AC 2003-337: CONCEPTUAL ISSUES AND STUDENT ATTITUDES TOWARD ACTIVE LEARNING EXERCISES IN INTRODUCTORY MECHANICS

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Conceptual Issues and Student Attitudes Toward Active Learning Exercises in Introductory Mechanics

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Abstract – This paper will report on results of an assessment of in-class active learning exercises in introductory physics courses. The assessment is being conducted to explore conceptual issues in student understanding of Newton's Laws. Students work in small groups on activities that have been specifically designed for this purpose. Examples of these activities are provided. We also present the results of a survey of student attitudes toward their experience in collaborative learning. The goal of this paper is to explore common misconceptions and student difficulties in mechanics across a wide range of student abilities and backgrounds. Suggestions are provided on how to enhance the classroom experience based on these activities and surveys.

Introduction

The past several years have seen a renewed enthusiasm for the development of new instructional materials and approaches in introductory physics education at the college level[1]. At the core of these efforts is a shift away from a traditional physics curriculum that emphasized textbook problem-solving, descriptive knowledge, deductive reasoning and a top-down approach to instruction. Physics education research has been instrumental in the move towards a student-oriented approach that recognizes that students learn better when they are actively engaged in the learning process itself. In particular, the pioneering works of Arnold Arons and Lillian McDermott have provided an excellent framework for systematically modifying the traditional method of instruction[2,3].

Such an approach has been shown to be particularly useful in engaging a diverse student body, such as exists in the College of Engineering & Science at the University of Detroit Mercy (UDM)[4,5]. The student body at UDM is nearly sixty percent women, and over forty percent students from underrepresented groups. Enrolment in introductory physics courses that are part of various engineering undergraduate programs, broadly reflect this diversity.

This paper represents an attempt by the authors to further incorporate a more student-centered approach to the subject through the use of in-class exercises that promote critical thinking and collaborative learning. The paper is written as follows: In the next section, we give a brief description of the exercises and the goals underlying these activities. Subsequently, we analyze the ability of students to apply Newton's Laws and the principles of mechanics based on their responses to these assignments. Student attitudes towards these in-class exercises were assessed using surveys, whose results we report in the paper. Finally, we conclude by indicating directions for future research.

Description and Goals of Collaborative-Learning Activities

The activities described below were assigned to two groups of undergraduate students – engineering majors in a calculus-based course and science majors in an algebra-based course. Students were given an entire class period of fifty minutes to work on the first activity, while we limited the time spent on the second activity to a thirty minute session. For both activities, students were first required to work on the problem individually for a brief period of time. Subsequently, they collaborated with their neighbors to continue working on the problem.

In the first activity, students were provided a problem on analyzing free-body diagrams (see Figure 1, Appendix A), which would require them to correctly apply Newton's Second and Third Laws. The problem involved a piece of paper held on to a refrigerator by a magnet. Rather than ask them to draw the free-body diagrams for the paper and the magnet, they were given two free-body diagrams and asked to identify all the forces involved with each object. For each force, they were asked to identify the magnitude, the type (for example gravitational, frictional, normal forces etc.), as well as the two objects involved in the interaction. One force vector was provided in the figure to ensure a unique solution to the problem. The students were required to fill in a table and answer a couple of questions based on their calculations. At the end of the exercise the students were asked to fill out a survey to gauge their opinions on the appropriateness and usefulness of the activity.

In the second activity (see Figure 2, Appendix A), students were tested on their ability to apply the principles of rotational equilibrium through the problem of a person standing on a stationary ladder that is resting against a wall. In this case, they were not only asked to identify the forces, but were also required to calculate the appropriate torque for each force. A similar survey was administered at the end of this activity.

It was our goal to utilize these exercises to investigate various issues surrounding the application of Newton's Laws to the principles of equilibrium. The activities were designed to address the following questions:

1. To what extent do students understand the role that force vectors play in representing interactions between objects in a free-body diagram?
2. To what extent are students able to correctly identify the force-pairs dictated by Newton's Third Law, and to apply their reasoning to calculate unknown force magnitudes?
3. To what extent are students able to correctly apply the principle of equilibrium arising from Newton's Second Law, in order to calculate the magnitude of unknown forces and torques?

