach styme the development of conceptual understanding?

(III) Is there a relationship between problem-solving skills and conceptual understanding, and if so, how is it influenced by teaching style?

Each instructor balances the need for robust problem solving with 'shortcuts' based on intuitive thinking or conceptual understanding. Do students in a class that is focused on first principles or process-based approach to longform problems have a larger gap between their problem-solving skills and conceptual understanding than a course that focuses on 'shortcuts' or intuition?

Classroom Design and Problem-solving Expectations

A previous paper [12], detailed the instructional design and university types for the three instructors. They are summarized again here:

> **University A** is a southeast R1 public institution that uses mastery-based grading and a flipped style classroom approach [13]. Dynamics is taught as a 2-credit course and has enrollments of 40-50 students. Students receive points for each objective item that they are able to complete in the exam. There are multiple objectives for each problem and each exam only has 1 or 2 problems. Grades are based students attaining mastery of the objectives. The rubric used for scoring each objective is: a – complete and correct, b – minor calculation error, c – minor conceptual error, d - major conceptual error, and e – no evidence shown.
>
> **University B** is a midwest R1 public institution that uses an active learning lecture format with a mastery-based grading approach called SMART (Supported Mastery Assessment through Repeated Testing) [14, 15]. Dynamics is taught as a 3-credit course that has enrollments of 80-100 students. Students receive points for getting the correct answer to the problem. Short problems have a single correct answer. In longer problems, some points are awarded for making it to a pre-defined intermediate step. Students are graded on attaining mastery of the problems. The rubric used for scoring each problem is: 100% for a correct answer with support, 80% for an incorrect answer because of a non-conceptual mistake like a minor calculator error and 0% if there is a conceptual error.
>
> **University C** is a midwest M1 public institution that uses a mixture of traditional lecture / active learning in the classroom and partial credit rubric-based grading. Dynamics is taught as a 3-credit course and has an enrollment of 15-35 students. Students receive points on exams based on a partial credit rubric. The rubric divides the problems into: 40% for graphical set up, 30% for equations, 20% for the solution, and 10% for clarity/neatness.

The most relevant aspect of this paper is the solution process approach that is used by the instructors.

Instructor A expects students to solve by derivation from first principles, Instructor B expects students to use a systematic approach that has been outlined in the course 'compass', and instructor C expects students to use a standard approach that starts from coordinates and moves to kinematics and then kinetics.

Methods

To assess the three research questions, the three aforementioned instructors created a set of exam problems that would be used in all three classes. These problems were similar in scope and topic, but each instructor tailored the question to match the needs of his or her students.

Each exam question contains two complementary parts. The first part is a longform or homework style problem requiring a detailed written solution with multiple steps. This type of problem is best solved by a robust methodology and repeated practice, but students may try to solve the problem by intuition or the memorization of a similar problem. The second part of the problem is a multiple-choice question (selected from the DCI or the proposed problem pool for the RBDCI).

Each longform and concept question were selected as a pair based on the overlap of the required concept needed to solve the problem. While the overlap is not perfect, it was deemed sufficient for this study.

The data that was collected included the student scores on the longform question (as graded by the course instructor) and the multiple-choice answer for the concept inventory question.

The authors acknowledge that the data itself is complicated by several issues including those related to teaching style. At University A, rigid body dynamics is covered quite early in the semester so students are solving these problems earlier than the students at Universities B and C. At University B, students are given two attempts at each exam and may leave a question blank because they solved it on the first exam or plan on solving it on the 2nd exam. Additionally, Universities A and C made the concept problem a regular exam question while University B made the concept problems a bonus question.

As one can expect, creating rigid study controls across several universities can be challenging. This study is designed to be exploratory in nature, thus we acknowledge that there are limitations in the data.

Exam Problems Being Studied

The authors explored a total of 10 longform-concept inventory question pairs. In this paper 3 question pairs and student results are presented in detail.

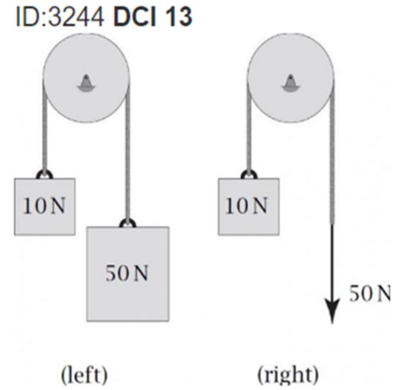
In the following section, the concept inventory question is provided. All three faculty used the same concept inventory question. After the concept inventory question are three variants of the longform question. These are presented differently because each instructor modified questions to match their usual exam format and structure. The core concepts being tested in the problem have not been changed, but text, structure, and images have been modified.

