Using Peer Instruction Pedagogy for Teaching Dynamics: Lessons Learned from Pre-Class Reading Quizzes

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Abstract –Peer Instruction (PI) is a widely used pedagogy which generally includes the use of two main teaching strategies: student pre-class preparation with an associated online quiz, and active in-class engagement including small-group discussions about conceptual questions. As an instructor trying this pedagogy for the first time, my purpose was to investigate both students' learning and attitudes in my first/second year engineering dynamics course, using their answers to the reading quizzes as the main source of data. In short, students with the highest quiz marks did well in the course, indicating successful reading and learning strategies. Similarly, students with the lowest quiz marks attained lower overall marks. Students who did less well in the course were also more negative about the PI format (the class size of 17 did not allow for statistical analysis). Negative comments tended to be related to an expectation that the teacher should lecture more, indicating less understanding of cognitive principles. These results will provide a baseline for evaluating future teaching efforts which will include examining whether more directly encouraging deep learning strategies will be more effective for student learning.

Keywords: peer instruction, dynamics, metacognition, learning strategies.

1. INTRODUCTION

Peer Instruction (PI) is a widely used pedagogy developed in physics education where students do pre-reading assignments and quizzes before class, and "lectures" include lots of small-group discussion about conceptual questions, interspersed with short, mini-presentations by the instructor [1]. Several studies have quantitatively analyzed the effects of this pedagogy in physics, showing an increase in student engagement and a substantial increase in learning, as measured by summative evaluations, compared to a traditional lecture approach [2,3].

However, improved conceptual understanding and course performance are only one measure of student

success. There has been little work done in qualitatively studying students' metacognition and learning strategies as they are exposed to this style of instruction, and whether their metacognition can be further cultivated through formative assessments. Metacognition has been defined as awareness of one's own level of understanding of a topic, while deep learning strategies include integration of theory with real life experience.

In preparing to teach this course using Peer Instruction for the first time, I was particularly concerned about the students' pre-class readings and their ability to complete the pre-class quizzes. What would be an appropriate expectation and therefore appropriate assessment of students' learning from the reading assignments? What kinds of strategies would students use in preparing for class? Could I cultivate deep learning strategies using quiz questions that asked students to elaborate on concepts, compare/contrast different concepts, and to practice appropriate retrieval and application of concepts?

Therefore, the purpose of this preliminary investigation was to develop and test pre-class reading quizzes as an effective assessment of student learning, and also as a means to cultivate students' deep learning strategies and attitudes towards learning.

2. COURSE DESCRIPTION

2.1 Learning Outcomes

This first/second year Dynamics class was designed to help students achieve the following learning outcomes:

1. Students will be able to perform kinematic and kinetic analysis of particles in 2-dimensions, using the concepts of dynamic equilibrium, impulse, impact and momentum, and work and energy.
2. Students will be able to perform kinematic and kinetic analysis of rigid bodies in 2-dimensions, using the concepts of dynamic equilibrium, and work and energy.

3. Students will be able to analyze particles and rigid bodies under the action of static or dynamic friction.
4. Students will be able to calculate moments of inertia of 2- and 3-dimensional bodies, using integration.
5. Students will be able to express numerical answers to problems using proper mathematical symbols and terminology (eg. vector vs. scalar quantities), proper accuracy (eg. number of significant figures), and correct metric units.
6. Students will be able to describe mechanics concepts by answering word problems and real-life engineering problems in both written and oral presentation form, using accurate terminology and clearly explained reasoning.

2.1 Course Components

The class consisted of 3 hours of “lecture” time, 1.5 hours of tutorial, and 1 hour of lab time, per week. Students were assessed using traditional out-of-class assignments (worth 15%), a midterm (worth 25%), and a final exam (worth 40%), which included both conceptual and computational problems. Lab reports were worth 10% of the course. Pre-class reading assignments were also given and the associated online quizzes were worth 10% of the course mark.

2.2 Lecture and Tutorial Formats

During the “lecture” time, emphasis was placed on having students actively discussing various concepts during class. Each class would begin with a brief summary of the concepts the students had already read about, with a focus on addressing questions that students described in their pre-class quiz, according to Just-In-Time-Teaching [4]. Due to the complex nature of some of the problems students are expected to be able to solve in this course, approximately half the lecture time was spent using the Peer Instruction pedagogy where students were presented with conceptual questions with multiple choice answers, and were expected to answer the question themselves first, then turn to a neighbor to discuss their answers until they not only came to an agreement but could also explain their reasoning. The other half of the lecture was typically spent working on computational problems.

