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Labatorials in introductory physics courses

Mandana Sobhanzadeh[1], **Calvin S Kalman**[2] and **R I Thompson**[3]

[1] Department of General Education, Mount Royal University, Calgary, Alberta T3E 6K6, Canada

[2] Department of Physics, Concordia University, Montreal, Quebec H3G 1MB, Canada

[3] Department of Physics and Astronomy, University of Calgary, Calgary, Alberta T2N 1N4, Canada

E-mail: Calvin.Kalman@concordia.ca

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Abstract

Traditional lab sections in introductory physics courses at Mount Royal University were replaced by a new style of lab called 'labatorials' developed by the Physics Education Development Group at the University of Calgary. Using labatorials in introductory physics courses has lowered student anxiety and strengthened student engagement in lab sessions. Labatorials provide instant feedback to the students and instructors. Interviews with students who had completed Introductory Physics labatorials as well as the anonymous comments left by them showed that labatorials have improved student satisfaction. Students improved their understanding of concepts compared to students who had taken traditional labs in earlier years. Moreover a combination of labatorials and reflective writing can promote positive change in students' epistemological beliefs.

Keywords: laboratories, reflective writing, undergraduate education

(Some figures may appear in colour only in the online journal)

1. Introduction

In this paper we present a new approach to the physics laboratory, the labatorial that lowers student anxiety, strengthens student engagement, provides instant feedback to students and instructors. Students' improved understanding of concepts was noted by the laboratory instructors and seen in the comparison of final exam results in the years that labatorials were used to earlier years when traditional laboratories were taken by students. Moreover a combination of labatorials and reflective writing can promote a positive change in students' epistemological beliefs (Kalman *et al* 2015).

The physics laboratory has long been a distinctive part of physics education (Kirkup *et al* 1998, Hanif *et al* 2008, Sharma *et al* 2014, Aceituno *et al* 2015). Physics laboratories play a central role in the teaching and learning of physics at high school and undergraduate levels in universities. There is, however, little research done on the educational influence of physics laboratories on students (Sokoloff *et al* 2007). Based on our experience and the published reports we know that many students believe that traditional physics laboratories are uninteresting and tiresome (Sokoloff *et al* 2007). In the traditional physics laboratories, students spend 2 or 3 h collecting data, carrying out calculations, plotting graphs to present the results gained and verify a relationship. Unfortunately, much of the traditional laboratory experience of students focuses on recipe experiments, which include limited challenges and often choke their creative talents (Hanif *et al* 2008, Ahrensmeier 2013). Traditional physics laboratories can be important in the development of many experimental skills and in demonstrating physics concepts, but they generally do not foster creativity in methodology or experimental design (Sharma *et al* 2014).

Prior to the introduction of labatorials, introductory courses at Mount Royal University (MRU), contained tutorials and traditional physics labs with a focus on experimental physics techniques and data analysis. Students were required to prepare a lab report, which was handed in to the lab instructor, marked, and returned the following week. Therefore, students received feedback after the course had progressed to another topic. Consequently, there was no incentive to review comments or to work out the correct answers. Additionally, we were using electronic sensors, microcomputer interface, and DataStudio software in the physics laboratories for data collection and analysis to help students see the data and graphs in real time. Even though DataStudio software displayed various physics concepts such as position, velocity and acceleration in real time, the interpretations of many students as found in their lab reports were not consistent with their observations and the materials taught.

In order to improve the experience of students in the laboratories, MRU replaced the traditional laboratory experimental exercises with labatorials developed by the Physics Education Development group at the University of Calgary (Ahrensmeier *et al* 2012, Ahrensmeier 2013). The name ‘labatorial’ comes from a combination of ‘laboratory’ and ‘tutorial’.

Labatorials in the University of Calgary were inspired by the introductory physics tutorial system in the University of Washington (McDermott and Shaffer 2001). The curriculum used at the University of Washington is entitled ‘Tutorials in Introductory Physics’ and was written by the Physics Education Group at the University of Washington. The Tutorials are worksheets that require students to work through concepts that have been identified by research to be particularly difficult. Some tutorials require students to perform experiments and answer questions based on their observations. However, there is still a traditional laboratory system for the first year physics courses at the University of Washington. Labatorials have been described by Ahrensmeier *et al* (2012) and Ahrensmeier (2013) but there has not been any research to examine students’ perspectives on labatorials including their positive and negative aspects. In this paper a case study on labatorials is presented along with their advantages and disadvantages.

In this new style of lab, students use a worksheet with conceptual questions, calculation problems, and instructions for the experiment and computer simulations. Labatorials highlight the physics concepts covered in lectures and encourage students to present and share their ideas with one another. Each lab section has one lab instructor assigned to a maximum of 16 students. Students work in groups of three or four using a labatorial worksheet that starts with conceptual questions. In the first part of the worksheet we ask student to make predictions (appendix A) and after performing the experiments they discuss whether or not the results support their hypothesis. There are usually three to six checkpoints in each labatorial. The purpose of the checkpoints is to encourage an ongoing interaction between the students and the lab instructor and provide feedback in the lab. Each time the students reach a checkpoint; they review the answers with the lab instructor. All students in one group must have the same answers. If the answer to a question is wrong or students are not proceeding in the right direction, the lab instructor leads the students

Table 1. Comparison of labatorials and traditional labs.