In the course of grading and analyzing student responses, we found that an overwhelming number of students were unable to complete the second activity in the limited time that we had allotted for this purpose. Consequently, in the next section, we have focused more attention on the pedagogical issues arising from the first exercise on free-body diagrams. However, we shall point out interesting similarities in student understanding that we found in both activities.

Conceptual Issues in Student Understanding: Observations & Analysis

On the role of force vectors in free-body diagrams, we found that a majority of students had trouble identifying the two objects involved in each interaction. Students were explicitly told that the free-body diagrams in Figure 1 were of the magnet and the paper. Yet, many identified some of the force vectors as acting on the door, Earth or other objects. Only 48% of the students were able to correctly associate the free-body diagrams in Figure 1 as that of the paper and magnet, respectively. These students were subsequently able to translate this knowledge into the correct entries in the third column of Table 1.

We found that among the 52% of incorrect responses, most had labeled the free-body diagrams correctly but were inconsistent in identifying all force vectors in a free-body diagram as acting *on that object* alone. In other words, the majority of these students were unable to correctly fill out the third column in Table 1. Our analysis leads us to conclude that the students who made these mistakes either did not have a clear understanding of the concept of a force or of the representation of force-vectors on a free-body diagram.

However, these activities were not designed to test their understanding of these underlying concepts. Rather, they were designed to assess students' ability to apply principles that were based upon the concepts of forces and free-body diagrams. In subsequently analysis, we excluded all 52% of students who gave these incorrect responses, based on the fact that they had demonstrated a clear lack of understanding of the underlying concepts.

Table 1: Solutions to free-body diagram exercise shown in Fig. 1, Appendix A.

	Type of force	Object causing force	Object the force is acting on	Magnitude (N)
A	Frictional	Paper	Magnet	0.60
B	Magnetic	Door	Magnet	2.50
C	Gravitational	Earth	Magnet	0.60
D	Normal	Paper	Magnet	2.50
E	Frictional	Door	Paper	0.75
F	Normal	Magnet	Paper	2.50
G	Gravitational	Earth	Paper	0.15
H	Frictional	Magnet	Paper	0.60
I	Normal	Door	Paper	2.50

We then investigated the ability of students to apply Newton's Third Law to find the magnitudes of unknown forces. As illustrative examples of such an application, it is clear from Table 1 that force vectors A and H represent a Third-Law pair, as do force vectors D and F. In analyzing student answers, we found that only 33% of these students were able to calculate the correct magnitudes for these forces by identifying that they should be equal and opposite.

Finally, we also found that students had a difficult time recognizing the significance of the Second Law in equilibrium situations. Most did not use the fact that the forces should all add up to zero in each component direction to constrain the magnitude of forces acting in that direction – reasoning that would have considerably simplified the completion of the last column in Table 1 above. As an example, we notice, from the free-body diagram of the magnet in Figure 1, that forces represented by vectors A and C are an equilibrium pair. A similar situation holds for the forces represented by vectors B and D. We found a rather interesting pattern when tabulating student responses to these two specific examples.

We found that only 16% were able apply the principle of mechanical equilibrium to calculate the correct magnitudes for vectors A and C, whereas 88% of them were able to correctly identify the magnitudes of the force vectors B and D. Upon closer inspection of their calculations, we noticed that all the students who incorrectly calculated the magnitudes of A and C had used the relationship between normal forces and maximum static frictional forces ($F_{friction,max} = \mu F_{normal}$) to calculate the magnitude of force vector A, even though that equation is clearly invalid in the given situation. In every single case, the magnitude they calculated for A was the product of one of the given coefficients of friction times an identifiable normal force from Table 1. Many of these students, in turn, did not use the correct value of the normal force (represented by force vector D) in the above relation. Instead, they incorrectly identified the magnitude of the normal force with the weight of the magnet, seemingly based on their experience with objects on horizontal surfaces.

We noticed a similar pattern with the second exercise involving the application of the principle of rotational equilibrium. From Figure 2, it is clear that force vectors f_1 and f_4 form an equilibrium pair, as do f_2 and f_3. We found that, despite being unable to complete the problem, 59% of the students managed to correctly calculate the magnitudes of force vectors f_1 and f_4 using the principle of equilibrium. Insufficient time prevented most students from identifying the magnitude of vector f_3, needed for calculating f_2.

