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Analysis of Student Understanding of Force Using the Dynamics Concept Inventory, Think-Alouds and Confusion Matrices

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Work in Progress: Analysis of Student Understanding of *Force* using the Dynamics Concept Inventory, Think-Alouds and Confusion Matrices

Concept inventories have been used to measure student understanding of different concepts in many different courses. They are designed to have distractor answers to help those evaluating student responses identify where there may be misconceptions. But it still may be difficult to determine a student's thought process at the time they answered the question.

In this study we use a combination of Think-Alouds and Confusion Matrices to evaluate student responses to two questions regarding Force applied to particles and rigid bodies in the Dynamics Concept Inventory. A Think-Aloud is a recording of a student expressing their thoughts aloud while taking an exam. A confusion matrix is a 2x2 matrix with column headings scoring Student Oral Reasoning as correct or incorrect and row headings scoring Question Outcome as correct or incorrect. It is expected to illuminate the influence of luck versus true understanding.

As expected, preliminary analysis indicates students have a stronger conceptual understanding of how forces affect particle motion than rigid body motion. This seems to carry through before and after a dynamics class.

Work in Progress: Analysis of Student Understanding of *Force* using the Dynamics Concept Inventory, Think-Alouds and Confusion Matrices

Introduction

Concept inventories are a great way to evaluate student understanding of material and as a tool to evaluate teaching [1]. Concept inventories have been developed for subjects such as Physics, [2], Statics [3], [4], Dynamics [5] , Strength of Materials [6], Heat Transfer [7] and many other topics [8]. At times, students can matriculate through classes based on procedural efficiency because they are good at knowing how to solve different *types* of problems; yet, they may still not have a good conceptual grasp of the material in question even by the time they graduate. Some work has also been done to make correlations between concept inventory and course performance [9], [10], [11].

Even more challenging is assessing student's actual thought process at the time they are selecting answers for a concept inventory test. Haven't you said to yourself, at least once, when grading an exam, "What were you thinking?" in response to a conceptual error from a student? To get to the answer of this "What were you thinking?" question, we asked students to vocalize their thought process while taking a Dynamics Concept Inventory in an online setting. Videos of their test were recorded using proctoring software and graded for correctness of both Question Outcome, if the student answered correctly, and Oral Reasoning, if the student vocalize the correct process. More on this to follow.

This work is a continuation of our previous work on a dynamics concept inventory and a performance evaluation with student Think–Alouds and confusion matrices [12]. Previously, two questions were evaluated, and the results indicated students struggled to understand what was happening in the problems. This led to improved presentation of the questions to hopefully improve student understanding. The current work evaluates two additional questions focused on the topic of force. Our objective is to gain insight into students understanding of *force* on particles versus rigid bodies. The bigger picture of this work is to gain insight into a student's process when analyzing conceptual problems.

Methods

We followed the same procedure from previous work in which confusion matrices are used to analyze results of student responses to questions in a Dynamics Concept Inventory [12]. The answers to the DCI exam were evaluated and recorded in the Learning Management System at our university. In addition, video and audio of the student taking the exam was recorded using a proctoring software: Proctorio. Videos were viewed and scored independently by two faculty for Oral Reasoning – an indication as to if the student thought process was sound in selecting their answer. These data were collected in a confusion matrix (see Table 1 below), a commonly used statistical classification tool that is a 2x2 contingency table, that can provide insight to the types of errors students are making [13]. Usually, we expect/hope students land in the upper left of this matrix in which they select the correct answer for the correct reason. But often students may achieve the correct answer for an incorrect reason (upper right of matrix) – they are lucky.

Table 1. Confusion matrix used to score concept inventory student transcriptions regarding oral reasoning.

		Student Oral Reasoning	
		Correct	Incorrect
Question Outcome	Correct	Correct Answer and Correct Reasoning	Correct Answer but Incorrect reasoning
	Incorrect	Incorrect Answer but Correct Reasoning	Incorrect Answer and Incorrect reasoning

In this study we selected two questions from the DCI that investigated a student's concept of force acting on bodies. Questions 11 and 15 were selected because one focuses on a Force acting on a Rigid Body, and the other focuses on a Force acting on a Particle. The first question (Question 11) asks students to describe the motion of the center of mass of a rectangular mass on a frictionless table when a constant force is applied.

Question 11

Question 11

The box of mass m is initially at rest on smooth, frictionless, *horizontal table.* The box is pulled by a string that exerts a *constant* force $\vec{F}$ applied at the hinge at A. The orientation of the line of action of $\vec{F}$ is constant and the center of mass of the box is at G. Concerning the path of the mass center of the box and how the orientation of the box will change, which of the following statements applies?