	Labatorial	Traditional lab
Interaction between students and TAs/lab instructors	There is more interaction between students and TAs/lab instructors in labatorials than in traditional labs especially at the checkpoints.	
Students engagement and interaction among students	More students are engaged in labatorials since all students in each group are supposed to have the same answers and defend their results at each checkpoint.	
Methodology	Instead of having an 'introduction' section at the beginning of the lab, students answer some conceptual questions related to the experiments. They make predictions and perform and sometimes design experiments to test their predictions.	In the traditional style laboratories students follow the instructions to get the results that support what they have learned in the lectures.
Feedback	Labatorials provide ongoing feedback in the lab.	Students are required to prepare a lab report, which is handed in to the TA/lab instructor, marked, and returned the following week.

to find the correct answer by themselves, exploring and discussing alternative ideas. Students do not need to write a lab report. There is a post-test at the end of each labatorial, which contains 10 conceptual multiple choice questions about the topic of the experiment. Some questions were derived from conceptual questions at the end of each chapter in the textbook. The post-test is worth two of the 10 marks for each labatorial.

Old style laboratory weekly reports require a great deal of investment of student time and staff time. In many universities, increasing class sizes makes the marking of weekly lab reports challenging. In addition to saving a considerable amount of staff time by using labatorials, the major goals of using labatorials in introductory physics labs are to help students: (1) gain a better understanding of the physics concepts; (2) investigate the application of physics principles in real life; (3) improve their experimental and analytical skills using MBL tools; (4) evaluate their preconceptions and compare them with their observation; (5) interact with their peers and the lab instructor in a collaborative learning environment.

Labatorials were also designed to address typical student misconceptions (Ahrensmeier *et al* 2012). For example, many students say that tension is the centripetal force in a pendulum. In a labatorial about circular motion (appendix A) we asked students to draw a free body diagram for a cylinder hanging from a string when it is not moving. We also asked them to draw a free body diagram for the lowest point when the cylinder is moving. In the experimental set up the string was tied to a force sensor. Most students say that the force measured by the force sensor is the centripetal force. However when they calculated the centripetal force using the velocity, mass and length of the pendulum ($F_c = mv^2/r$), they found that the calculated result was not consistent with the force measured by the force sensor. We asked students to call the lab instructor and discuss the possible explanations (appendix A).

In table 1, we compare labatorials and traditional labs.

To help students construct their own understanding of concepts and become active learners, we ask them to do reflective writing on the sections of the textbook related to each experiment before coming to the lab. Reflective writing (Kalman and Rohar 2010, Kalman 2011, Huang and Kalman 2012) is a metacognitive activity, which has students examine textual material, before coming to the classroom or laboratory in the manner of a hermeneutic circle (Gadamer 1975/1960). The hermeneutic approach starts by having students initiate a self-dialogue about each textual extract. Within the framework of such a dialogue, there exist two 'horizons.' There is the horizon that contains everything that a student believes from the particular vantage point of encountering the textual extract. The second horizon encompasses the potential in the textual extract; the sense in which the words, in the textual extract, are related within the language game understood by the author of the textbook. The student approaches the textual extract with preconceptions (misconceptions) about the material within the textual extract. The key quintessential experience occurs when the student is pulled up short by the textual extract. 'Either it does not yield any meaning or its meaning is not compatible with what we had expected' (Gadamer 1975/1960, p 23). At this point the dialogue begins. The student questions what is known within the entire horizon (Kalman 2011, p 163)

We have studied the effect of the combination of reflective writing and labatorials on students' epistemological beliefs (Kalman *et al* 2015). It was found that a combination of labatorials and reflective writing could promote positive change in students' epistemological beliefs. In this paper we focus solely on labatorials and students' experiences with this collaborative group activity. There are many points mentioned by the interviewees explaining why they found labatorials helpful. However, some points are not specific to the characteristics of labatorials and thus these points are relevant to traditional laboratories as well. For instance hands-on experiment, group work, seeing the application of principles and concepts in the lab are positive aspects of both traditional labs and labatorials. Therefore, in this paper we try to focus on the specific characteristics of labatorials that make this new style of laboratory helpful. The main research question is:

How are 'labatorials' helpful in introductory physics courses?

To address this question, we conducted semi-structured interviews with seven students in fall and winter semesters[4] at the beginning and end of the 13 week course (appendix B). Since it took time to find students wiling to be interviewed, at the time of the pre-interview, students had already taken one or two labatorials. We compared the pre- and post-interviews to see if students constructed recurring categories that might reveal underlying themes regarding their views towards labatorials. In the interviews, students explained how they worked on labatorial worksheets and discussed what they gained what they expected out of labs. As is usual with semi-structured interviews, interviewees' general ideas about labatorials were followed by specific probe questions to provide detailed information about how labatorials are helpful. All the students in the course were given the opportunity to submit anonymous comments. We also analysed these comments to validate the interviewees' statements.

