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Active Learning Laboratories in a Restructured Engineering Physics-Mechanics

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Abstract

Over the past several years an engineering physics (mechanics) course has been completely restructured. Prior to the restructuring, the course had a traditional structure, consisting of a separate lecture (3 hours three times per week), laboratory (3 hours once a week) and recitation (1.5 hours once a week). Beginning in 2009, the traditional structure was discarded in favor of a single, blended class meeting 2.5 hours three times per week. Moreover, the new class was designed to operate as an active learning course (i.e. with very little lecture) by making use of several active learning methods including peer instruction (aka think-pair-share) and interactive peer laboratories. The implementation of the active learning methods was done in phases over several years and each phase was assessed using the Force Concept Inventory (FCI) assessment test, administered on the first and last days of class. Results from the FCI test, collected over a six-year period, show that the overall gain in performance has tripled as a result of the combined effects of the changes. The results also show that both active learning methods (peer instruction and interactive laboratories), which were phased in at different times, improved the student's conceptual gain.

To support the restructured active learning course, the author developed an active learning textbook that consists of nearly a thousand peer instruction questions and over thirty interactive laboratories, many of which are multi-part. This paper focuses on the development and implementation of the interactive laboratories. It covers the educational benefits of the interactive laboratories and describes how they are incorporated into the class. The paper summarizes all of the interactive laboratories that have been developed thus far. It also presents the complete details for a single, representative interactive lab, to illustrate how the interactive labs are performed. Lastly, the paper presents the FCI data that show the conceptual gains obtained by the interactive labs.

1.0 Introduction

Throughout the sciences, the overall structure for educating students has remained pretty much unchanged over the years. Be it a biology, chemistry, or physics class, students typically learn by attending a classroom several times per week and participating in a longer, weekly group laboratory. Typically the classroom experience is comprised of lectures and it is fairly common for the laboratory and lecture to be administered by different individuals.

While this structure may be effective at processing students through the science courses, studies have shown that it has some significant educational disadvantages. Over the past several decades, physics education research has shown that students were not learning the concepts and/or were not engaged by the methods used in "traditional" physics education.[1-4] Those and other studies have motivated a significant amount of research on physics education and much progress has been made. A significant body of physics education research has focused on developing and incorporating classroom techniques that reduce or eliminate lecture and replace it with active learning methods.[5,6] Often the focus of the active learning strategies has been to

move away from methods that lead to students memorizing facts and mimicking solutions and toward developing conceptual knowledge.[7] Other studies have looked at changing/enhancing the experimental/laboratory component.[6,8]

Physics education research has also focused on developing quantitative methods that can be used to assess the effectiveness of the traditional teaching structure as well as the impact of new teaching strategies. Those efforts led to the development of a number of standardized physics assessment tests.[9,10] Via administration of the assessment tests, numerous physics educators have shown that active learning methods and improved laboratory experiences provide substantial gains over the traditional lecture/lab format. Details of these methods, their assessment, and the evolution of physics education research have been documented in several books on physics education strategies.[5,11,12]

Despite the fact that the traditional structure has been shown to be relatively ineffective and that a number of new techniques have been shown to significantly increase conceptual understanding, many courses continue to use the traditional lecture/lab format or have only incorporated a few select techniques. Beginning in 2008, the author has worked to transform a traditional physics course (with separate lecture, laboratory, and recitation components) into a structure where all of the components are amalgamated together. Additionally, the lecture elements have been substantially reduced in favor of active learning techniques. The transformation has been conducted in phases that included: blending the separate lecture, laboratory and recitation elements into a combined experience; development of interactive laboratories; introduction of electronic response systems (clickers); incorporation of peer instruction (a.k.a. think-pair-share) questions; development of an active learning textbook; and, the removal of any remaining lecture elements in favor of pre-class videos (i.e. a flipped-classroom element). Each year, as new features were phased in, pre- and post-course assessments were conducted using the Force Concept Inventory (FCI) test.[9] The FCI test results show substantial performance gains as each of the phases were implemented. With all of the changes that have been incorporated thus far, the gain in the FCI test is approximately triple that of the traditional lecture and laboratory format. Details on the evolution of the class, the active learning methods that were used, results of the annual assessment tests, and best practices/advice for each of the methods were presented and published at the 2014 ASEE Annual Conference.[13] This paper focuses on the interactive peer laboratories that were developed as part of the overall transformation. Included in the following sections are: the motivation for switching to the interactive laboratories; the structure of the labs; how the labs are incorporated into the classroom; a summary of the 31 interactive labs that have been developed thus far; a detailed presentation of a single, representative lab; assessment data on the effectiveness of the interactive peer laboratories; and, tips/advice for implementing the interactive labs.

2.0 Background

2.1 Course Restructuring

Prior to 2009 the Engineering Physics I (Mechanics) course was taught in the traditional style. The course was five credit hours and comprised of a three-credit lecture (meeting three hours per week), a one-credit laboratory (meeting three hours per week), and a one-credit recitation

(meeting one and a half hours per week). In total, the students were occupied for seven and a half hours per week with "in-class" work. Beginning in 2009, the originally separate lecture, recitation, and lab components were abandoned in favor of a blended class that incorporates all of those elements. The new course structure was designed to meet three times per week, with each meeting being two and a half hours long. The net meeting time with the students remained unchanged at 7.5 hours per week and the course remained five credit hours.

2.2 Motivation for the Laboratory Changes

As part of the restructuring process, considerable time was spent evaluating the role of the laboratories and their effectiveness; this was done via two methods. First, the author reviewed student observation data and written comments for the laboratory sections. Second, the author (who was the classroom instructor) taught several of the laboratory sections to observe the students and their experiences within the laboratory component. (In the traditional structure, the labs were taught by a separate laboratory instructor.) These efforts led to several generalizations/observations about the laboratory experiences:

a) Despite using a fairly popular physics laboratory textbook, the students felt that the labs were disjointed and were often out of phase with the lecture material. The labs were also prone to be further disjointed since the laboratory instructor was not completely "in tune" with what was discussed each day in class.
b) The setup and tear down of the lab equipment took up a significant amount of time and the students gained very little insight from those processes.
c) During the lab the students suffered from "cookbook syndrome". It seemed that they were preoccupied with the rote following of instructions rather than intellectual thought. Students would not pause prior to an experiment to predict what might happen nor would they reflect on their results. It was not uncommon to see students collect nonsensical results, write them down, and move on without sensing that something was wrong.
d) The primary method of evaluating the laboratories was through grading of the laboratory reports. However, the lab report scores often did not correlate with how well a given student understood the concepts covered in the lab. The lab scores also did not correlate well with the overall course grades. (It was not uncommon for students to have very high lab grades yet earn a low grade for the course.)
e) The laboratory equipment was expensive and took up a significant amount of storage space.
f) A number of students noted that they did not get much knowledge out of the laboratories despite the significant amount of time that was allocated to lab (3 hours per week).
g) There were typically 13 laboratory periods in a semester and the first period was usually used as a lab orientation. Thus, only a select few topics could be covered in the lab, leaving many important topics unaddressed.
h) Since the labs were self-paced and each group was allowed to leave when finished, the students took on a race mentality were it seemed they were more interested in getting done (and getting out of lab) rather than taking their time and learning from the lab.