Tutorials were designed to give students additional practice with solving problems computationally. Recommended problems from the book were posted in advance, with the recommendation that students try the problems before the tutorials and come to the tutorial session with questions.

2.3 Pre-class reading quizzes

Students were required to do a pre-class reading before each class which addressed a new topic (14 times over the semester). Pre-class reading quizzes being worth 10% was considered high enough for students to take their pre-class reading assignment seriously. Students’ best 13 quiz marks were used to comprise their total quiz mark. The quizzes were administered online and students were required to complete them by the night before each class.

The format of each quiz was 2-3 questions, which were designed to encourage students to use deep learning strategies such as compare/contrast, application and reflection [5]. The first question was short answer and typically asked students to explain similarities and differences between two concepts in the reading, and the second question was typically a multiple-choice or true/false simple application problem (Appendix A). The final question (not included in Appendix A) always asked students to *explain briefly what was the single point of the reading they found most difficult or confusing and why?* It also asked *what strategies did they use to understand this point? And if they did not find any part of it difficult or confusing, what part did they find most surprising or interesting and why?*

To encourage students to make a reasonable effort on the quizzes but to also recognize that they were being tested after the first time they had seen new material, the quizzes were marked based on effort as well as correctness (Appendix B).

At the middle of the semester (Quiz 6) and at the end (Quiz 14), an optional unmarked question was also added to give students a chance to give feedback on the course format and how it impacted their learning (Appendix C).

3. METHODS

3.1 Participants

All students registered in Winter 2012 Engr 3349 Dynamics were be asked to contribute their data to the study. The course enrollment was 17 students, and 14 students consented to having their data used.

Participant identities were kept from me (the researcher/instructor) until final marks had been submitted, to minimize any perception of undue influence to participate. This study was approved by the Mount Royal University Human Research Ethics Board.

3.2 Data Gathered

Student online quiz responses, as well as quiz and overall course marks were used as data.

3.3 Data analysis

Pre-class quizzes were used as the primary data source. Quiz marks and overall course marks were used to assess the quality of the quizzes as well as to classify students according to their achievement in the course. Answers to the short answer questions on each quiz were coded for evidence of using surface-level or deep learning strategies. Student responses to the feedback questions were coded for student attitudes towards learning.

4. RESULTS

4.1 Student Achievement

As shown in Figure 1, students with the highest pre-class quiz marks generally did well in the course, indicating that they had successful reading and learning strategies. Similarly, students with the lowest quiz marks attained lower overall marks.

Fig. 1. Student achievement by quiz and overall course mark.

Students were classified into low, med, and high-achieving categories according to their overall course mark.

4.2 Learning Strategies

Questions asking students to elaborate on concepts and make distinctions between concepts were intended to help students think in ways that would help them remember and understand the concepts better. However,

overwhelmingly, students used surface-level descriptions of the similarities and differences between concepts rather than explaining differences in meaning or explaining different contexts where the concepts can be applied. For example, in response to Quiz 8 question 1, one student said *"The law of conservation of momentum states that as long as no resultant force on a particle at certain interval of time then change in momentum is zero. The law of conservation of energy states that energy can be transferred to either kinetic or potential energy, as long as the total mechanical energy is constant. Both are similar in the sense that as long as there is no external or internal forces acting on the system then both conservation laws are valid. The one obvious difference between them is one is about momentum and the other is about energy."* Even the high-achieving students sometimes responded to these types of questions by summarizing surface-level differences between concepts.

In their responses to the feedback questions, the lower achieving students described learning strategies that amounted to waiting for the instructor to explain something. For example, one lower-achieving student did not show any evidence of using deep learning strategies but made comments such as *"It is hard for me to understand what to do with the many equations without seeing them in action."*

In some students' responses, deeper learning strategies were more evident. For example, many students described spending time and effort making sure they understood the derivations of the equations. One students' comment, *"Sometimes in the reading I found it hard to tell which moment they were talking about at any given time, so I had to read everything several times. In general I found the whole thing difficult and confusing. To try and understand it I read the page over several times but I'm still not sure I ever really got it, so I hope seeing it in class will be easier,"* is representative of this common response. Additionally, many students mentioned going to the internet to help them figure out the concepts they were reading about.