In all three cases, the assertion is made that if a student is able to correctly solve the longform question, they should have adequate conceptual knowledge to correctly answer the concept question. Note, the authors are not saying they should be able to get the question right. Solving a concept question requires a different skill set than solving longform questions. Put another way, if the multiple-choice selection for the concept problem was removed and the problem was written longform, the solution process should match that of the longform questions being asked.

Problem 1 – Pulley

Concept Question (From DCI):

Both systems shown have massless and frictionless pulleys. On the left, a 10 N weight and on a 50 N weight are connected by an inextensible rope. On the right, a constant 50 N force pulls on the rope. Which of the following statements is true immediately after unlocking the pulleys?

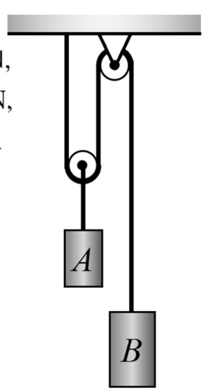


a) In both cases, the acceleration of the 10 N blocks will be equal to zero.
b) The 10 N block on the left will have the larger upward acceleration.
c) The 10 N block on the right will have the larger upward acceleration.
d) The tension in the rope on the left system is 40 N.
e) In both cases, the 10 N block will have the same upward acceleration.

Longform Question – Instructor A

Two blocks, *A* and *B*, each have weight W_A and W_B, respectively. The system is released from rest in the position shown. The two pulleys in the system are frictionless and the mass of each can be neglected. The cord will not extend. Find the initial acceleration of each block and determine the time it takes for block *B* to move a distance *d*. Use the given values:

$W_A = 10$ N,
$W_B = 30$ N,
$d = 50$ cm

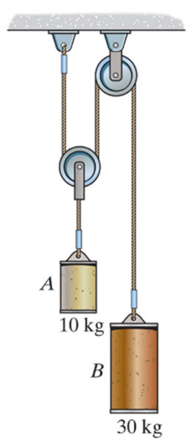


Longform Question – Instructor B

Two blocks are released from rest. Find:

1. the acceleration of block A,
2. the tension in the cable,
3. the velocity of block A after 10 seconds have passed.

- You must have clearly defined coordinates.
- You must have Free Body Kinetic Diagram(s).
- You must have a clear constraint equation.



Longform Question – Instructor C

The system shown is released from rest.

Find: Determine the tension in the rope and the acceleration of each mass at this instant.
(Neglect the mass of the pulleys)

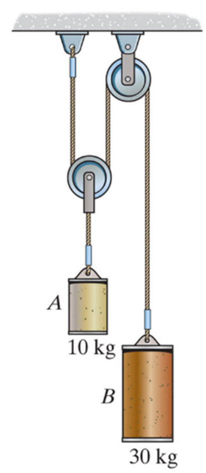


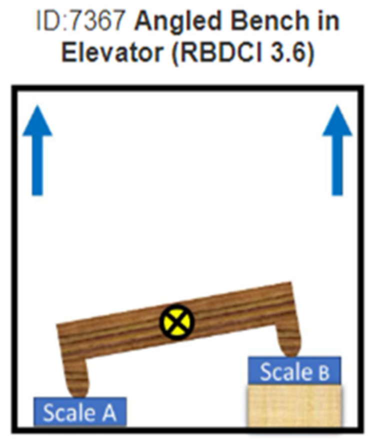
*Image courtesy of Dynamics, by Hibbeler (13th ed)

Problem 2 – Crate

Concept Question (From RBDCI)

A bench is in an elevator. The bench is resting at a slight angle with a scale under each foot. At the instant the elevator begins to move up, what can be said about the reading on each scale relative to the original reading on the scales (when the elevator is at rest)?

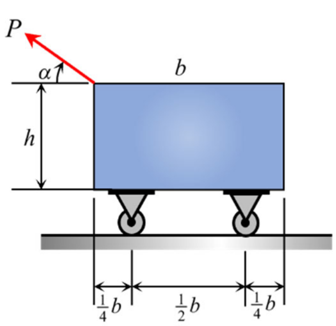
a) Scale A's reading will increase more than B.
b) Scale B's reading will increase more than A.
c) Scale's A and B will be equal but will decrease.
d) Scale's A and B will be equal but will increase.