2.3 Changes to the Laboratory Component

The laboratory issues noted in the previous section were the primary factor that led to restructuring the course into a blended format. As part of the restructuring, the original 12 separate labs were replaced by 31 labs that were blended in with the learning of the conceptual knowledge. The laboratory experiences were restructured to address each of the issues noted in section 2.2, as outlined below.

a) By merging the laboratory elements within the classroom component, the laboratories can be directly connected to the lecture material. Moreover, each of the 31 labs was subdivided into separate modules. Within a typical class period, there is a continuous "bouncing" back and forth between coverage of concepts and applications of the concepts. In some cases the labs come after the conceptual portion to illustrate and reinforce it. In other instances the labs are used to introduce and motivate the conceptual exploration.
b) In the interactive laboratory structure, the laboratory equipment is at the front of the room and is operated by the instructor. Also, all of the equipment is setup prior to class by the instructor. Thus, the students do not setup and tear down the experiments. This frees up a considerable amount of time that can be used for much more productive activities. It should be noted that the experimental setup, sensors and instrumentation, data collection, and analyses are all incorporated into the interactive laboratories. Experience has shown that the interactive laboratories provide considerably more discussion and thought about the experiment than when the laboratory operated as a stand-alone component.
c) Interactive laboratories are purposely designed to engage the students. The students continually make predictions, evaluate the data, perform analyses, and reflect on the results. They are tasked with delineating limitations in the experiment, sources of error, suggestions for improvement, alternate methods for exploring the concept, etc. In short, the experiments have been made active rather than having students passively follow a lab manual.
d) In the interactive laboratories, the students are evaluated continuously. This is done in two ways – via electronic clickers and instructor review. Interspersed within the interactive labs are electronic response (clicker) questions that the students must answer. Their responses to those questions are part of the overall course grade. Also within the labs, the students typically make predictive graphs and calculations. Once they have made a prediction, they review it with their neighbors and/or have it checked by one of the instructors. Grade data shows that the scores connected to the interactive laboratories correlate much more closely with the overall course grade than when the labs were separate.
e) Rather than having numerous sets of laboratory equipment, only one set is required, reducing costs and storage needs.
f) Student feedback on the interactive laboratories has been considerably more positive than when the laboratories were separate. The students frequently comment that the laboratories challenge them to think, relate directly to the material covered, and greatly aid in learning the material. Numerous students have stated that they wished other classes with laboratories used a similar approach.

g) The number of laboratories has increased from 12 to 31. Additionally, the 31 labs are split into modules and are distributed throughout the class. Virtually every concept that is explored in class is also targeted with an interactive laboratory and key concepts are targeted multiple times.
h) With the interactive laboratories, the pacing of the labs is set by the instructor and the labs are distributed throughout the class period. There is no means for the students to rush through the interactive labs.

3.0 Executing the Experiments

This section provides details on how the course, in general, and the interactive laboratories, in particular, operate. Contained in the following sections are information on how the course is staffed, how a typical interactive laboratory is conducted, and the role of the instructors in an interactive laboratory.

3.1 Course Staffing

The physics class described herein operates with a maximum capacity of 45 students. Because of the active nature of the new course structure, there is a need for considerable interaction between the students and instructor. To facilitate those interactions, each two and a half hour class is staffed by two instructors. One instructor functions as the lead and the other acts as a "floater". When the students are engaged in active learning, which is a majority of the time, both instructors float among the class and interact with the students. In addition to helping the students during the active learning experiences, the lead instructor orchestrates the course, controls the pace of the class and leads discussions. Without the need for separate laboratory sections, the laboratory instructor, who functioned independently in the old structure, now joins the lead instructor in the classroom and serves the role of the floating instructor. In terms of contact hours with the students, the staffing requirements for the new structure are exactly the same as they were in the old structure. The laboratory instructors no longer instruct labs but rather assist in the blended classroom. The author sees no reason why the process could not be implemented with larger classes, provided more than two instructors were in the classroom. Since larger programs would have more instructors freed up from laboratory instruction, it should be possible to include more floating instructors in the classroom without increased staffing demands.

3.2 – Execution of a Typical Interactive Lab

In a typical interactive laboratory experience the instructor first reviews the experimental setup with the students to make sure they understand the experiment, what data is being collected, what sensors are being used, how the sensors operate, etc. Next, students are given a short period to think about the experiment and ask questions. Then each student makes a self-prediction for the outcome that can take various forms such as:

- Creating a drawing: Example: "Draw the proper free-body diagram that would apply for this experiment."

- Predicting the shape of a graph. Example: "A cart is released from rest at the top of the ramp. Predict the position, velocity and acceleration graphs as a function of time."
- A deductive conclusion. Example: "If the spring is compressed twice as far as the previous experiment, how much farther will the cart travel up the ramp?"
- An analysis. Example: "In the experiment that was just done, what must the spring constant have been?"
- A conceptual deduction. Example: "If the initial velocity of the projectile is doubled, the maximum height of the projectile will be a) two times, b) four times, c) 1.4 times, d) 2.8 times, e) the same as the previous experiment."

In many cases the electronic clickers can be used for the predictions. For example, as an alternative to asking the students to construct a predictive graph, one can ask "Which of these graphs would most likely represent the cart's velocity versus time?" The benefit of using electronic clickers wherever possible is that they provide immediate feedback to the instructor. Where clickers are not used, such as in the creation of graphs or calculations, the instructors float around and observe the students' work, noting common errors and misconceptions.

Following the self-predictions, the students then discuss with one another what the expected outcome of the experiment should be and are allowed to submit a revised prediction. (This group interaction component is very productive and is why the author prefers to call the experiences interactive peer labs.) After the group discussions, the experiment is then conducted and the results are discussed. Typically the entire process takes five minutes or less from start to finish. These experiments can then be delivered to the students throughout the class period in a just-in-time manner to most effectively link the experiments to the concepts and theories. It is also useful to note that the interactive laboratories are effectively no different than the conceptual peer instruction questions that are used to introduce and reinforce conceptual material.