Only a few students seemed to relate the concepts in their readings to personal experiences. These comments appeared spontaneously, as students were not explicitly asked to do so. In response to Quiz 2 question 3, one student said *"The most interesting section I found was that these formulas are used for skid-pad calculations. I've been using skid-pad numbers for years for racing but didn't know the math behind them."* The same student also said *"The most interesting part was the way this can be used for aviation as relative motion is commonly displayed in most aircraft. My father used to be a pilot and I now understand the calculations that he used to do during long flights,"* in response to quiz 3. However, on the same quiz, a different student said *"I found that because there was no real life example in the book the*

concept of relative velocity was difficult to understand. I didn't fully understand the concept until I completed the previous two examples and researched the concept online."

4.3 Student Perceptions of Course Impact

The high-achieving students gave exclusively positive feedback about the format of the course. For example, one of them wrote, *"The questions gone over in lectures... allow a practical environment in which theories and concepts can be understood."*

The comments of medium-achieving students were mixed, with 2 students making negative comments. For example, one student wrote, *"I often need the explanation of a more knowledgeable mind in order to fully understand the concept."* However, 6 out of the 8 students in this group gave positive feedback, as evidenced by statements such as *"In the lecture, I can follow the material better rather than getting the information as new material during the lecture and trying to understand it afterward."*

Students who did less well in the course were also mixed in their feedback comments. Two students in this group felt negatively about the course format, writing comments at the end of the semester which tended to be related to an expectation that the teacher should lecture more, indicating less understanding of learning principles. For example, one student wrote, *"Seeing that I paid x amount of dollars for the course, I would prefer not to be graded on how I teach myself, rather on how the teacher does."*

5. DISCUSSION

The importance of active learning pedagogies and cultivating students' effective learning strategies are well recognized. This study describes a preliminary investigation of using Peer Instruction in engineering dynamics, in particular the pre-class reading quiz as an effective assessment of student learning, as well as a means to cultivate students' deep learning strategies and attitudes towards learning.

In summary, the higher achieving students in the course did better on the quizzes, and also were most positive about the format of the course and its impact on their learning. The medium achieving students were mixed in quiz performance as well as in their perceptions of the course. This trend continued for low-achieving students.

Although there was not a large enough class size for statistics to yield any significant result, the quiz marks seemed to be loosely associated with the overall class marks. While the quiz marks were relatively high, this was acceptable because the main purpose of the quizzes

was to provide an incentive for students to come to class prepared for the discussions. The quizzes being worth 10% prevented the higher quiz marks from inflating the overall marks in the course. On the other hand, since students were completing the quizzes before they received any assistance on a new topic from the instructor, it was also important that the quizzes were not too difficult. The range of quiz marks seems to indicate that these goals were achieved.

It is not surprising that students who were the highest achievers in the course also did well on the quizzes. It is likely that the strong students already had successful reading and learning strategies before starting the course, but responses to questions asking about similarities and differences between concepts indicate that all students would benefit from more explicit coaching on this skill. All students tended to rely on surface-level descriptions of concepts and few related concepts to their every day experiences, which are strategies that help with deeper understanding.

While high-achieving students would likely do well independent of any instructor efforts, it is the medium and lower-achieving students whose negative perceptions of the course were most concerning. While peer instruction has been, in large quantitative studies, shown to improve students' learning, as instructors it is our imperative to design our courses to improve chances of success for all students. In the future, links to online resources will be curated and provided to students as part of their pre-class reading assignments. It also is hoped that more explicit coaching of cognitive principles and effective learning strategies will be beneficial. This kind of coaching could also help address the problematic expectations that a teacher should lecture more in class. It is also expected that co-ordinated efforts between instructors in multiple courses will be important for helping students develop metacognition and deep learning strategies.

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APPENDIX A: QUIZ QUESTIONS 1 & 2

Quiz 1

1. Explain, in your own words, the similarities and differences between 'average' and 'instantaneous' velocity and acceleration.
2. Is it possible for an object's instantaneous velocity and instantaneous acceleration to be of opposite sign at some instant of time?
(Yes / Need more information / No)

Quiz 2

1. Explain, in your own words, the similarities and differences between rectangular and n-t coordinates, when used to describe velocity and acceleration of curvilinear motion.
2. Without air resistance, an object dropped from a plane flying at constant speed in a straight line will:
(Need more information / Move ahead of the plane / Quickly lag behind the plane / Remain vertically under the plane)

Quiz 3

1. You are driving north towards an intersection at a constant speed. Another car is approaching the same intersection from the east, and is driving at a different, but constant speed. Is the relative velocity of the second car, with respect to you, dependent on the position of the two cars? Explain in your own words.
2. Explain, in your own words, and using the concept of relative motion, why it is more difficult to run into the wind than to run with the wind behind your back (blowing in the same direction.)