2. The course

Phys1201 at MRU is a 13 week course with around 200 first year students that includes three lecture hours per week, with weekly 1 h traditional tutorials and ten 2 h labatorials. Because the number of students is large as is typical in North America, the course is divided into three to four lecture sections and around 15 lab sections each semester. Each section contains a roughly equal number of students and is taught by a different instructor. Phys1201 is a non-calculus course that provides an introduction to Newtonian mechanics. The topics covered include: vectors, motion in one and two dimensions including projectile motion, circular motion, forces,

[4] Regarding research ethical issues, one of the authors was not allowed to interview the students who were in her lab sections.

work and energy, impulse and momentum, and collisions. The textbook, 'Classical Physics', is a custom edition for MRU taken from 'College Physics: A Strategic Approach' (Knight *et al* 2009), and 'Physics for Scientists and Engineers: A Strategic Approach' (Knight and Knight 2007).

There are 16 students enrolled in each lab section. Course materials and homework are available online using Mastering Physics. The grade is based on 15% labatorial, 5% tutorials, 5% Mastering Physics, 20% midterms, 50% final, and 5% in-class 'clicker' questions. There are 10 labatorials during the semester. The first labatorial focuses on error analysis and instruction on reflective writing. The reflective writing activity is worth 20% of the labatorial mark. One week prior to each labatorial, lab instructors post a list of the textbook sections that are related to the concepts that will be discussed in the next labatorial. Students are asked to read the textbook sections and submit their reflective writing to their lab instructor three days before each lab. Students provide nine writing products during the semester. This means that students have metacognitively examined the concepts that are the basis for each labatorial. Moreover instructors reading the reflective writing have an idea about students' views on these concepts.

3. Students' perspectives on labatorials

Four first year students enrolled in the Phys1201 course participated in the interviews held in a winter semester. The first interviewee was a student who intended to study geosciences in MRU subsequently referred to as student A. We refer to the second and third students, who planned to study chemistry students B and C respectively. The fourth student wished to enter the biology major beginning in his second year and we call him student D. In the following fall semester we interviewed three students enrolled in Phys1201 course. We call them students E, F, and G.

All interviewees A to G had passed physics in high school (grade 12) and were enrolled in a General Science major. They also did the same 10 labatorials during the semester.

Prior to this study we conducted a pilot study and interviewed three first year students enrolled in the Phys1201 course. The pilot study helped assess the feasibility of the project in terms of sampling and analysis. It also helped us modify our research and interview questions and determine what resources and data we needed to improve this study. The results of the pilot study are not included in this paper.

3.1. Broad categories

The points mentioned by all interviewees explaining the reasons why labatorials are helpful in learning Phys1201 course can be classified into two broad categories: first the influence of labatorials on learning skills listed below, and second the emotional influences of labatorials noted by students in the interviews:

1. Labatorials integrate communications and discussions in a friendly environment.
2. They decrease students' anxiety.
3. They improve self-confidence.

It is important to help students discover how to acquire knowledge by doing experiments and develop the habits and skills they need in order to become independent learners. The following points mentioned by interviewees are related to learning skills:

1. Doing labatorials validates students' ideas and pre-knowledge; and integrates them with the experiments.
2. They involve thinking, comparison, reasoning, and explaining.
3. They help explore the relationship among various physics concepts.
4. They provide instant feedback.
5. They improve student engagement.
6. They improve students' understanding of the concepts.

The first two points are highly related to each other. Labatorials get students to make predictions and this values their pre-knowledge and their opinion. This makes them feel that their opinions are important and doing labatorials integrate their beliefs and knowledge with the experimental results gained. Students need to compare their predictions with the experimental results gained and discuss whether or not the results support their predictions. This process involves thinking, comparison, reasoning, and explanation. Interviewees' perspectives on the 'prediction process' of labatorials are presented in tables 2 and 3. Students' improved understanding of concepts was noted by the laboratory instructors and seen in the comparison of final exam results in the years that labatorials were used to earlier years when traditional laboratories were taken by students. A summary of what interviewees said about labatorials is provided in appendix C.

3.2. Comments left by students

Most anonymous comments left by students were consistent with what interviewees said about labatorials. For examples: '*Labatorials are very helpful in the fact that they show us real examples of something we do not understand, to make it easy to understand and comprehend*', and '*Labatorials help me understand the material much better than the actual lecture section does*', and '*I love the way the labatorials explain concepts, its been very useful for increasing my understanding. The classes go very smooth and everyone is progressing*', and '*The labatorials are very helpful, I really appreciate that there are no lab reports and that we are encouraged to work in groups. They make concepts easy to understand and I wish the other course labs were like labatorials*'.

4. Challenges of using labatorials

It was a big change to replace the old style physics laboratories with labatorials. The transition created many challenges, which are described in this section along with the solutions used to overcome them. The first time we applied the labatorial style labs in MRU we had two hour weekly training sessions for lab instructors during the first semester to familiarise them with labatorial goals and strategies. We continued our training sessions during the second semester. We believe that training and discussion sessions for lab instructors are a vital part of labatorial activity. At MRU there is only one lab instructor for each 16-student lab section (the original University of Calgary implementation used four instructors for 48 students), which sometimes resulted in student groups who have completed a labatorial section waiting while the lab instructor completes a checkpoint section with another group. This delays the laboratory and some students find it frustrating. Some feedback we have received from students is that they would prefer groups of two or three members as most of the time not every member of every group participates. However, because we have just one instructor in each lab, a larger number of smaller groups would not be practical. We decided to use a writing method in the lab at each checkpoint. In the period of our pilot test, we asked students to provide a brief report of the concepts and activities covered at each checkpoint. Students moved to the next checkpoint while the lab instructor reviewed the students' reports. This decreased the verbal interaction between students and lab

Table 2. Interviewees' perspectives on the 'prediction process' of labatorials in the fall semester.