It is important to reiterate that the interactive laboratories are not simply demonstrations that the students passively observe. During a typical interactive laboratory the students: provide input on the experiment, the equipment used and its setup; do pre-analysis to develop the supporting theory; provide input on how to collect and process the data; perform analysis of the results; discuss sources of error; and, suggest potential improvements. Further detail on the structure of the interactive labs is given in sections 4.2 and 4.3.

3.3 The Role of the Instructors

When operating a class with interactive peer laboratories, the instructors have various responsibilities. Prior to class, the instructors must setup and debug the experiments to avoid unproductive downtime during class. In introducing the experiment, it is very important for the instructor to thoughtfully engage the students on the experimental goals, setup, instrumentation, etc. While the students are making self-predictions and having peer discussions, the instructors should float around and interact with the students, observing their work and listening to their discussions. If electronic response units are used, the data should be reviewed in real-time. Based on all of these observations, the instructor should work to address and clarify any misconceptions and sources of confusion that were identified before moving on.

4.0 The Interactive Laboratories

4.1 Peer Interactive Laboratory Summary List

Table 1 lists the interactive laboratories that have been developed for the engineering physics – mechanics course taught by the author. It also lists which class period(s) the activity occurs in. Note that at the author's institution the course has 41 meeting periods, three of which are used for midterm examinations.

Table 1 shows that the interactive laboratories address all of the important topics in a mechanics course and that numerous labs are used to address the important concepts. The table shows that a number of labs span several class periods. The interactive laboratories are not short demonstrations, but rather fairly involved experiences that involve a great deal of interaction, often spread over multiple periods.

Table 1: Interactive Laboratory Topics

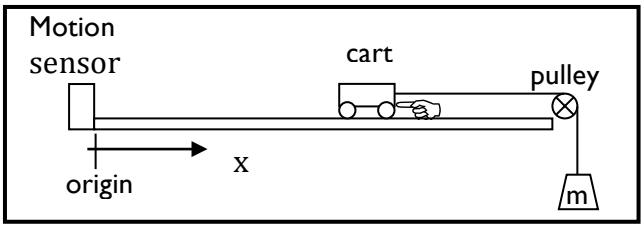
Interactive Lab Name	Class Period(s)
Activity 01: Motion Analysis – Position	2
Activity 02: Motion Analysis – Motion Diagrams	2,3
Activity 03: Motion Analysis – Velocity	3,4
Activity 04: Motion Analysis – Acceleration	4,5
Activity 05: Motion Analysis – Relating Position, Velocity and Acceleration	5,6
Activity 06: Kinematics – Linear Motion with Constant Acceleration	6
Activity 07: Basic Vector Operations	7,8
Activity 08: Kinematics – 2-D Motion	8, 9
Activity 09: Projectile Motion	9,10
Activity 10: Newton's Laws – Part 1	11,12,13
Activity 11: Newton's Laws – Part 2	13,14
Activity 12: Newton's Laws – Part 3	14
Activity 13: Newton's Laws – Part 4	15,16
Activity 14: Friction	17
Activity 15: Drag	18,19
Activity 16: Uniform Circular Motion	19
Activity 17: Work and Energy Basics	20
Activity 18: Work by a Constant Force	21
Activity 19: Conservation of Energy – Part 1	22
Activity 20: Conservation of Energy – Part 2	23
Activity 21: Conservation of Energy – Part 3	24
Activity 22: Power	24
Activity 23: Conservation of Energy – Part 4	25,26
Activity 24: Conservation of Energy – Part 5	27
Activity 25: Center of Mass and Conservation of Momentum	28,29,30,31,32
Activity 26: Rotational Motion – Part 1	32,33
Activity 27: Rotational Motion – Part 2	33,34
Activity 28: Newton's 2nd Law for Rotational Motion	35
Activity 29: Energy Conservation for Rotational Motion	36
Activity 30: Combined Motion and Angular Momentum	37
Activity 31: Simple Harmonic Motion	37,38

4.2 Illustrative Example

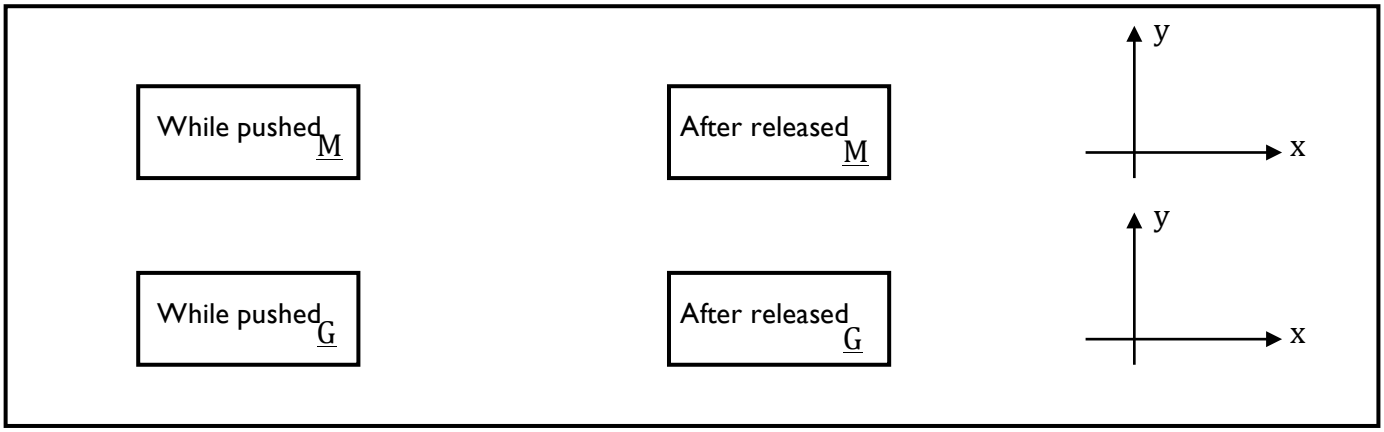
To provide a better insight into the interactive laboratories, this section explores one of the activities in complete detail, namely Activity 13. This is one of 4 interactive laboratories that focus on Newton's Laws. The following pages show the activity as it appears in the class workbook.[15]

