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Promote Students' Understanding of Engineering Dynamics: A True/False Reasoning Practice

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Introduction

Dynamics is a challenging course for many engineering students. Last year, 15- 20% of the students who enrolled in dynamics did not pass the course (received a grade of D or lower) at South Dakota School of Mines & Technology (SDSM&T), a 4-year engineering college in the Midwestern U.S. In a questionnaire conducted in the middle of a semester, students indicated that this course was challenging because of two primary reasons: the requirement of mathematical skills and the "understanding" of the concepts and principles in Dynamics, Physics, and/or Statics. Students mentioned that they could not develop the connections between specific problems and the dynamics principles due to their superficial understanding.

To apply the dynamics principles to solving engineering problems, students should be able to "recall or recognize information, ideas, and principles in the approximate form in which they were learned" and "translate comprehend, or interpret information based on prior learning [1]." Constructivism suggested a person learns by relating things in a meaningful way and the structure of current knowledge determines the learning process:

> *There are two ways in which learning serves the future. One is through its specific applicability to tasks that are highly similar to those we originally learned to perform… A second way in which earlier learning renders later performance more efficient is through … the transfer of principles* and attitudes… *Transfer of principles is dependent upon mastery of the structure of the subject matter. – Bruner* [2]

The authors believe that the superficial understanding of the concepts and principles is one of the primary factors lead to the hurdles in the learning of dynamics. The goal of this study is to investigate how students relate the concepts and principles in dynamics with their prior knowledge. More specifically, what are the misunderstandings students have in learning dynamics?

Concept Inventories and Concept Maps

Concept maps have been widely applied as a heuristic tool in engineering education to promote meaningful knowledge structures for students. A concept map allows a student to organize a collection of concepts and to identify/present the relationships between each other using a graph [3-4]. Studies suggest that concept mapping be a valid tool to categorize and to reflect changes in students' structures of knowledge in STEM disciplines [3, 5]. However, concept maps emphasize the macro relationships among concepts and may not reflect students' understandings of an individual concept.

Concept inventories referred to here comprise of a series of instruments for the assessment of students' conceptual understanding of STEM disciplines. The questions were designed based on in-depth research of the common mistakes/misconceptions on the most basic concepts and incorrect mental models. Hestenes et al. [6] designed the first concept inventory in 1992 on students' interpretation of Newtonian concepts, and the first dynamics concept inventory (DCI) was not available until 2005 [7]. Although the 29 questions in the DCI address the ten "most important" concepts, students have a broader spectrum of misconceptions in the learning of dynamics. Furthermore, the DCI questions are not explicit enough to help some students especially those who may fail in the course connect abstract concepts and principles in dynamics with specific examples described in the questionnaire.

Design of the Reasoning Practices

The Engineering Mechanics Dynamics [8] was adopted as the textbook for the dynamics course at SDSM&T. There are four chapters discussing the dynamics concepts and principles about particles. The topics included curvilinear motion, work and energy and impulse and momentum. Following the book design, a reasoning practice was conducted after every two chapters. The reasoning practices in this pilot study focused on conceptual understanding of the kinematics and kinetics of a particle. Five to ten questions were provided for each reasoning practice.

To engage students with different learning styles, the reasoning practice questions kept a balance of concrete information and abstract concepts [9]. Each question in the practice starts with a statement, which is either a phenomenon or a conclusion derived from the dynamics concepts. The students worked on the questions individually for 10-15 min. Each student was asked to judge whether the statements were true or false. If a student thinks a statement is false, the student needs to justify for his/her answer using a dynamics concept/principle or an opposite example. After that, 3-4 students discussed as a team for another 15-20 min to achieve consensus on their answers. The correct answers were disclosed by the end of the review session.

To provide students with equivalent practice opportunities as those in the control semesters, the content of the review session, including a brief summary of the present two chapters and one representative question as well as the solution to it, was uploaded as a PDF file on Desire2Learn (D2L), an integrated learning platform designed to create a single place online for instructors and students to interact and was available to the students till the end of the semester. Students in both semesters were encouraged to contact the instructor for questions through email or face-to-face during office hours.