Interviewee	Interviewees' opinions about the 'prediction process' of labatorials
A	'Labatorials involve understanding the questions, hypotheses, observations, and analysis to make conclusions. Making predictions helps you think through the various possibilities and come up with an answer to the original question. I like the 'hypothesis' part since this part makes you think about what you already know. Labatorials combine your knowledge with the experiments. You do not sit down to prove what you learned in the class. You think about what you know and write down what you think you will find based on your knowledge. In labatorials, experiments are the tools that test your predictions. Your prediction matters and this process also makes the experiments more interesting'.
B	'Each labatorial is like a small project. There is a question and you need to understand it first. I like the 'prediction section' very much. It makes you understand the question better and actually think about what you already know about the question. Making prediction involves thinking, discussion and judgement. I found the writing assignments very helpful at this stage of the experiments because you need to come up with a possible solution based on what you already know about the experiment question'.
C	'In the prediction section you propose an answer to the labatorial question based on what you know. The prediction parts of the labatorials involved thinking and reasoning when I spent a great deal of time on the reflective writing assignments. I actually did not care much about the reflective writing assignments at the beginning of the semester and, as a result, for the first labatorials I just guessed something and wrote it down to fill up the prediction section without reasoning. But after the second midterm I started spending a great deal of time preparing my reflective writing assignments and making sense of the book sections related to the labatorials and I actually thought about what I had learned and used thinking and reasoning to come up with a reasonable possible solution'.
D	'The prediction parts make you think about what you already know and try to combine your knowledge with your observations and the results of each experiment. What I like about labatorials is that you should not change your predictions, even if the experimental results show that you were wrong. I think this is what scientists do. I remember I performed the projectile motion experiment several times to find out why the results do not match my predictions. Finally, I realised that the launching level was higher than the landing level and this was the reason I did not get what I expected. My predictions were actually right, but the experimental situation was different from the situations that I based my predictions on'.

instructor. Preparing a written report at each checkpoint took a great deal of lab time and students did not have enough time to think about the labatorial activities and the results gained. The three students interviewed in the pilot test all found the report activity frustrating and stressful. They did not find the report activity beneficial and we have since discontinued use of the written summary method since its one trial implementation.

5. Concluding remarks

All interviewees appreciated the instant feedback provided in labatorials. By using the highly interactive labatorial method, students can find the correct answer in the lab and they do not write a report after doing the experiment. Labatorials provide ongoing feedback and enforces conceptual understanding that is advantageous both to students and to instructors during the semester. They help students identify their strengths and weaknesses and target areas that need work. It also helps faculty recognise where students are struggling and address problems immediately. This assists

Table 3. Interviewees' perspectives on the 'prediction process' of labatorials in the winter semester.

Interviewee	Interviewees' opinions about the 'prediction process' of labatorials
E	'In the labatorials I learned that an incorrect prediction does not mean that you are wrong. There were some labatorials in which my predictions were not supporting the numerical data gained. It was because I did not think about the factors that would affect the experiment and I expected to get the same results as what I predicted without considering these factors. For example, for Newton's second law, the track was not level and the values of the acceleration after increasing the cart's mass did not match what I expected. The prediction parts of the labs involve thinking about what you already know and comparing your predictions with the experimental results also involves thinking, comparison and judgement'.
F	'I did not learn anything in high school and for the first labatorials I was not confident enough to make predictions based on what I knew. But I learned a lot of new stuff during the semester and also the reading part of the writing assignments helped me make reasonable predictions in the last four labatorials. I learned many new concepts in the lab that I had not thought about before. I like the fact that you do not change your predictions in the lab. Instead, the lab instructor wants you to explain what might have been wrong that your predictions do not support the results of the experiment. This motivated discussion and explanation in our group. In general I think the prediction parts of the labs are designed to motivate thinking, explanation, discussion and comparison in the lab'.
G	'Making predictions made me think about what I learned in the class. I also used what I learned from the text and my own personal experiences to anticipate the results of the experiments. This (the prediction) process involves thinking ahead and also helps students make connections between their prior knowledge and what they observe and perform in the lab'.

students in gaining a better understanding of concepts. All interviewees valued the discussions happening among the peers and also the interaction with the lab instructor at the checkpoints.

All interviewees appreciated the opportunity that labatorials provided for students to express and defend their ideas in a friendly environment. Discussing questions, listening to the other students' opinions and also defending one's own ideas are not only helpful in learning physics, but also in future collaborative work and social life.

We found that labatorials improved student satisfaction, one of the important goals that we achieved by using this new style of lab. The grading process for labatorials focuses on guiding the students to eventual conceptual understanding rather than worrying about getting answers 'correct' initially. As such, full marks for a labatorial exercise are granted to all students who complete the full worksheet by the end of the lab period, regardless of whether or not initial answers were 'correct' and whether or not guidance by the lab instructors was required. Students are encouraged to explore and discuss alternative methods without the threat of losing marks. As a result students have more confidence to discuss and defend their opinions.