Activity Session – Activity 13: Newton's Laws, Part 4

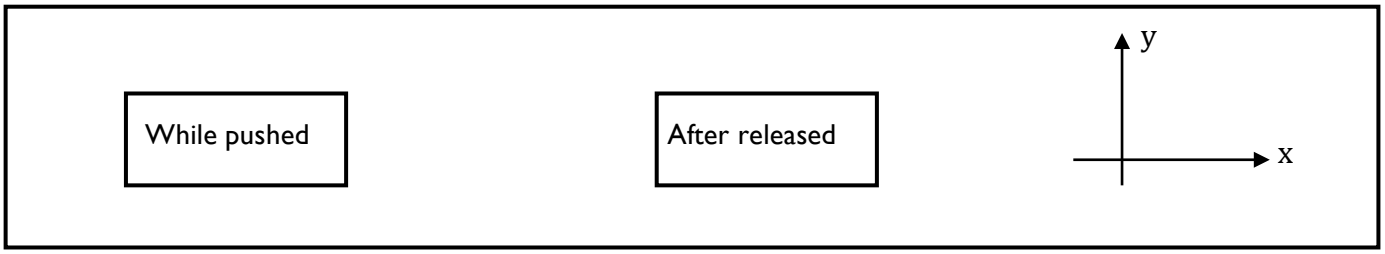
Newton's laws and the concepts therein (force, mass & acceleration) make up a substantial portion of this class. We will explore these concepts via lecture discussions, example problems and a number of activities. This activity will focus on various applications of Newton's Laws. This activity will be completed in sequence as guided by the instructor. Please follow along with the instructor – do NOT go ahead. Use the Black, Blue, Red pen method!



13.1 We will continue with some of the experiments we started in Activity 10. In the first demonstration, a cart connected to a suspended mass will be placed far away from the motion sensor. The cart will then be given a strong push toward the motion sensor. The cart has low friction wheels and we can effectively ignore any friction between the cart and track. Representing the cart as a rectangle, use a blue pen to show all of the forces you believe are acting on the cart. Draw two FBD's, one for when it is being pushed and one after it is let go. Try to draw the lengths of your force vectors to a visual scale. Be sure to show the forces acting in the direction you think they act (the cart begins at the far right of the track and is pushed to the left – it is caught when it comes to a stop).



13.2 The class will now discuss what forces act on the cart. Use your red pen to make corrections, as needed, on the FBDs below.



13.3 Tell me how you did on the previous part.

A) I got it correct on my own and my group agreed
B) I got it wrong on my own but correct after the group discussion
C) I had it correct on my own but changed to the wrong answer after group discussions
D) I got it wrong and my group got it wrong
E) I and my group were really confused!

What were the major misconceptions/sources of confusion?

13.4 During the time the cart is being pushed,

A) The velocity and acceleration are both positive
B) The velocity is positive and the acceleration is negative
C) The velocity is negative and the acceleration is positive
D) The velocity and acceleration are both negative.

13.5 After the cart is released

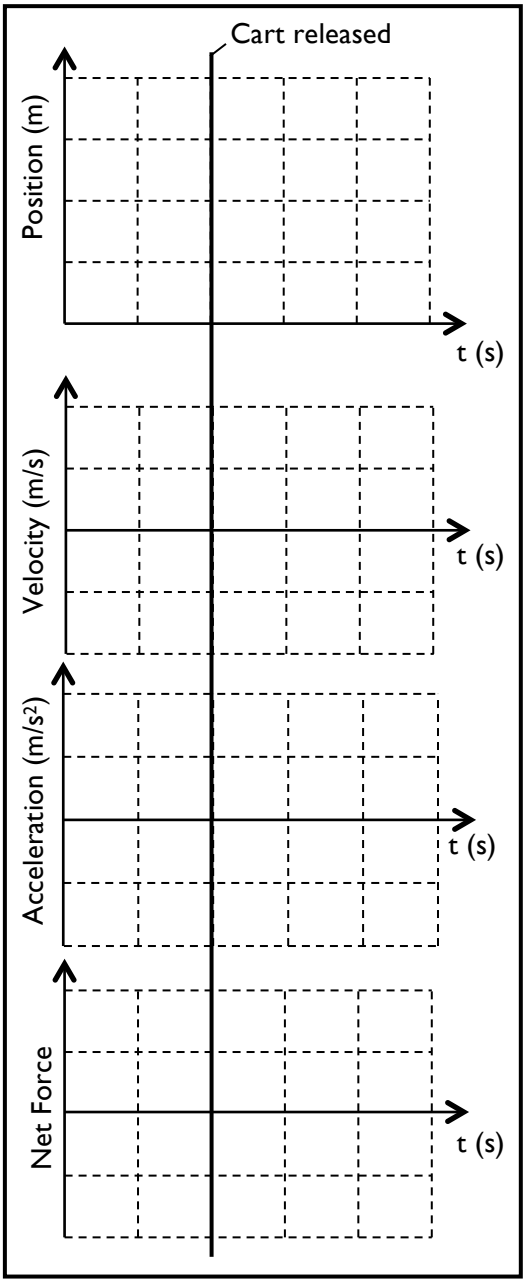
A) The velocity and acceleration are both positive
B) The velocity is positive and the acceleration is negative
C) The velocity is negative and the acceleration is positive
D) The velocity and acceleration are both negative.

13.6 The cart will be moving fastest

A) Sometime after the push has ended
B) Sometime before the push has ended
C) Just when the push has ended
D) It depends on the strength of the push

13.7 Using the black/blue pen method, on the given axes sketch your personal and group predictions for the position, velocity and acceleration of the cart versus time as well as the NET horizontal applied force versus time. Consider both periods (while the cart is being pushed and after it is released). Use the vertical line as a marker for when the instructor releases the cart. The cart will be caught just when it stops moving.

13.8 After the experiment has been completed, use your red pen to sketch the actual results.



13.9 Tell me how you did constructing the _____ graph.

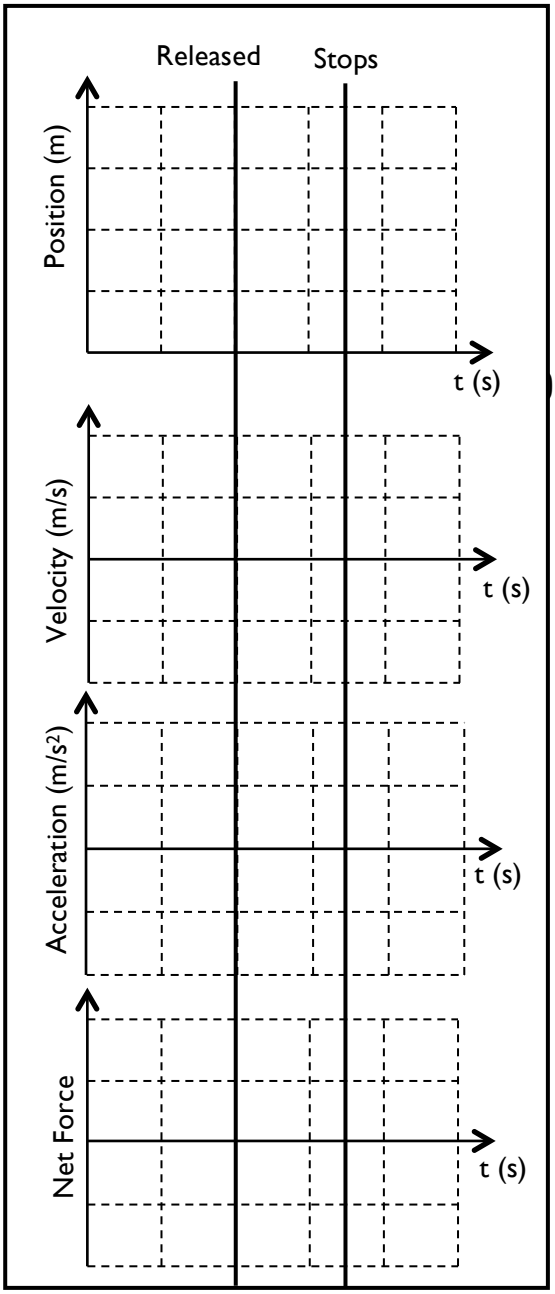
A) I got it correct on my own and my group agreed
B) I got it wrong on my own but correct after the group discussion
C) I had it correct on my own but changed to the wrong answer after group discussions
D) I got it wrong and my group got it wrong
E) I and my group were really confused!