Longform Question – Instructor A

The cart has a force P applied to it. The cart has a uniform mass per area given by ρ and starts from rest. (1) Find the acceleration of the cart, (2) find the reaction force of each wheel (assume the wheels act as a normal force at the middle of the wheel's connection to the cart), and (3) find the velocity of the cart when it has moved a distance d (use energy methods for this part). Use the given values:

$$P = 300\text{N}, \quad \rho = 150\frac{\text{kg}}{\text{m}^2},$$
$$h = 0.4\text{m}, \quad b = 1\text{m},$$
$$\alpha = 30°, \quad d = 2\text{m}$$

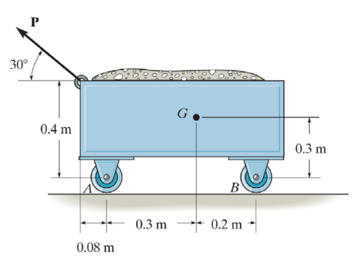


Longform Question – Instructor B

A force of $P = 300N$ is applied to the 60 kg cart. The mass center of the cart is located at G. Find the reactions at both wheels and the acceleration of the cart.

A FBKD is required.

HINT: Assume cart doesn't tip.



Longform Question – Instructor B

A force of $P = 300N$ is applied to the 60 kg cart. The mass center of the cart is located at G.

Find: Determine the

1. Total reaction on the wheels at A and
2. Total reaction on the wheels at B.
3. The acceleration of the cart.

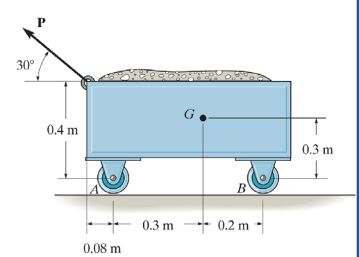


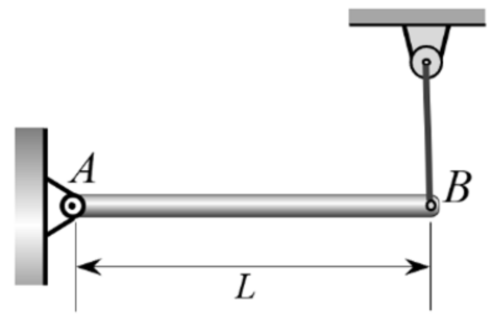
*Image courtesy of Dynamics, by Hibbeler (14th ed)

Problem 3 – Rod Problem

Concept Question (From DCI):

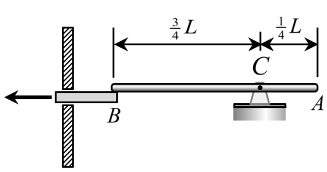
A uniform rod of length L and weight W is supported as shown. Before the cable is cut, the reaction at A is equal to half the weight of the bar. At the instant right after the cable B is cut, which statement is true about A?

a) The reaction at A is equal to the total weight W
b) The reaction at A is larger than W
c) The reaction at A is less than W
d) The reaction at A remains unchanged



Longform Question – Instructor A

The bar ACB has a mass per unit length of ρ and a length L. It is hinged at C at the location shown in the diagram. The support at B is suddenly removed. Find (1) the *initial* reaction that the pin C exerts on rod ACB, (2) the *initial* angular acceleration of the system, and (3) the total energy of the system.

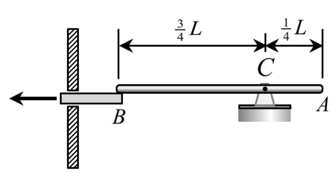


Longform Question – Instructor B

The bar AB has a mass of 4 kg and a length $L = 1m$. It is hinged at C (as shown in the diagram) and supported at B.

When the support B is suddenly removed…

1) Find the initial reaction that the pin C exerts on rod ACB,
2) Find the initial angular acceleration of the system.