Quiz 4

1. Summarize, in your own words, the strategy for solving pulley problems.

Quiz 5

1. Explain, in your own words, why a free body diagram is important.

Quiz 6

1. Describe, in your own words, the similarities and differences between using the method of work and energy, and using Newton's 2nd law to solve dynamics problems.
2. When you do positive work on a particle, its kinetic energy:

(Increases / Decreases / Remains the same / Need more information about the way the work was done)

Quiz 7

1. Describe, in your own words, the similarities and differences between using the Work & Energy method and the Conservation of Energy method to solve dynamics problems.
2. A car slows down as a result of air friction. Which is true?
(The car's kinetic energy decreases / Heat is generated / The energy of the car+road+air system is constant / All of the above / None of the above)

Quiz 8

1. Describe, in your own words, the similarities and differences between the principles of Conservation of Energy and Conservation of Momentum, and their applications.
2. A rocket is propelled forward by ejecting gas at high speed. The forward motion is a consequence of
(Conservation of energy / Conservation of momentum / both of the above / neither of the above)

Quiz 9

1. Describe, in your own words, the similarities and differences between analyzing the kinematics of a particle vs. a rigid body.
2. For a rigid body in rotation, any two different points on the body will have
(The same velocity and acceleration / the same angular velocity and angular acceleration / The same velocity but different acceleration / The same angular velocity but different angular acceleration)

Quiz 10

1. Explain, in your own words, how the relative velocity equation can be applied to a rigid body undergoing absolute motion in 2D.
2. A rear-wheel drive car moves with constant speed v to the left, as you view it. From your point of view, what is the direction of the velocity of point A on the tire, if at this instant, A is a point on the front of the tire which has the same height as the center of the wheel?
(Horizontal to the left / Down and to the left / Straight down / Down and to the right / Straight up)

Quiz 11

1. Describe, in your own words, the similarities and differences between analyzing the kinetics of a particle in translation versus a rigid body in translation.

2. The location of the centre of mass of a body will affect how much force is required to accelerate that body in a given direction.
(True / False)

Quiz 12

1. Describe, in your own words, the similarities and differences between analyzing the kinetics of a particle in translation versus a rigid body in translation.
2. The location of the centre of mass of a body will affect how much force is required to accelerate that body in a given direction.
(True / False)

Quiz 13

1. Explain, in your own words, the similarities and differences between summing moments about G and summing moments about O, for a rigid body in rotation (where G is the center of mass, which is not necessarily the same as O, the center of rotation.)
2. For a rigid body in rotation, its moment of inertia about O, the center of rotation, is always equal to or greater than the moment of inertia about G.
(True / False)

Quiz 14

1. What points on a rigid body must be used when calculating work, and kinetic & potential energy (due to gravity)?

APPENDIX B: Quiz Marking Schemes

B.1 Quiz question 1 rubric

The first question of each quiz was a short answer question, and was marked out of 2, as shown in Table 1.

Table 1: Question 1 (short answer) rubric.

	Not acceptable	Competent	Excellent
Effort/ thoroughness	0	0.5	1
Correctness/ clarity	0	0.5	1

B.2 Quiz question 2 rubric

The second question of each quiz (for all but quizzes 4, 5 & 14) was either multiple choice or true/false, and was marked out of 1, as shown in Table 2.

Table 2: Question 2 (multiple choice or true/false) rubric.

	Incorrect	Correct
Question 2	0	1

B.3 Final quiz question rubric, marked out of 2.

The final question on each quiz was short answer and reflective in nature. This question was marked out of 2, as shown in Table 3.

Table 3: Final question (short answer reflection) rubric.

	Not acceptable	Competent	Excellent
Effort/ thoroughness	0	0.5	1
Correctness/ clarity	0	0.5	1

APPENDIX C: Feedback questions

C.1 Optional feedback question on Quiz 6

How is this course going for you so far? In general, what is working for you and why? In general, what is not working for you and why? In particular, please comment on the "lecture" format of reading the theory before class.

C.2 Final feedback question on Quiz 14

In this course, you were asked to do pre-readings in advance of each topic, so that class time could be focused on practicing the application of the theory, rather than just introducing the theory. Please comment on whether the course format *affected your learning* and/or *affected your attitude towards learning*, in this or any of your other courses. Your response will be marked for effort only (a clear, thoughtful response) as there is no right or wrong answer. Please feel free to be honest! Any additional comments are also welcome.