What were the major misconceptions/sources of confusion?

13.10 How do the directions of the net force and acceleration compare?

M:	G:	C:

13.11 We will now consider the same case except we will not stop the cart. Instead, we will give it a push toward the sensor, allow it to stop, and then return in the other direction. Using the black/blue pen method, on the given axes sketch your personal and group predictions for the position, velocity and acceleration of the cart versus time as well as the NET horizontal applied force versus time. Consider all periods (while the cart is being pushed, after it is released until it stops and when it is moving in the return direction). Be sure to use the vertical line markers on the graphs.



13.12 After the cart has temporarily stopped and has started moving the opposite way, what are the sign of the velocity and acceleration?

A) Velocity and acceleration are both positive
B) Velocity is positive and acceleration is negative
C) Velocity is negative and acceleration is positive
D) Velocity and acceleration are both negative

13.13 After the experiment has been completed, use your red pen to sketch the actual results.

13.14 Tell me how you did constructing the _____ graph.

A) I got it correct on my own and my group agreed
B) I got it wrong on my own but correct after the group discussion
C) I had it correct on my own but changed to the wrong answer after group discussions
D) I got it wrong and my group got it wrong
E) I and my group were really confused!

What were the major misconceptions/sources of confusion?

13.15 After the cart has temporarily stopped and has started moving the opposite way,

A) The FBD changes because the tension force changes
B) The FBD changes because the acceleration changes
C) Both A) and B) are correct
D) The FBD is the same as it was just before it stopped
E) None of the above

13.16 As a general rule, when the velocity and acceleration have the same sign the object's speed is

A) increasing, B) decreasing, C) it depends – more data is needed

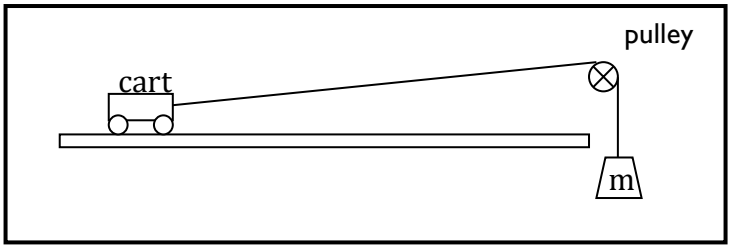
13.17 As a general rule, when the velocity and acceleration have the opposite sign, the object's speed is
A) increasing, B) decreasing, C) it depends – more data is needed

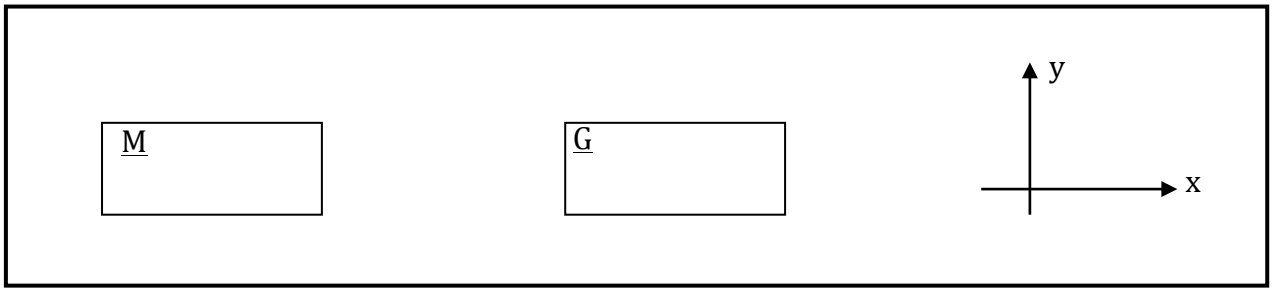
MATERIAL OMITTED – The interactive laboratory is paused to explore conceptual material and solve problems.

Activity Session – Activity 13 (concluded): Newton's Laws, Part 4

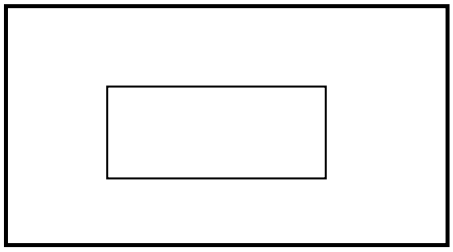
We will return to Activity 13 and continue to explore applications of Newton's laws. This activity will be completed in sequence as guided by the instructor. Please follow along with the instructor – do NOT go ahead. Use the Black, Blue, Red pen method!

13.18 Consider the cart being pulled down the track by the string and suspended mass. For this test, unlike the previous cases, the string pulling the cart will be inclined away from the track. In the space below working alone and then with your group, draw a FBD for the cart just after it is released.





13.19 Show the correct answer in the space provided using your red pen.



13.20 Answer the following questions with your clicker:

i. Assuming the suspended mass is the same, would you expect the acceleration of the cart to be: A) greater than B) less than C) the same as when the string is parallel to the track?
ii. Assuming the suspended mass is the same, the normal force on the cart will be: A) greater than B) less than C) the same as when the string is parallel to the track?
iii. Assuming the suspended mass is the same, the normal force on the cart will be: A) =W B) >W C) <W ?

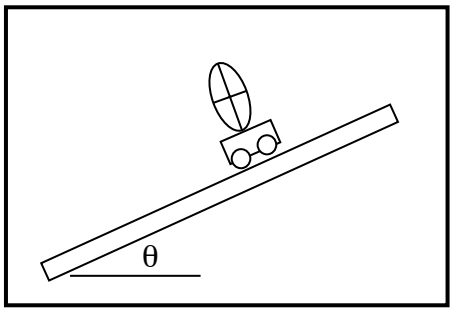
13.21 In this configuration, what does the force sensor measure?