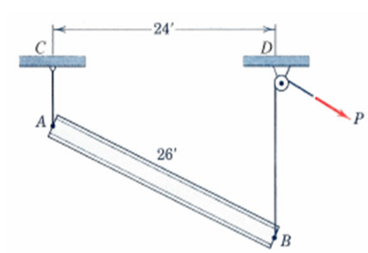


Longform Question – Instructor C

The uniform I-beam weights $650\ lbf$ and is supported in the fixed position shown by the force $P = 325\ lbf$. The distance between A and C is 1 ft. Note: Treat the beam as a slender rod.

Find: If the cable BD suddenly breaks, determine the

1. components of acceleration of the center of mass,
2. tension in the cable AC.



Data

After the exams were given, faculty graded each exam using their standard rubrics. In order to create reasonable comparisons between the data, students were placed into bins based on their grades in that exam.

The three categories used are Mastered, Mastering, and Struggling. Struggling students are those who were not able to achieve a passing grade (70%) on the exam. Mastering students are those who achieved a passing grade, but had some mistakes, Mastered students are those who have mastered the material and achieved 100%.

For each exam score category, the researchers tallied the number of times each concept inventory multiple choice option was selected. In some cases, students opted not to answer the concept question. This was more common for Instructor B who used the concept inventory question as a bonus question rather than as a regular question.

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
No Response				
1		X	Y	=X+Y
2				0
**3			Z	=Z
4				0
5				0
TOTALS	0	=X	=Y+Z	=X+Y+Z
% of Students with Correct CI Answer	0	0	$=\frac{Z}{Y+Z}$	$=\frac{Z}{X+Y+Z}$

Figure 1 - Data Presentation Format. Student answers to the concept inventory questions are binned according to student exam performance and concept inventory answer (or no response). In this figure, X represents the number students who scored between 70-99% and responded to the CI question with answer #1. Columns and rows are summed to get Totals, the bottom row calculates the percent of students in the column who correctly answered the concept inventory questions. Totals do not include the blue 'No Response' row since those students did not answer the concept inventory questions. The correct answer to the concept inventory question is marked with **.

Results

Figures 2-4 show the student answers for on the concept inventory questions for problems 1 through 3 respectively. The exam performance data is shown in graphical form in Figure 5.

Instructor A results for Problem 1

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR				0
1	0	0	0	0
2	1	1	0	2
**3	0	2	1	3
4	0	0	0	0
5	21	17	5	43
TOTALS	22	20	6	48
% Correct	0.0%	10.0%	16.7%	6.3%

Instructor B results for Problem 1

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR	23	27	9	59
1	1	0	0	1
2	3	1	1	5
**3	3	1	2	6
4	0	0	0	0
5	11	5	8	24
TOTALS	18	7	11	36
% Correct	16.7%	14.3%	18.2%	16.7%

Instructor C results for problem 1

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR				0
1	0	0	0	0
2	0	0	0	0
**3	4	0	0	4
4	1	0	0	1
5	5	1	1	7
TOTALS	10	1	1	12
% Correct	40.0%	0.0%	0.0%	33.3%

Figure 2 – Concept Inventory answers for problem 1; binned by instructor and student exam scores.

In problem 1, the students instructors A's class had concept inventory question success that was showed a positive relationship with student score. Instructor B showed a similar relationship, but not as strongly. Instructor C's class only had 12 students, but exam success did not correlate with concept inventory success. However, the overall success for students in class A was much lower than B and C.

Instructor A results for Problem 2

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR			2	2
1	8	4	10	22
2	6	2	3	11
3	0	0	0	0
**4	4	2	4	10
5	--	--	--	--
TOTALS	18	8	17	45
% Correct	22.2%	25.0%	23.5%	22.2%

Instructor B results for Problem 2

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR	15	18	8	41
1	8	6	6	20
2	3	1	0	4
3	2	10	4	16
**4	1	11	6	18
5	--	--	--	--
TOTALS	14	28	16	58
% Correct	7.1%	39.3%	37.5%	31.0%

Instructor C results for problem 2

	Exam Performance			
	0-70%	70-99%	100%	TOTAL
NR				
1	1	2	0	3
2	1	0	0	1
3	0	1	0	1
**4	0	3	2	5
5	--	--	--	--
TOTALS	2	6	2	10
% Correct	0.0%	50.0%	100.0%	50.0%

Figure 3 – Concept Inventory answers for problem 2; binned by instructor and student exam scores.

In problem number 2, instructor A's class lost the positive relationship between exam scores and CI scores. The positive relationship did show up much stronger in classes B and C. The overall success of the students remained higher in B and highest in C.