Appendix A. A sample of labatorial activity

MOUNT ROYAL UNIVERSITY

Department of Chemistry and Physics

PHYS 1201

Lab 8—Circular Motion

Preparation: Read Physics: Second Custom Edition for Mount Royal University, section 3.8, 6.1, 6.2, and 6.3.

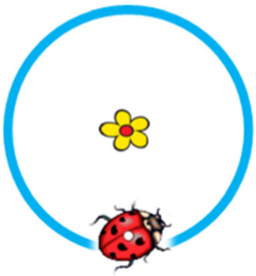


Figure A1. Lady bug crawling in a circle around a flower.

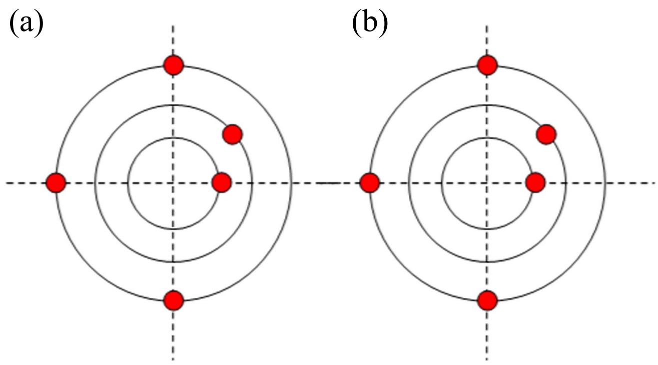


Figure A2. (a) Velocity vectors (expectations). (b) Acceleration vectors (expectations).

Equipment: force sensor, photo-gate, metallic cylinder, long string, PhET simulation
Learning goals: explore circular motion
Question 1:
A Lady bug is crawling in a circle around a flower like in the picture below.

a. Sketch what you think the *velocity* and *acceleration* vectors would look like on figure A1.
b. Use *Ladybug Motion2D Simulation* (ladybug-motion-2d_en.jar) to check your ideas. Startup the simulation and choose circular motion. Make corrections if necessary.

Question 2:
Suppose the bug is on a rotating plate.

a. Draw what you think the *velocity* and *acceleration* vectors would look like at the locations shown in figures A2(a) and (b). Indicate the higher velocity and acceleration with longer arrows.
b. Use the *Ladybug Revolution* simulation (rotation_en.jar) to check your ideas and make corrections on figures A3(a) and (b). Start the simulation by clicking on the plate and spinning it.

Question 3:
A pocket watch and Big Ben are both keeping perfect time.

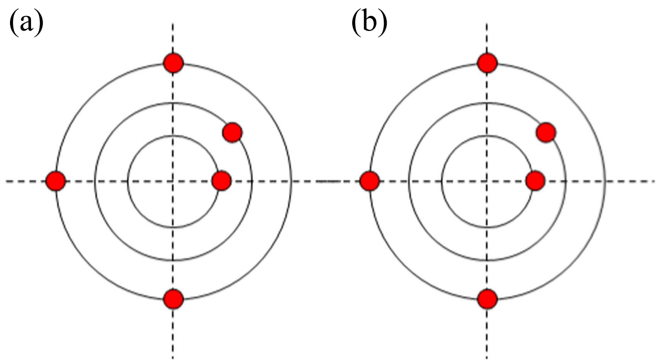
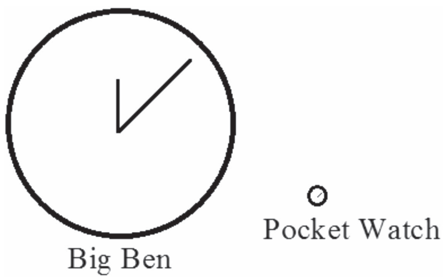


Figure A3. (a) Velocity vectors. (b) Acceleration vectors.

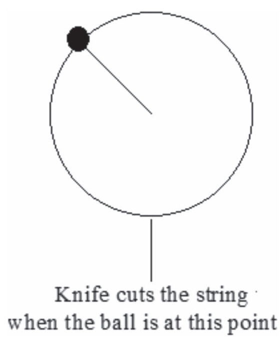


a. Which minute hand has the larger angular velocity ω (change in angle per time)? Why?
b. Which minute hand's tip has the larger velocity (tangential velocity)? Why?

Checkpoint 1: before moving on the next part, have your instructor check the results you obtained so far.

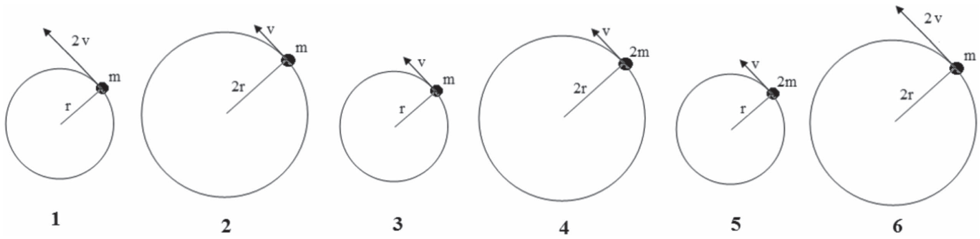
Question 4:

A ball swings in a vertical circle on a string counter clockwise. During one revolution, a very sharp knife is used to cut the string at the instant when the ball is at its lowest point. Sketch the subsequent trajectory of the ball until it hits the ground.