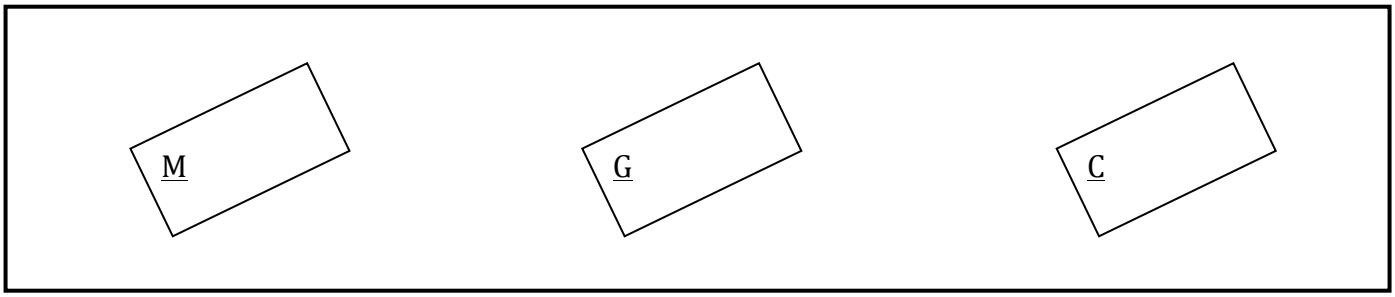
M:	G:	C:

13.22 For this case as the cart moves down the track, its acceleration will

A) remain constant as the cart moves down the track
B) decrease as the cart moves down the track
C) increase as the cart moves down the track
D) be zero as the moves down the track

13.23 Let's return to our fan cart. We know the fan creates a force on the cart. Our goal is to determine the size (magnitude) of this air force. Suppose we don't have a sensor to measure the fan's force. Being bright physics students, we put the fan cart on an inclined ramp and turn it on. We then adjust the ramp angle so that the cart remains stationary (i.e. the ramp is steep enough that all the fan can do is keep the cart in place). For this scenario, working alone and then as a group, draw a FBD for the fan cart. You can neglect friction.





Ramp angle (degrees)_____ Cart Mass (grams) _____

13.26 Working from the FBD and the data above, calculate the force exerted by the fan.

M:	G:	C:

13.27 Tell me how you did calculating the fan force.

A) I got it correct on my own and my group agreed
B) I got it wrong on my own but correct after the group discussion
C) I had it correct on my own but changed to the wrong answer after group discussions
D) I got it wrong and my group got it wrong
E) I and my group were really confused!

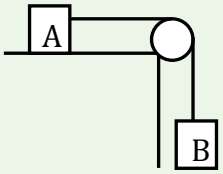
What were the major misconceptions/sources of confusion?

13.28 A force sensor will now be used to measure the fan force. The measured force value is: _____. Working as a group, compare this to the force calculated in step 13.26. Give a percent difference, defined as: (calculated – experimental)/experimental.

13.29 Can you come up with another way to measure the fan force without using a force sensor? Discuss this in your group and write your idea(s) below.

13.30 After discussing this as a class, note below the method used and the result obtained. How does this method compare to the previous two? As a group, discuss which is more accurate and why.

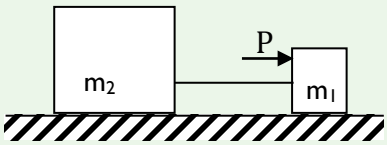
13.31 Two masses are connected by a rope that passes over a frictionless pulley. Mass A rests on a frictionless surface and is initially held stationary. If mass A is released,



A) The system will remain at rest since there is no external force acting on it
B) Mass B will accelerate downward at the acceleration of gravity
C) Mass B will accelerate downward at an acceleration > g
D) Mass B will accelerate downward at an acceleration < g
E) None of the above is correct

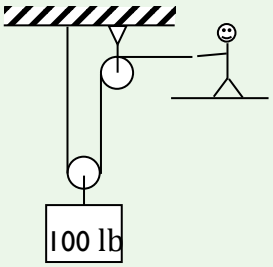
13.32 Considering the same situation, when mass A is released
A) The tension in the rope will decrease
B) The tension in the rope will increase
C) The tension in the rope will remain the same
D) There is insufficient information to tell

13.33 Two blocks, 1 and 2, are connected by a string. The blocks rest on a frictionless surface. A person pushes on the side of block 1 with a force **P** causing the blocks to move. If the mass of block 2 is much larger than block 1, the tension in the string will be



A) Greater than the force P
B) Less than the force P
C) Equal to the force P

13.34 A crate is lifted by using the pulley arrangement shown. If the crate has a weight of 100 lb, what force must the person apply to lift the crate at a constant speed?



A) 100 lb
B) 200 lb
C) 400 lb
D) 50 lb
E) Insufficient information

13.35 As a group, summarize several key things you learned from this activity.

4.3 Features of an Interactive Laboratory

Section 4.2 shows a representative interactive laboratory activity. The interactive laboratories range from 2 pages to 13 pages in length, with the average length being 6 pages. This section reviews the major components of the interactive laboratories that are illustrated in section 4.2 and discusses in more detail how the interactive laboratories are conducted.

The activities begin with a header box (shaded in red) that states the purpose of the activity. The students are also reminded that they will be working through the activity at the pace set by the instructor. The labs consist of a series of numbered steps. In the case of the example shown in section 4.2, there are 35 steps.

All of the labs begin with a discussion of the experimental setup. The students are all able to see the actual experimental setup at the front of the classroom. The interactive laboratory also includes a schematic of the setup so the students can refer back to it at a later time (step 13.1).

The laboratories activities contain many elements. Activity 13 begins with the students drawing a free-body diagram. The students first create a FBD on their own using the blocks tagged with the letter M (which represents My prediction). They then compare their results with their neighbors. If they choose to change their FBD, they create a new one in the blocks labeled G (revised after Group discussions). Lastly, the instructor discusses the correct answer with the class. Any students who did not get the correct result on their own or through group discussions must then show the correct result in step 13.2. By doing the work in this manner, the instructors can quickly look at the workbooks to see if students were able to get the answer on their own, if they needed help from their group, or if they were unable to develop a correct answer. This strategy is used throughout the interactive lab activities.

Step 13.3 provides a way to quickly archive that data via the electronic clicker systems. It also allows the instructor to determine if additional discussion is necessary. For example, if a reasonable number of students reply with answer D or E, then further discussion is likely warranted. Within the class workbook, any instructions shown in a green box make use of clickers for submitting a response.