Instructor A results for Problem 3

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR		1		1
1	11	4	2	17
2	8	4	3	15
**3	4	4	1	9
4	1	1	2	4
5	--	--	--	--
TOTALS	24	13	8	46
% Correct	16.7%	30.8%	12.5%	19.6%

Instructor B results for Problem 3

	Exam Performance			
MC Ans.	0-70%	70-99%	100%	TOTAL
NR	14	8		22
1	11	15	0	26
2	5	4	0	9
**3	10	8	3	21
4	4	5	0	9
5	--	--	--	--
TOTALS	30	32	3	87
Correct	33.3%	25.0%	100.0%	24.1%

Instructor C results for problem 3

	Exam Performance			
	0-70%	70-99%	100%	TOTAL
NR				
1	2	0	0	2
2	2	3	0	5
**3	0	1	0	1
4	2	0	0	2
5	--	--	--	--
TOTALS	6	4	0	10
% Correct	0.0%	25.0%	0.0%	10.0%

Figure 4 – Concept Inventory answers for problem 3; binned by instructor and student exam scores.

In problem number 3, classes A and C had a positive relationship between exam success and concept success. Students in the struggling portion of Instructor B's class did better on the concept inventory than those who were scoring higher on the exam.

Figure 5 shows the performance of the classes on exams for Problems 1, 2, and 3 (top to bottom). Performance was lowest on the first exam.

Discussion

In Research Question III, the authors had hypothesized that the institutional and learning contexts would result in different rates of students moving from success in process-based solutions (longform) to success in concept-based understanding (concept inventory). As a result, it was expected that each teaching style would have a different relationship between longform and concept success.

These relationships were present in the context of problem 1. The success of Instructor A's students on longform and concept inventory problems showed a clear relationship. Instructor B's exam and CI scores do not