To inspire students' thinking and to encourage them to summarize the rules for applying the dynamics principles, the authors tried to create paired statements as shown in Table 1. Note that the categories for the questions, such as "Kinematics" and "Kinetics", were not shown to the students and the questions may not have been presented to the students in one practice.

Results

A total of 24 students enrolled in the dynamics course in fall 2015 at SDSM&T were involved in this pilot study as the experimental group and those in the fall 2014 semester were in the control group. Students' understanding of the concepts/principles involved in the reasoning practices was investigated in this pilot study. The common misunderstandings of these concepts were summarized in the following paragraphs.

Table 1. Sample questions for the reasoning practices

Num.	Sample Statements	True/ False	If false, why
	Kinematics		
1	If the Velocity-Time graph is a horizontal line, the particle is staying at rest.		
2	If the v-t graph is a linear descending line, the acceleration of the particle is decreasing.		
3	If a particle is moving in circle at a constant speed, the acceleration of the particle is zero.		
4	In curvilinear motion, the actual direction of the radial component of the acceleration of a particle can point towards or away from the coordinate system's origin.		
5	In curvilinear motion, the actual direction of the normal component of the acceleration of a particle can point towards or away from the center of curvature.		
	Kinetics		
6	The external resultant force must be in the same direction as the motion.		
7	The external resultant force must be in the same direction as the acceleration.		
	Work and Energy		
8	Gravitational potential energy can be either positive, zero, or negative.		
9	Elastic potential energy can be either positive, zero, or negative.		
10	When a spring is stretched by 5 in, it has more elastic potential energy than when it is compressed by 5 in.		
	Conservation of Linear Momentum		
11	If two same-size balls A and B are coming from the opposite direction, $m_A > m_B$. Ball B will experience a larger change of momentum.		
12	If two same-size balls A and B are coming from the opposite direction, $m_A > m_B$. Ball A will experience a larger change of momentum.		

Kinematics of a particle: Velocities and Accelerations

Among the five questions about velocities and accelerations (Table 1), no students made mistakes on the question about velocity only, however, more than 1/3 of the students had incorrect answers on three questions testing the relationships between velocities and accelerations as well as the use of coordinate systems when analyzing accelerations. The first misconception was accelerations would have the same changes as velocities, that is, if a velocity decreases, the acceleration would decrease with it. The second misconception was the ignorance of the characteristics of velocity. All students who made mistake on this question did not treat velocity as a vector but a scalar quantity. They thought if the speed does not change, the acceleration would be zero. The third misconception was caused by the confusions of the assumptions when use the radial and transverse coordinate components. Half of the students who made mistakes on the questions (#4 and # 5) believed "*(the actual direction of the radial component of the acceleration) always points away (from the origin)*".

Kinetics of a particle: Forces and accelerations

Only two questions were designed for this section in this pilot study (Table 1). Ten students made mistakes on question #6 and eight on #7. Interestingly, most students who made correct judgments over the two questions justified for their answers; however, no students who made mistakes on either or both questions did so. Some students used abstract justification, such as "*It (the external resultant force) can resist motion*"; while some provided concrete examples as "*Friction*". It is believed that the second cohort of students has not developed correction connections between external forces and kinematics of a particle.

Work and energy of a particle

Three questions were used for this section in this pilot study (Table 1). Five students had wrong True/False judgment on question #8 and eight students on question # 9; however, no students had wrong answer for question #10. There was one student who made correct true/false judgment on questions #8 but gave a wrong explanation. Two types of misunderstandings were reflected in students' justifications for their answers on questions #8. Type 1: Thought gravitational potential energy was the same as elastic potential energy, which cannot be negative. Type 2: Confused gravitational potential energy with work done by gravity.