Steps 13.4 through 13.6 trigger the students to think about the problem and provide responses via their electronic clickers. Initially, the students respond on their own. If a substantial portion of

the class gets the answer correct (typically 80% or more), no group discussion is initiated. If a significant number of the students have trouble answering on their own, they are then instructed to initiate group discussions. While the group discussions take place, the instructors listen in and provide assistance. After the group discussions have taken place, the students answer the same question a second time. If the response rate is sufficient, the instructor moves on to the next question. If it is not, the instructor may lead a discussion to clarify the topic. Another alternative is for the instructor to provide some assistance (e.g. hints, things to consider, identification of misconceptions, clarifications, etc.) and then initiate a second round of group discussions followed by another round of clicker responses. It is very important that the instructors monitor the class and adjust the pace as needed.

In the case of laboratory 13, steps 13.5 and 13.6 are intended to review concepts from earlier in the course that are helpful for undertaking step 13.7. Step 13.7 shows another common interactive laboratory component – making predictive graphs. In this case, the students are tasked with making predictions for the position, velocity, acceleration, and the applied force versus time. As with all components, the students first make their predictions on their own using a black pen. The students then discuss their graphs with their neighbors. If they decide to make changes, they use a blue pen to show their revised predictions. After all of the predictions have been made, the experiment is conducted and the actual plots are created in real time on the screen. The results are then discussed, including any deviations between the actual results and the theoretical predictions. If the students did not get the results correct, they show the correct answer on the graph using a red pen. As noted before, this method allows the instructors to quickly look at the students' graphs to determine if they were able to correctly create them on their own, though group interactions, or not at all. Step 13.9 provides an opportunity to collect the data electronically via the clickers.

Step 13.10 illustrates another interactive laboratory component, where the students are asked to make a deductive conclusion. They do this on their own (M), update if needed after group discussions (G), and record the correct result (C).

In steps 13.11 to 13.15, the experiment is modified and the students go through a similar set of processes. The intent is to determine if they can apply what they just learned to a related, but slightly more difficult, situation. This if followed by two additional deductive questions which are administered via the electronic clickers (steps 13.16-13.17).

Following step 13.17, the instructor temporarily leaves the interactive laboratory to do other things such as development of additional concepts, having the students solve problems, or development of a derivation. Those events are also included in the course workbook but have been omitted in section 4.2 to save space. (The actual workbook contains approximately 4.5 pages of interactive activities that further explore Newton's Laws without using experiments.)

After working through those pages using active learning methods, the instructor returns to the interactive laboratory beginning at step 13.18. This begins with an introduction of a new experimental setup. The methodology is similar to that described above. Looking further ahead, in step 13.23 the experiment changes yet again; the interactive laboratories frequently make use of multiple experimental setups and those are all pre-configured prior to class.

Step 13.26 shows another common element of the interactive laboratories, a calculation. In this case the students apply Newton's law to develop a theoretical prediction for the outcome of the experiment. As with all of the components, this is done individually, discussed within a group (and updated, if needed), and finally reviewed by the instructor.

While many times the instructor develops the experiment ahead of time, the students are frequently asked for alternate or better ways to explore the topic. This is done in Step 13.29, for which the student's are tasked with devising alternate methods for measuring the force of the fan. In Step 13.30, the instructor chooses one of the suggested methods, configures it with input from the students, and then executes the experiment. This is followed by a reflective exercise in Step 13.30 where the students evaluate which method might be best.

Laboratory activity 13 concludes with four electronic clicker questions (Steps 13.31 – 13.34) that require the students to apply the concepts they developed during the laboratory (and previously in the class) to new situations that were not explored in the lab. As always, these questions are answered individually, discussed in groups if the correct response rate is low, and, if needed, discussed by the instructor.

All of the activities conclude with an overall reflective question (Step 13.35) where the students work in groups to summarize the important concepts they learned from the activity. The instructor then picks several students to share their lists with the class to develop a more comprehensive summary.

Following the conclusion of Activity 13, the class will again work at developing new concepts. Peer instruction questions coupled with the electronic clickers are often employed when the new concepts are being developed just as they are in the interactive laboratories. Following that, the cycle continues with interactive laboratory activity 14.

4.4 Summary

Based on the discussions in the previous sections, it should be clear that the interactive laboratories proceed quite differently than most traditional labs. The laboratories earn the name "interactive laboratories" as they require the students to thoughtfully interact with one another and the instructor for each and every step. (Because of the amount of development that takes place through the peer discussions, the author prefers the longer title of interactive peer laboratories.) Also, the students do not proceed to the next step without an assessment by the instructor that they are ready to do so. Most of these things are quite different from a traditional laboratory, and often missing. It might be argued that the students lose something by not conducting the experiments themselves (i.e. by not physically setting up and touching the experiment). However, in the author's opinion, if done correctly, the interactive labs require substantially more thought on the part of the students. Students discuss the experimental setup and the instrumentation with each other and the instructor, they analyze the data, evaluate the experiment and its sources of error, suggest modifications or changes to improve the experiment, devise new experiments, and apply the concepts covered in the lab to related problems. At each and every step there is thoughtful discussion. One interesting thing to note is that, as with all

experiments, things do go wrong. The instructor has observed that the students become quite adept at identifying the problem and pointing it out to the instructor (e.g. things like a sensor that was not configured properly - perhaps with the wrong sample rate.) It is quite clear that the students learn a great deal about experimental techniques through the interactive labs. Moreover, with 31 interactive labs being conducted for most of a 2.5 hour class period 3 times per week, the students get substantially more exposure to experimentation than they do in a traditional laboratory structure.

5.0 Results

In order to truly determine the benefits of the interactive laboratories, assessment data was collected. The changes to the course structure described in this paper, along with other changes that were made, have been assessed both quantitatively and qualitatively and the results are contained below.

5.1 Quantitative Assessment Data

Table 2 gives the results from the FCI test over the past 6 years. Details on the FCI test can be found in Reference 16. Particular details on the FCI test as applied to the physics class taught by the author and described in this paper can be found in Reference 13.

Table 2 gives the number of students enrolled, N, the pre- and post-class averages on the FCI test, the average FCI gain calculated using equation (1), and the pass rate for the course.

$$G = \left[\frac{(post\ class\ average)-(pre\ class\ average)}{100-(pre\ class\ average)}\right] \quad (1)$$

Table 2: FCI Assessment Results

Year	N	Pre	Post	G	Pass Rate	Phase
2008	80	49	-	11.7	52.5	0
2009	85	47	65	18	52.9	1
2010	71	49	78	29	63.4	2
2011	74	50	83	33	66.2	3
2012	86	51	83.5	32.5	65.1	4
2013	78	48.5	81.5	33	59.0	4
2014	81	48.9	80.1	31.2	74.0	5

The Phase refers to the structure of the course, as delineated below:

- Phase 0 – the course was offered in the traditional lecture/lab format (i.e. before any changes were made)
- Phase 1 – the first offering of the course with the lecture, laboratory, and recitation blended together, as described in section 2.3. A modest amount of active learning was

introduced via a reduced suite of interactive laboratory demonstrations and classroom exercises.