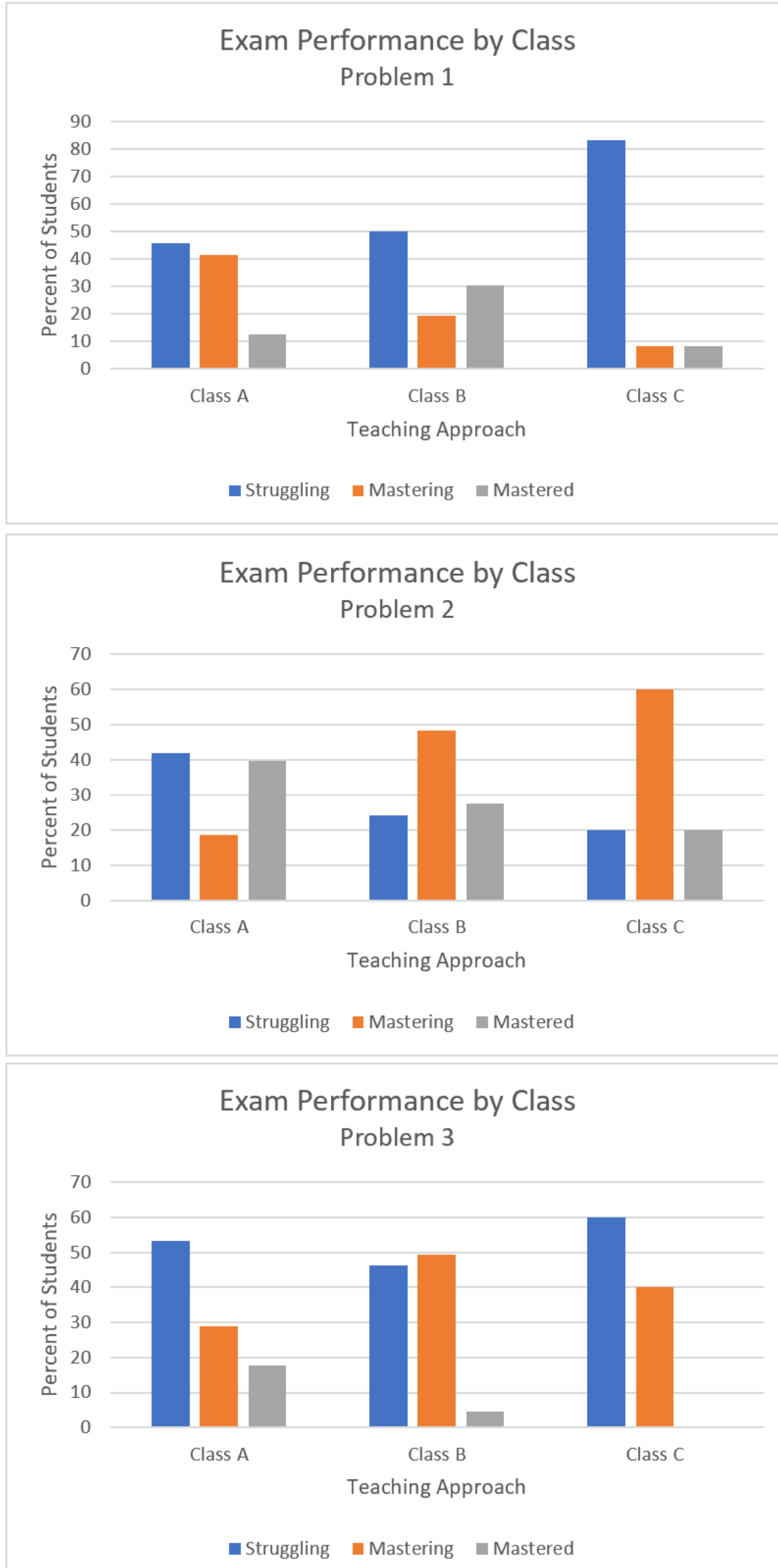


Figure 5 – Shows the exam performance as a percent of each student in the class.

appear to be related and Instructor C's data shows an inverse relationship (although the sample size is small).

However, problems 2 and 3 show that these relationships do not persistent across the three questions. At this time, it has not been determined if this change is due to inherent randomness in the data or if the relationships persist (across semesters) and is due to teaching styles. Alternately, the change could be because some instructors emphasized different topics in the class. It could also be the case that some concepts are easier to develop and thus indications of conceptual understanding show up in this test while the full understanding of other concepts is developed later.

Thus, the data is currently inconclusive on Research Question III, but it does indicate that further study would be useful (see future work).

Research Questions

(I) Do problem-solving skills differ among students taught with different approaches?

(II) How does conceptual understanding vary among students in different teaching environments?

(III) Is there a relationship between problem-solving skills and conceptual understanding, and if so, how is it influenced by teaching style?

The data for Research Question II is more interesting. The authors had hypothesized that mastery-based grading forced students to focus more on process than concepts. The presumption in a strong process-based teaching approach is that process comes first and consistent use of process leads to conceptual understanding. This hypothesis appears to be validated by the results.

The percent of students successfully answering the concept question was highest for Instructor C. There is an exception with problem three, but it should be noted that Instructor C chose to use a much harder version of the longform question. It is the case that Instructor C's students had consistently higher success on the concept questions, and that Instructor A's (mastery-based grading and fundamentals teaching style) students struggled the most with the concept questions. This result strongly indicates that conceptual understanding does vary among students in different teaching environments and that students in a process focused course may initially lag in conceptual understanding compared to more traditional approaches.

The data for Research Question I is found in Figure 5. After reviewing the data, it was determined that the coarse binning of grade data worked well for binning concept inventory data, but disguised differences in longform problem success. As such, Research Question I cannot be answered at this time and an analysis of this question will be left for a future study.

As acknowledged at the beginning of the paper, the number of uncontrolled variables is too great to exhaustively explore or conclusively answer these questions and that is not the goal here. The results are adequate to raise questions about when, in the learning process, conceptual understanding develops and how different instructional styles impact the time between algorithmic and conceptual understanding.

Future work

Future work on this project involves expanding the number of problems being considered and regrading problems to extract specific information about the concept being measured.

Repeating this study in future semesters will enable the authors to see if relationships between exam scores and concept inventory answers persist or disappear.

In the current study, the concept questions were given at the same time as the longform questions. A better approach would be to give the concept tests three times in the semester. Once at the beginning to get a pre-instruction baseline, once alongside the longform questions and again at the end of the semester after the student has had time to move from process to conceptual understand. That way instructors can track the temporal development of conceptual understanding.

It remains unknown how much effort students put into a concept test if there is no grade attached, or in the case of instructor B, if there are only bonus points awarded. As such, it may be important to be consistent with the reward structure for answering concept questions.

Finally, in future work we will attempt to answer to Research Question I. All authors will grade several problems from each other's exams in order calibrate grading scales.

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