Question 5:

The following figures show particles moving in horizontal circles on a table top. Rank in order, from largest to smallest, the string tension and explain why?



Checkpoint 2: before moving on the next part, have your instructor check the results you obtained so far.

Question 6:

In this part of the experiment we will have a cylinder hanging from a string tied to a force sensor (figure A4). The cylinder will move like a pendulum. There is a photo-gate which measures the velocity of the cylinder at the lowest point of the swing.

a. Draw a free body diagram for the hanging cylinder when it is not moving.
b. If the cylinder was moving what would the free body diagram look like at the lowest point? Please call your lab instructor to check your free body diagrams.
c. Make sure photo-gate is directly below the hanging cylinder. Connect the photo-gate to PASCO black box (Channel 1). Open PACO Capstone and click on 'Hardware Setup'. An image of the PASCO black box will appear. Click on channel 1 and choose 'One Photogate (Single Flag)' option. Click on 'Hardware Setup' to disappear the PASCO black box image. Click on the eye image below the 'Tools' option on the left and hit the 'Timer Setup' option to add 'Timer Setup' below the 'Hardware Setup' on the left. Use calipers to measure the diameter of the cylinder (it is around 0.028 m). Click on the 'Timer Setup' tab and click on 'Cancel' and enter the measured diameter of the cylinder as the 'Flag Width' and click on 'Save'. Now you can click on the 'Timer Setup' to close the setup window.
d. Connect the force sensor to port 'A'. On PASCO Capstone, click on 'Hardware Setup' to appear an image of the PASCO black box and then click on 'A' and add the 'force sensor'. Below the image of the PASCO black box, now you have two instruments. One is the 'Photogate (Single Flag)' and the other one is the 'Force Sensor'.
e. Remove the pendulum from the force sensor and hit 'Record' and drag 'Digits' to the main page. Click on 'Select Measurement' and choose 'Force (N)' option. When there is nothing attached to the force sensor it should read zero. To set the reading zero, press the 'TARE' button on the force sensor. When the force sensor shows zero, stop recording data.
f. For this part of the experiment, re-attach the pendulum. Start the cylinder swinging and hit the 'Record' button on PASCO Capstone software. Record about 10 s of data. Choose 'Two Displays' option and select the graph options on both displays to create velocity-versus-time

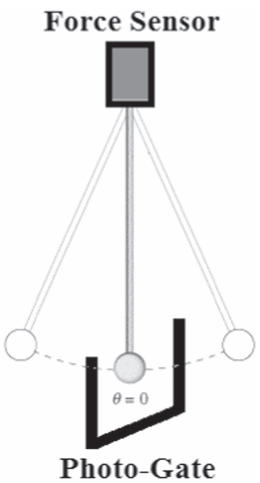


Figure A4. Object hanging from a string has a periodic motion.

Table A1. Measured, calculated, and experiment data.

	Length of the pendulum (m)	Mass of the cylinder (kg)	Velocity of the cylinder (m s^{-1})	Force (force sensor) (N)	Calculated net force (N)
Point #1					
Point #2					
Point #3					
Point #4					
Point #5					
Point #6					
Point #7					

and force-versus-time graphs. Add a coordinates toll on each graph and choose seven velocity data and note the force at those data points. Enter you data into table A1.

g. Measure the length of the pendulum from pivot point of the pendulum to the centre of the cylinder.
h. What type of force does the force sensor measure in this experiment?
i. Calculate the net force for each velocity and record your data in table A1. Show a sample calculation below.
j. How does the net force you have calculated compare with the force that the force sensor has measured?
k. Try to come up with the possible explanation if your calculated values are far from your experimental results. Call your lab instructor.
l. If you want to repeat the experiment again, what could you do to get better results?

Final Checkpoint: please clean your area and have your instructor check your work before leaving lab.

Appendix B. Interview questions

Pre-interview

Q1. How do you study for the course PHY1201?

Probe: You told me that you use … to study for this course. What other materials do you use in studying for this course?

Probe: Do you use your own reasoning, past experiences, what the teachers say, what you read in books?

Q2. Before the next question, let me first give you the definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let us call all those ideas in your mind before you entered this course your pre-understanding. How do you think this pre-understanding helps you?

Probe: Do you bring your pre-understanding into studying for this course?

Q3. What was your understanding of the relationship between force and motion before entering the course PHYS 1201 (pre-understanding)?

Probe: Did your pre-understanding help you understand the relationship between force and motion? How?

Q4. How do you think the role of this pre-understanding helped you in your study?

Q5. What do you expect out of the course?

Probe: Does reflective writing activity help you meet your expectations of the Phys 1201 course? How (in which way)?

Probe: Do you find labatorials helpful for you when studying for this course? Why?

Probe: Does labatorial activity help you meet your expectations of the Phys 1201 course? How (in which way)?

Probe: Do you find reflective writing activity helpful for you when studying for this course? Why?

Q6. What do you expect out of the labatorials?