Student responses to these exercises have raised important pedagogical issues. The idea that force vectors in a free-body diagram indicate forces acting *on* an object, produced by various external agents, is a difficult concept for many students to grasp. Students also do not recognize the important constraint imposed by Newton's Third Law on the magnitudes of forces between pairs of objects. Exercises specifically targeted towards training the students in these concepts and their applications are crucial to their understanding of Newton's Laws.

These exercises were also designed to engage students with abstract reasoning skills rather than the concrete skills required for traditional problem-solving assignments. Students' starkly differing responses while calculating the magnitudes of forces A and C versus those of B and D in the free-body diagram exercise make it clear that where students did not have equations to rely upon, they worked collaboratively to apply abstract principles - Newton's Second and Third Laws – in order to correctly solve the problem. However, in those cases where they had a choice to use equations they had learned in class, the overwhelming majority incorrectly relied on those equations.

Assessment of Student Attitudes

By way of assessment, students were asked to complete a survey after the completion of each activity. The survey consisted of five statements that are listed below. A Likert scale (SA=strongly agree, A=agree, N=neither agree nor disagree, D=disagree, SD=strongly disagree) was used to rate these statements. Results are shown in Tables 2 and 3 as percentages of the total sample (N=50).

The survey statements were:
1. The level of difficulty of the problem was just right for me.
2. The problem forced me to think about physics concepts (rather than just plugging in numbers).
3. Working with other students helped increase my understanding of the physics concepts required to solve the problem.
4. I was able to complete the problem in the time available to me.
5. The problem was representative of the material we were taught in class.

Table 2: Student responses to free-body diagram exercise shown in Fig. 1, Appendix A.

	SA	A	N	D	SD
Statement 1	8	67	14	10	0
Statement 2	41	55	4	0	0
Statement 3	53	37	8	2	0
Statement 4	14	41	16	27	2
Statement 5	27	67	4	2	0

Table 3: Student responses to rotational equilibrium exercise shown in Fig. 2, Appendix A.

	SA	A	N	D	SD
Statement 1	8	52	26	14	0
Statement 2	46	48	6	0	0
Statement 3	43	41	12	2	2
Statement 4	2	24	10	58	6
Statement 5	26	60	14	0	0

It should be noted that the survey statements were subjective in nature. For example, the notion assessed in Statement 5 that the exercise was representative of material taught in class partially reflects students' perceptions of their own level of understanding. A similar case can be made regarding student perceptions of the difficulty level of the problem. This fits well with our goal of broadly assessing the attitudes of students towards these types of collaborative exercises.

From the tables, it is clear that, with the exception of Statement 4, more than 60% of the students either "Strongly Agreed" or "Agreed" with the other statements for both activities. The inadequacy of the limited time allotted to the second exercise is reflected in student responses to Statement 4 in Table 3. Overall, we believe that the surveys indicate that the students found the activities to be useful and educational.

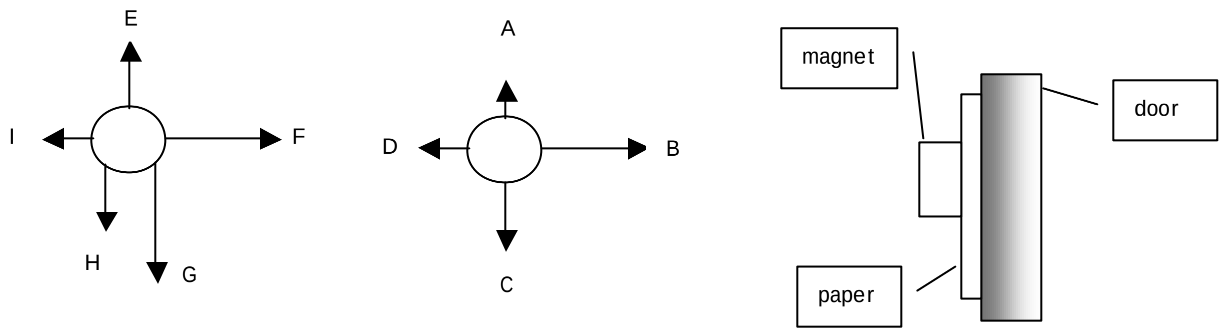
Conclusion

These activities have raised two important pedagogical issues within the context of conceptual exercises in introductory mechanics. Most importantly, they have demonstrated the need to train students in abstract reasoning skills using carefully developed problem contexts where they do not have the "choice" to use equations and other concrete reasoning methods to solve problems.