> *Type 1:*
> *"It is always positive or zero."*
>
> *Type 2:*
> *"Gravity only acts in one direction-downward."*
> *"If you pull an object up, gravitational potential energy is negative & vice versa. If it doesn't move, it is zero."*

Questions #9 and #10 can be derived from the same equation: $V_e = \frac{1}{2}ks^2$ and almost all students listed it in the explanation for question #10, including the eight students who had wrong True/False judgment on question #9. Here are two sets of answers from the eight students:

> *Question #9*
> *Student 1: "(Elastic potential energy) depends on our datum, and if you are pushing or pulling the spring."*
> *Student 2: "(Elastic potential energy) depends on if spring is compressed or stretched. "*
>
> *Question #10*
> *Student 1: "It is the same PE,* $V_e = \frac{1}{2}ks^2$ *"*

Student 2: "the |change in position| (absolute value) is s in both cases."

Linear impulse and momentum

Four questions with a focus on the conservation of linear momentum of a system of particles were involved for this section in the pilot study (Table 1). The two questions (#11-#12) were involved in this pilot study (Table 1). Only four students had correct answers and explanations on questions #11 and #12. Many students made incorrect analogy between momentum and inertia and failed to connect linear momentum with mass and velocity. Some students believed when two particles collide, the one with larger mass would experience a smaller change of momentum. While some students thought the one with larger change velocity had larger change in linear momentum.

> "$m_A > m_B$*, therefore, B with lighter mass changes momentum greater*."
> "*If the ball B starts going one direction, gets hit, and ends up going in the other direction, it will experience a larger change in momentum.*"

Reflection in problem solving

To avoid sharing information about the test questions, two questions on potential energy (PE) of a particle and the principle of conservation of linear momentum were test and re-tested in one midterm examination in the fall 2014 (control group) and fall 2015 (experimental) semesters, respectively. Students' mistake rates on the two questions were compared in Figure 1.

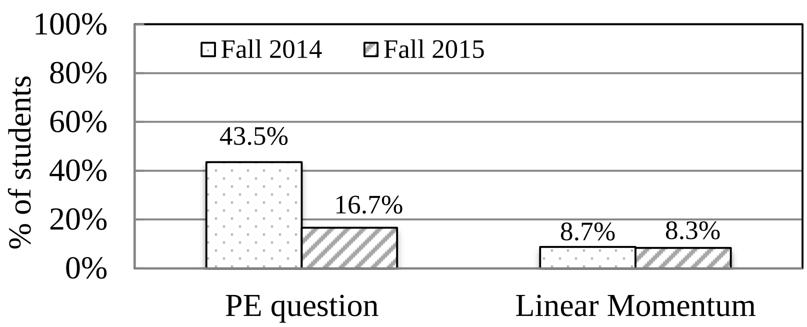

Figure 1. Comparison of mistake rate

Ten (10) out of 23 (43.5%) students in the fall 2014 semester failed to identify the total potential energy of the particle using the given datum while only 4 out of 24 (16.7%) students in the fall 2015 semester made similar mistakes. No significant difference was found on students' mistake rate on the linear momentum question.

Discussions and Future Study

Although the students were able to achieve correct consensus on most statements during the reasoning practices, a few misconceptions persisted before the instructor provided hits or explanations to them. For example, although some students on a team had correct T/F judgement over statement #6, the team drew wrong conclusion over the relationships between the directions of resultant force and motion. It indicates the importance of instructor guidance during the peer learning practices. Therefore, the reasoning practices can be used as review practices in class as described in this paper.

It can also be assigned as pre-reading guidance to help students generate questions which will be addressed in class by the instructor or through peer discussions under the supervision of the instructor. Furthermore, the misconceptions identified in the reasoning practices in this study can be used as a reference for the instructors to select examples or homework problems during the teaching of dynamics.

At the time of this paper, only students' understanding and application of work and energy and conservation of linear momentum were tested. More test questions will be developed and repeatedly tested to investigate the impact of the reasoning practices on students' learning of dynamics.

The average grades of the midterm examinations in the fall 2014 and fall 2015 semesters showed no statistically significant difference. The future study will focus on 1) conducting the reasoning practices at other institutions to verify the findings in the pilot study and 2) exploring students' misunderstandings on other topics to develop comprehensive reasoning practices for Dynamics.

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