(a) Mass m will begin to rotate and point G will begin to move up and to the right.

(b) Mass m will begin to rotate and point G will begin to move down and to the right.

(c) Mass m will begin to rotate and point G will begin to move to the right.

(d) Mass m will begin to rotate about point G, but point G will not move.

(e) Mass m should not begin to rotate.

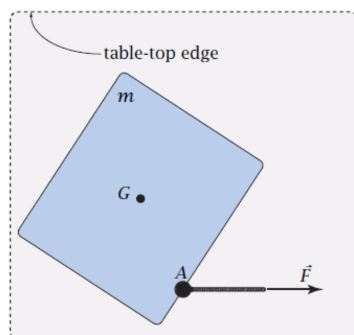
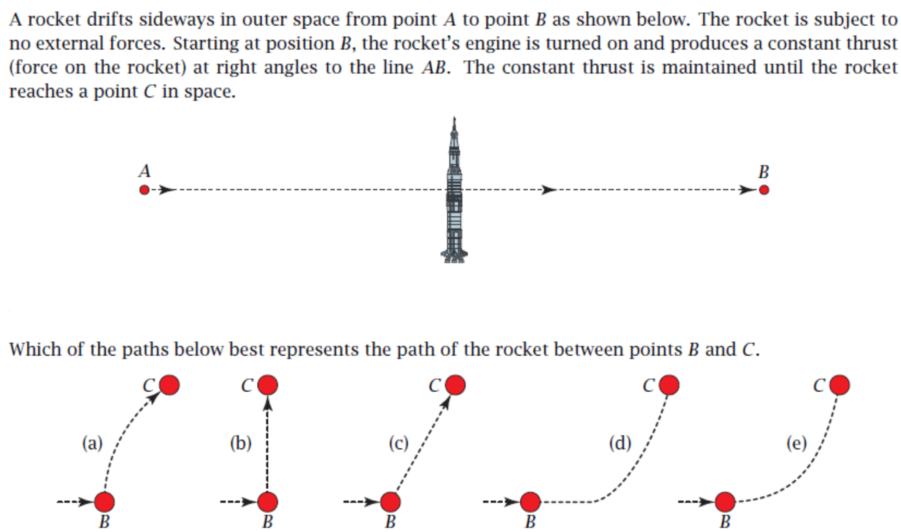


Figure 1: Question 11 from DCI. This question gets at the concept of force acting on a rigid body and how the force would affect the motion of the center of mass of the rigid body.

Question 15


A rocket drifts sideways in outer space from point *A* to point *B* as shown below. The rocket is subject to no external forces. Starting at position *B*, the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line *AB*. The constant thrust is maintained until the rocket reaches a point *C* in space.

Which of the paths below best represents the path of the rocket between points *B* and *C*.

Figure 2: Question 15 from DCI

This question tackles the concept of force acting on a body and how a constant force might affect the path of the body.

General Performance Results

General scoring of student answers to these two questions for before and after a dynamics course are indicated in Figure 3 below. For question 11, about rigid body motion with a force applied, indicates only about one-third of the students answered correctly. The most common distractor answers were B and D.

Pre-Course Results

		c	
Q11	A	5	12.20%
	B	13	31.71%
	C	13	31.71%
	D	8	19.51%
	E	2	4.88%
	Total	41	100.00%

Post-Course Results

		c	
Q11	A	1	2.78%
	B	9	25.00%
	C	13	36.11%
	D	12	33.33%
	E	1	2.78%
	Total	36	100.00%

Figure 3: Question 11 Pre- and Post-Course results

Whereas over 45% of the students correctly answered the question about force acting on a body to affect its motion in what is, essentially, a particle motion problem. And answer C is the most common distractor answer. This, we believe is an indication of students not necessarily connecting the concept of what constant acceleration looks like when it is integrated to motion – a basic calculus concept.

Pre-Course Results

		e	
Q15	A	1	2.44%
	B	0	0.00%
	C	12	29.27%
	D	5	12.20%
	E	23	56.10%
	Total	41	100.00%

Post-Course Results

		e	
Q15	A	1	2.78%
	B	5	13.89%
	C	10	27.78%
	D	3	8.33%
	E	17	47.22%
	Total	36	100.00%

Figure 4: Question 15 Pre- and Post-Course results

Confusion Matrix Results

The confusion matrix results are shown in Figure 5 for both concept inventory questions and independent evaluations. Each question has 4 matrices, pre- and post-course for each evaluator. Overall performance on both questions 11 and 15 was poor as evidenced by the large number of incorrect responses who also had incorrect reasoning (row 2 and column 2 of each matrix). Student performance did not improve post-course for Question 11 and decreased for Question 15.