A second issue is raised by our observation that most students were unable to make much progress while working individually on the problem. Clearly, the dynamic interaction between students was necessary to allow them to make significant progress in the allotted time. This fact, coupled with their very positive responses to working collaboratively, reinforces the usefulness of this pedagogical method. We plan further study of this collaborative-learning dynamic using these exercises with future groups of engineering and science students.

Appendix A

After receiving your physics test you are so proud of it that you stick it to the refrigerator with a magnet. The magnet has a mass of 60.0 g and the exam paper has a mass of 15.0 g. The magnetic force on the refrigerator door is 2.50 N. Assume that g is 10 N/kg and the coefficient of friction between the magnet and the paper is 0.40 and the coefficient of friction between the paper and the door is 0.35. Shown below are two free-body diagrams, one for the magnet and one for the paper. They are not labeled and either are the nine forces. The lengths of the arrows are not necessarily correct although the directions are.



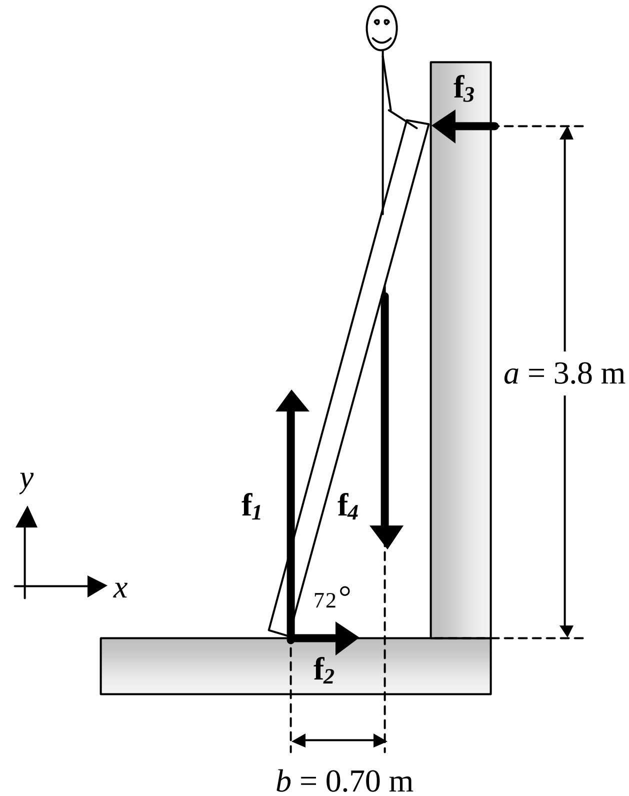
a) Fill in the following table describing each force as was done in class.

	Type of force	Object causing force	Object the force is acting on	Magnitude (N)
A				
B				
C				
D				
E				
F				
G	gravitational			
H				
I				

b) Which forces would change if the magnet were replaced with one that was identical but stronger?
c) Calculate the weight of the heaviest exam paper that could be held up by this magnet.

Figure 1: Free-Body Diagram Exercise

An 83-kg person stands on a lightweight ladder. The forces acting on the ladder are shown as f_1, f_2, f_3 and f_4. Use the bottom of the ladder as the axis of rotation. The ladder is in equilibrium. Use g = 10 m/s^2 for your calculations.



a) Fill in the following table describing the forces and torques on the ladder.

Force	Type of force	Object causing force	x-component of force	y-component of force	Moment-Arm	Torque due to force
f_1						
f_2						
f_3						
f_4						

b) What minimum coefficient of friction is needed to keep the ladder from slipping on the floor?

c) The person now steps down a couple of rungs of the ladder. The minimum coefficient of friction needed to keep the ladder from slipping

i. Increases
ii. Decreases
iii. Stays the same
iii. It depends on the situation

Figure 2: Rotational Equilibrium Exercise

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