Probe: Does the reflective writing activity help you meet your expectations of labatorials? How (in which way)?

Q7. How do you work on each labatorial worksheet in the lab?

Q8. How do you do your reflective writing activity?

Q9. Did you find reflective writing helpful for you when studying for this course? Why?

Probe: How helpful is reflective writing for you in the lab?

Q10. Did you find labatorials helpful for you when studying for this course? Why?

Q11. If the answer to Q2 is yes, how does reflective writing help you use your pre-understanding?

Probe: How does reflective writing help you to engage in your studying process?

Q12. If the answer to Q2 is yes, how does the labatorial activity help you to use your pre-understanding?

Probe: How does labatorial activity help you to engage in your studying process?

Q13. Do you think that physics knowledge can change? How?

Post-interview, winter 2014

Q1. How do you study for the course Phys 1201?

Probe: So you told me that you use … to study for this course. What other materials do you use in studying for this course?

Probe: How do you get physics knowledge? What do you rely on for getting knowledge?

Probe: Do you use your own reasoning, past experiences, what the teachers say, what you read in books?

Q2. Are your ideas about learning physics different now, compared to before you took this course?

Probe: What experiences in this course had helped you shape your ideas about learning physics? How did these things influence you?

Q3. What exactly did you do at the beginning of this course to promote your learning of the content?

And what exactly did you do in the middle of this course to promote your learning of the content?

What exactly did you do at the end of this course to promote your learning of the content?

Q4. Before the next question, let me first give you a definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the life world. Let us call all those ideas in your mind before you entered this course your pre-understanding. What do you feel were the concepts contained in your pre-understanding?

Probe: Would you define your understanding of pre-understanding? What do you consider as your pre-understanding?

Probe: Did you bring your pre-understanding into studying for this course?

Q5. How did you use this pre-understanding in this course?

Probe: What if what you read (or what teacher says) is not consistent with your pre-understanding? What do you do in this case?

Probe: In what way does your pre-understanding help you in studying for this course? (or if it does not help you can you explain why?)

Probe: Have the concepts in your pre-understanding been changed by taking this course?

Q6. What was your understanding of the relationship between force and motion before entering the course PHYS1201?

Probe: Did your pre-understanding help you understand the relationship between force and motion? How?

Q7. What is your understanding of the relationship between force and motion now?

Probe: What activities help you shape your present ideas about the relationship between force and motion?

Q8. How did you go from your pre-understanding to your present ideas about the relationship between force and motion?

Q9. Based on the procedure you just described, how does reflective writing help you in examining your ideas?

Probe: What about labatorials? Did they help you to engage into the procedure? How?

Q10. In our pre-interview you told me about your expectations of this course. Did the Phys 1201 course meet your expectations?

Probe: How do you feel about the course right now?

Probe: Did reflective writing activity help you meet your expectations of the Phys 1201 course? How?

Q11. You also told me about your expectations of labatorials in our pre-interview. Did Phys 1201 labatorials meet your expectations?

Probe: What did you get out of labatorials?

Probe: Did the reflective writing activity help you meet your expectations of labatorials? Would you explain how?

Q12. How did you do your reflective writing activity?

Probe: Did you change your procedure of doing reflective writing during the semester? Why? What did you change?

Q13. Did you find reflective writing helpful for you when studying for this course?

Q14. Did you find labatorials helpful for you when studying for this course?

Q15. Do you think that physics knowledge can change? How?

Appendix C. A summary of the interviewees' opinions about labatorials

Student A's perspectives on labatorials

In the pre-interview student A appreciated the conceptual questions at the beginning of each lab. He believed that labatorials take students step by step and help them to perform the experiments. He called the conceptual questions, problems and simulations at the beginning of each labatorial worksheet a 'warming up section' and explained that the warming up activities assist students in thinking about what they learned in class and what they already knew before doing experiments. He also liked that fact that labatorials provide an opportunity for students to compare their experimental results with the theoretical knowledge and what they expected. Student A believed that group discussion in labatorials lowered his anxiety since he knew that there were three other students in his group who would help him if he did not know the answers to the conceptual questions and also they did not lose any marks if the answers were wrong. The marking criterion that full marks are given to all students who complete the worksheet by the end of the lab gave him confidence to express his ideas about physics concepts in the lab without being worried about losing marks. He explained that he was really relaxed in the lab and the atmosphere was informative, and friendly. Each labatorial emphasises on the application of physics concepts in real life and student A believed that this makes the Phys1201 course more interesting. Student A also valued the fact that he did not need to prepare a laboratory report which he believed is time consuming and not helpful.

In the post-interview student A emphasised on the role of labatorials in understanding the physics concepts. He believed that the conceptual questions in each worksheet helped him think about the meaning of concepts and their application in real life. He explained that labatorials helped him think about the relationship among various physics concepts since in some experiments they needed to use their knowledge of previous labs to be able to do the experiments and analyse the results. He believed that both reflective writing and labatorials were effective ways to learn concepts.

Student B's perspectives on labatorials

At the time of the pre-interview, student B had completed two labatorials. He really liked the checkpoint system and explained that his work was checked three to four times during the lab and the instant feedback kept him and the other students in his group on the right track. He found it too early to judge labatorials in the pre-interview, but he believed that any activity that provides an opportunity for students to see the application of theories in real life is always helpful. He explained that he gained a better understanding of concepts when he sees their application in life.