- Phase 2 – The suite of interactive laboratories was expanded significantly and significant revisions were made to the activities. Overall, a substantial amount of active learning was added via the interactive labs.
- Phase 3 – Peer instruction and electronic response units (clickers) were included. The first version of the active learning workbook[15] was introduced. The interactive laboratories where further revised, broken into smaller segments, and distributed more evenly throughout the course to better mesh them with the lecture content.
- Phase 4 - Minor revisions to the interactive laboratories, peer instruction questions, and the active learning workbook were implemented.
- Phase 5 – Pre-class videos were developed for the first 8 class periods (approximately 20% of the classes) to eliminate any remaining lecture that was present in those classes. No other changes were made.

Data for 2008 represent the last time the course was offered in the original lecture/lab format described in section 2.1. It is important to note that the FCI test was not administered in 2008. The gain of 11.7 was estimated using an equation given by Hake[16] that, based on extensive data collection, has been shown to be a good correlation for all lecture-based classes. The pass rate for the course was 52.5% which was typical for offerings prior to 2008 (using the traditional lecture/lab format). In calculating the pass rate, grades of D, F or W (withdrawal) were considered failures.

The initial blending of the course and the introduction of a reduced set of interactive laboratories (Phase 1), boosted the gain to 18. This result falls within the bounds of other Interactive Engagement courses studied by Hake[16] for which the range in gain would be 15.9 to 37.1. Given that only a limited amount of active learning was incorporated in this phase of the course's development, it makes sense that the gain would be closer to the lower limit.

Table 2 shows that continued efforts to phase in more active learning has resulted in significant improvements to both the FCI gain, G, and the pass rate for the course. According to Hake, the upper limit on gain for students whose pre-test score was 50% is $G_{max} = 35$. The gains from the three most recent offerings of the course are all around 33 and are approaching the upper limit of the gains reported by Hake.[16] Additionally, over the last four years the pass rate for the course has averaged 66% compared to an average of 51% for the four year span from 2005-2008 (using the traditional structure). This represents a growth in pass rate of 15%.

Focusing solely on the impact of the interactive laboratories (up through phase 2), one can see that the addition of the interactive labs and blending them within the classroom environment was responsible for a significant performance gain on the FCI, going from 11.7% up to 29%. Moreover, the changes incorporated in phase 3, when peer instruction questions and electronic clickers were introduced, are also reflective on the interactive labs. This is because these enhancements were introduced to both the conceptual coverage and the interactive laboratories.

The data for 2014 require a bit of clarification as the gain, which had been fairly constant, dropped. During the spring semester of 2014, the author's institution was closed for a number of

days due to inclement weather. This resulted in the loss of 10 hours of instruction time. Hence, not all of the typical course content was covered that semester, including some content applicable to questions on the FCI test.

Taken in aggregate, the results show that the switch to the new course structure and the implementation of active learning methods have proven to be very beneficial. A significant amount of this enhancement was obtained through the development of the interactive laboratories described herein.

5.2 Student Feedback

Student observation data, especially the written comments, are also useful for assessing the benefits of the interactive laboratories. At the author's institution, the vast majority of the students take the mechanics physics course in the spring semester. However, the course is also offered in the Fall semester for students who are off track. That offering is typically taught by an adjunct using the traditional format with separate lecture, laboratory, and recitation components. In the most recent offering of the course in the traditional format (Fall 2014), on the student observation question "Which aspects of this course were least valuable?", 60% of the responses listed the lab. Comments included statements such as "The labs seemed to be pointless" and "didn't find labs useful to other material that we learned". There were no comments stating positive contributions made by the labs.

In contrast, for the most recent offering using the new format with the interactive laboratories (Spring 2014), not one student cited the labs with any type of negative connotation; all of the comments were positive. A number of students cited the interactive labs in the question addressing the most valuable aspects of the course. Also, in the question on suggestions for improvement, several students cited the desire for even more interactive labs.

While the student observation data are qualitative, they certainly show a preference for the interactive labs over the traditional laboratory structure.

6.0 Suggestions for Implementation

Having worked with the interactive laboratories for several years, a number of suggestions can be made for maximizing their effectiveness. Strategies for making this method effective are given below:

- Get the students engaged by guiding them through the important process of synthesizing, evaluating, predicting, and reflecting on a scenario.
- Create an atmosphere of curiosity. It is important for the instructor to establish an inquisitive atmosphere.
- Setup and debug the experiments ahead of time; this avoids unproductive downtime. When things do go wrong, use them as an opportunity for discussion with the students.
- Focus the experiments on a single concept. For more involved scenarios, break it down into a sequence of experiments.

- Keep the experiments short. While the interactive laboratories may span through a class or two, the physical act of performing any particular experimental typically last less than a minute and many are just seconds in length.
- Collect data in real time and display live results. Experience shows that the students enjoy seeing the data as it is created. This works much better than doing the experiment first and then displaying the results afterward.
- Couple the interactive labs with other active learning methods such as peer instruction questions. The author frequently uses the labs to "reveal" the answer to a peer instruction question.
- Get the students vested in seeing the outcome of the experiment. One of the roles the instructor can take is to pique student curiosity and even spark a friendly competitive spirit. It is very rewarding to hear students debate the outcome of an experiment, wager who is correct, and be excited to learn the correct answer.
- Use the labs to create interest for a discussion or a series of conceptual questions. In this instance, the experiment is used to pique curiosity for subsequent learning rather than to reveal a result. This works well for situations where students have common misconceptions.
- During the times when the students are asked to discuss within their group, listen in on their discussions. This will help identify the misconceptions they are having, as their conversations are usually very enlightening.
- Include some form of response system. The author has found that the electronic response units, used in conjunction with the interactive laboratories, have been extremely valuable, even for a relatively small class size. Prior to switching to clickers, the author distributed colored index cards with the letters A through E on them. By simply scanning the card colors that were held up, the instructor could quickly sense the distribution of answers. While this method is very easy to implement and inexpensive, it does not provide archival data and it is not feasible to assign grade points to the student answers. The author feels the later is very important as it makes the students take their answers much more seriously.

In closing, the author welcomes feedback and is willing to help and/or collaborate with others who are interested in applying these methods.

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