Independent evaluations by the authors were similar for question 11 but differed for question 15. There was some disagreement for question 15 on what constituted correct oral reasoning for correct answers. This was most notable in the pre-course for question 15. It is worth noting that evaluator 2 has much less experience evaluating student work in dynamics. Evaluator 1 noted the addition of vectors was considered correct reasoning in addition to time varying relationship between displacement and acceleration. Despite this evaluator discrepancy, the results indicate a significant percentage of the correct responses either lacked correct reasoning or students were unwilling to vocalize their reasoning. This could suggest luck over true understanding of the question concepts.

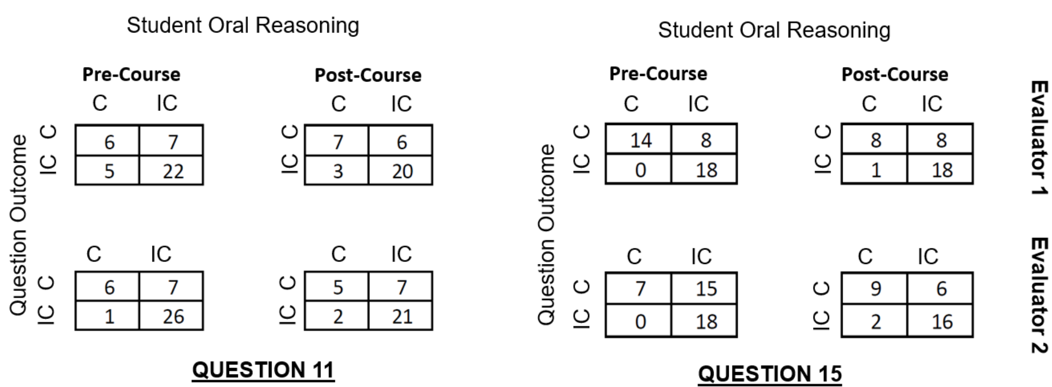


Figure 5: Confusion matrix results summarized for Question 11 and 15 as scored independently by the authors (Evaluator 1 and 2).

A few student responses were classified by both evaluators as correct oral reasoning but an incorrect question outcome. This was more common for question 11. To gain more insight into these difference classifications, sample student responses are presented in the next section.

Question 11 Student Discussions

Pre-Course Incorrect discussions:

"It's frictionless … I think it's going to move down and to the left. Mass M will begin to rotate … I think it will move down and to the right … but does it for sure rotate. Oh but this is a good point, mass M will begin to rotate about point G or point G will not move. I think that would happen if the force was excited in the middle like the axis is at the center of mass. I think it's going to be B."

Pre-Course Correct discussions:

"SO the mass will … and I don't think there's any reason for the center of mass to move either up or down. Since all of the force in the horizontal direction. I think it'll actually … the square will actually rotate about G … and then … and then that will … as it does that … it'll move the right a little bit. So …"

Post-Course Incorrect discussions:

"The center of mass won't move, I don't believe … because if the whole box is being rotated … the center of mass isn't going like translate … it's just going to rotate ... which means will stay in the same spot … so that way … its E."

"I don't think G would move because it's the center of mass … so its rotating … but that doesn't change where the center of mass is."

Post-Course Correct discussions:

"Ok so the box is initially at rest … pulled by a string … constant force … ok horizontal table … just like this … well the force is definitely going to cause it to rotate. And it's frictionless … like it's going to pull on it … I think … it's like this … I mean point G is definitely going to move to the right because the force is pulling it to the right. Pulling the whole box. But … since the force is at the bottom ... like towards the bottom of the box … but it's actually the force is directly horizontal so I don't think G is going to move down … if F was pulling down and to the right … then it would move down and to the right. It's just strait … so I think it's just to the right."

"Constant force … mass M will begin to rotate and point G will begin to move up and to the right?? If it's frictionless … then it should just pull it directly to the right without any rotation. But it will still rotate. But it should just be here. SO, G should just be moving to the right. Cause this is just horizontal."

Question 15 Student Discussions

Examples of student discussions from the question 15 before a Dynamics class. Notice that students are still thinking about how vectors add. However, others have made the correct connection between acceleration-velocity-position and calculus.

Pre-Course Incorrect discussions:

"Drifts sideways … starting at B … so the second it gets to B turns on constant thrust … right angle to the line AB. So it's going to be C, because it goes this way and it goes that way and add them together Pssst … it goes right there."

"OK … it'd be a straight line and cause it's a vector and since there's nothing to stop the rocket from moving the direction from A to b, it'd be this one because the .. B would show something stopping the A to B motion when but that won't happen in outer space."