In the post-interview, student B explained that labatorials helped him gain a better understanding of concepts. The conceptual questions at the beginning of each worksheet helped him think about the concepts and then he saw their applications while doing the experiments. He enjoyed the group discussions and found it helpful to hear the explanation of the concepts from his peers rather than professors. He explained that it is always great to hear other perspectives shared in a friendly way and appreciated the friendly and relaxed environment that labatorials created. He also believed that there was enough time in each lab to think about the questions and the outcomes of the experiments. The relationship among various labs was also another positive point that made student B gain a better understanding of concepts and the relationship between them.

Student C's perspectives on labatorials

In the pre-interview student C had completed two labatorials. She believed that the first two labatorials included a variety of activities such as conceptual questions, problems, PhET simulation and students' predictions of the experiments' outcomes that make the group work and experimental work more interesting and helpful. She believed that working on the concepts first and then doing the experiments related to them helps students get a better understanding of concepts and also improve students' performance in the lab.

In the post-interview student C emphasised that she really enjoyed labatorials. She explained that since she needed to do the writing assignments before coming to the laboratory she had a good understanding of the concepts before doing the experiments and this helped her in the analysis of the results of the experiments. She believed that the questions at the beginning of each labatorial worksheet helped her understand the concepts better.

Student D's perspectives on labatorials

In the pre-interview student D explained that he liked the group discussions and the checkpoint system. He found it very helpful to find out other students' views and discuss the questions in a friendly environment. He appreciated the checkpoint system that provides instant feedback in the lab and explained that preparing a lab report takes a long time and students receive feedback one week after doing the experiments. He believed that a written feedback including the comments of a lab instructor is not as effective as the verbal feedback that students receive in labatorials.

In the post-interview, student D explained that he found labatorials helpful because they gave him a chance to express his ideas and test them. This made him think about what he learned in the class and relate them to the experiments. He emphasised that labatorials played a significant role in understanding the physics concepts. He really liked the conceptual questions at the beginning of each worksheet that were related to the experiments.

Student E's perspectives on labatorials

In the pre-interview student E explained that she did not have confidence to mention what she thought about questions in the class. She never answered the professor's questions in the lectures since she found it embarrassing if her answer was not right. However, what she liked about labatorials was discussing her ideas with her peers. She believed that she had more confidence to talk about physics among the students who have the same level of physics knowledge as her. She did not find it tough to discuss the questions with the lab instructor since they were working in groups and she was not the only person responsible for the wrong answers. She found the discussions with peers and lab instructor very helpful in learning physics.

In the post-interview student E showed an appreciation for the conceptual questions, simulations and the problems included at the first section of the worksheet. The pre-experiment activity made her think about what she knew and what she learned in the class and the predictions that she needed to make before doing the experiments made her think about the concepts and the outcomes of the experiment. She found this challenging and explained that these challenges made labatorials more interesting. She believed that labatorials encourage communication and this made it easy for her to ask her questions and express her ideas. Student E liked the experiments that were related to each other. She needed to use what she learned in the previous labs to be able to do the experiment and also answer the conceptual questions.

Student F's perspectives on labatorials

Student F enjoyed labatorials a lot. He emphasised the fact that he learned the materials better when someone explained them to him. He did not take notes in the class because he wanted to focus on the instructor's explanations of concepts. In the pre-interview he said that students explain the concepts in a simple way and he learned a lot when a peer explained the materials to him. He enjoyed the conceptual questions at the beginning of each labatorial worksheet since all students in one group needed to have the same answers and this made them explain their ideas to each other and discuss over questions. He appreciated the explanatory nature of labatorials and the pre-experiment activities such as simulations and making predictions.

In the post-interview, student F had similar opinions about labatorials. He liked the layout of the labatorials that focus on the concepts first and there are various activities related to the concepts before doing the experiments. He believed that instant feedback is the most important aspect that makes labatorials helpful and enjoyable. He explained that writing a lab report is time consuming and students are not given a chance to defend their ideas and discuss the comments left on their lab reports.

Student G's perspectives on labatorials

Student G had completed the first two labatorials when we had our pre-interview. She found it too early to judge labatorials, but explained that she liked the conceptual questions at the first part of the labatorials worksheets. She also believed that labatorials provided a relaxed atmosphere in which students were able to express their ideas and discuss the questions.

In the post-interview she explained that she gained a better understanding of concepts since simulations, conceptual questions and predictions made before doing experiments caused her to think deeply about the concepts. She believed that labatorials encouraged students' participation and the checkpoint system initiated communication with the lab instructor. She appreciated the checkpoint system that provided instant feedback and helped students stay on track. She believed that labatorials provide an opportunity for students to defend their opinions, while in the traditional laboratories students receive a written feedback on their lab report one week later. She believed that the first part of each labatorial makes students work on formulas and concepts and the experimental part helps them use them in a real situation. Labatorials helped her to become articulate about her knowledge and gain a better understanding of the concepts through explaining them, discussing them and applying them in the experiments.

ORCID iDs

Calvin S Kalman https://orcid.org/0000-0002-7446-3652

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