"OK so here, I get it clearer instead of the one before. Here it is moving straight on the horizontal position and then it starts to have ah … a … vertical force, so it will create what I said in in the before, it will have a component ... so it will be ... so what I see here … it was moving. So it will keep, it will keep, its inertia will be on the left and they will, it will start having a thrust that is pushing now upward in the Y, in the Y direction, so it will have an X component and a Y component, will create a tangential motion going with a, with a , like a diagonal direction to point C, so what I see here it will be case, it will be case C, so it will be the one that is like diagonal from point B."

Pre-Course Correct discussion:

"The rocket drifts sideways in outer space … constant thrust. So, it's accelerating to it should be curved … right angles."

"If it's a constant thrust, and it's obviously the same mass, so that means the acceleration is constant. Now we want to look at the speed. If the acceleration in constant, that means – what does that mean for the velocity or for the speed in this case. Is constant … continually increasing. I always think about it from a calculus standpoint. Change in (undistinguishable) increasing, continually increasing. Its speed. I mean if I integrate a constant it's going to give me a linear motion so we are talking … it's going to be a linear motion. (Yawn). It's continually increasing just based on … Now that I'm thinking about this further, I'm going to have to get a location. Ds dt I have to think about that further. I think the position would then look quadratic which means the previous solution should not be the one I chose … So, I'm going to answer to E, just thinking about it further. If I'm arguing that the speed is continuously increasing, then, then my position should be more than … the shape is probably like E. and A is decrease … and C is increasing motion."

"So again, it should be the addition of two vectors which would give us straight line, which would give us C. *(Changed after reading Q16)* So if velocity is increasing … then it should look more like E."

Post-Course Incorrect discussions:

"Hmmm … Like the collision problems … this will also result in the direction going along the line of impact … where the Y coordinate. Wherever you make the coordinate system. SO this one will be B."

Post-Course Correct discussions:

"It's constant … then you can't be B or C because there's no acceleration. I think it can be either A or E … because if that's the path then the velocity is tangent and that would make the acceleration (mumble) zero. I think it will be E."

Discussion

Thus far, students' responses to these two questions asking about force acting on bodies indicate over 50 percent of students entering a Dynamics course come in with a good understanding of particle motion and its relation to acceleration and velocity. Although this dips a bit after a Dynamics course, it remains high – still around 50 percent.

When it comes to answering conceptual rigid body dynamics problems, students are less successful. This is probably because rigid body dynamics concepts are sometimes 1) harder to illustrate in a classroom setting, and 2) students have less experience with the concepts. Methods for correcting these issues include having hands on demonstrations to address these concepts so that students can experience and observe these phenomena. Of course, some of the obstacles here include the fact that some of the concepts can be difficult to illustrate; they can be more of a thought experiment. If we hope to have students leave our class with good a conceptual understanding of rigid body dynamics, and its associated phenomenon, we should probably find a good balance between illustrating concepts through a mix of 1) problem solving, since we want engineers to be good problem solvers, and 2) providing students realistic hands-on experiences with those concepts. However, developing those experiences is another challenge.

Finally, student comments indicate they rarely discuss their thoughts in terms of equations from dynamics. This was observed for all four questions evaluated thus far [12]. However, this did improve in the rocket (particle motion) problem – probably because it was a concept with which students are more familiar. This is a challenge that needs addressed to help students better understand that concepts in dynamics can be counterintuitive.

Conclusion

For two questions from a dynamics concept inventory exam, our results indicate student performance did not improve after the course for either topic (particle or rigid-body motion). Student oral reasoning also seemed to be unaffected by course content. As with most mechanics courses, dynamics course content is heavily focused on equation development and problem solving. Our results indicate students struggle to apply equations to conceptual questions where the correct response can seem counterintuitive.

Our methodology of using student Think-Alouds with classification of student responses into a confusion matrix is sound. For implementation, evaluator discrepancies were noted; in particular, we failed to identify correct or incorrect oral reasoning consistently in Question 15. After discussion of our scoring criteria, we realized that one evaluator was more strict/forgiving in terms of assigning correct/incorrect reasoning for different parts of the question. This could be reduced by explicitly identifying criteria to be considered correct oral reasoning before scoring.

Additionally, many students seemed uncomfortable verbalizing their thoughts during the exams and may not have been motivated to perform well since there was no incentive to perform well. This may be unavoidable given the general difficulty that a Dynamics course poses for many students, including knowledge that they are being recorded. The setting which students were asked to take the exam (their own home) may have influenced their desire to speak aloud. Perhaps providing 1) an isolated testing location and 2) a grade/cash incentive to encourage *active* participation is needed.

Finally, since most concept inventories include multiple questions that test the same concept, we should include analysis of these other problems to investigate these issues more fully. However, these results are representative of student's results. More analyses of student results on problems testing the same concept are part of future work.

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