SRRI Working Paper

# An Open-Ended Laboratory For College Physics Students

By John Clement

Working Paper

1980

# An Open-Ended Laboratory

# For College Physics Students

We have been investigating a new format for laboratories in an introductory physics course for engineers at the University of Massachusetts. In the laboratory experience discussed here, our basic aim has been to have students grapple with ideas of force, displacement, velocity, acceleration, mass and momentum. These concepts are logically tied together in the system of Newtonian mechanics for the physicist, but for the beginning student, they are unfamiliar and in some cases counterintuitive. We have tried to design a laboratory experience where students can discuss and explore the use of these concepts with concrete objects. At the same time we have tried to make the assignments open-ended, to encourage students to begin asking questions on their own.

Students were given a choice of 3 different sets of apparatus to work with: a ring stand and string with weights to hang on it to form a simple pendulum; a flexible plastic track, 5' long, down which one could slide coins when one end of the track was elevated on a support; and a metal cart which could be loaded with weights and which could be launched from an elastic band attached to the table.

Students were encouraged to work with a partner, and were given the list of questions below. They were required to answer questions 1 and 2 and to turn in a written report on their findings. They were not required to answer all of the questions, but were encouraged to pursue other questions which interested them in any order or to pursue questions of their own.

Investigating Qualitative Physics

Answer questions 1 and 2 and any others that interest you. Notice your option in question 4! Questions in Group II tend to be more difficult.

Group I

1) List factors you changed in an experiment and say whether or not they make a difference in what happens. Where changing a factor makes a difference, say whether it increases or decreases the magnitude of what happens.

2) Draw a picture of the motion -- show where the moving object is at a maximum speed; and where it is at a minimum speed.

3) Draw a graph (approximate) of speed vs. distance or speed vs. time.

4) Ask a question of your own about the system and try to answer it (do an experiment if necessary).

5) Draw a picture showing the direction of forces acting on the apparatus -- if you use "force arrows", make long arrows for stronger forces, and short arrows for weaker forces.

Group II

6) Draw a picture of the motion and several velocity vectors for the moving object at different points along the path of motion.

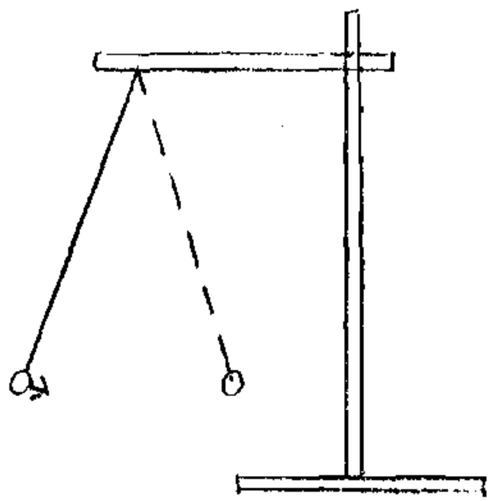
7) Draw vectors for the horizontal and vertical components of velocity in your picture of the motion.

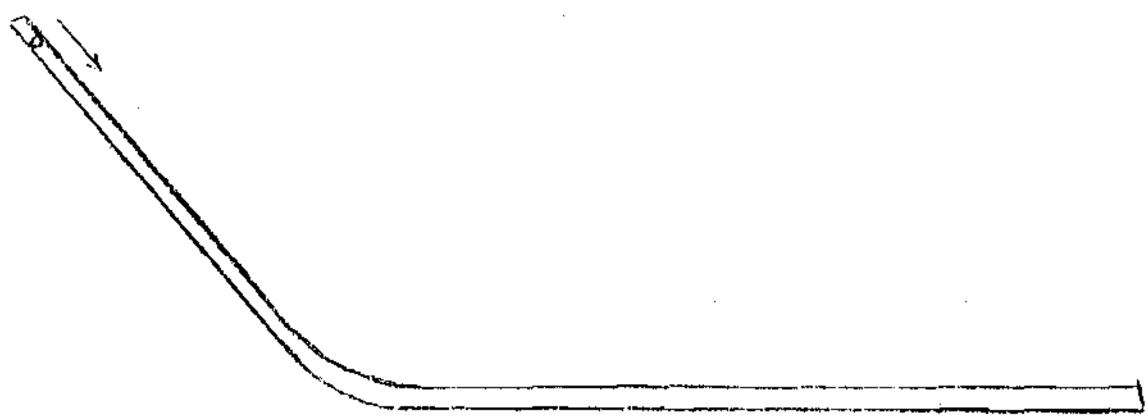
8) Describe how the moving object accelerates (one or two sentences.)

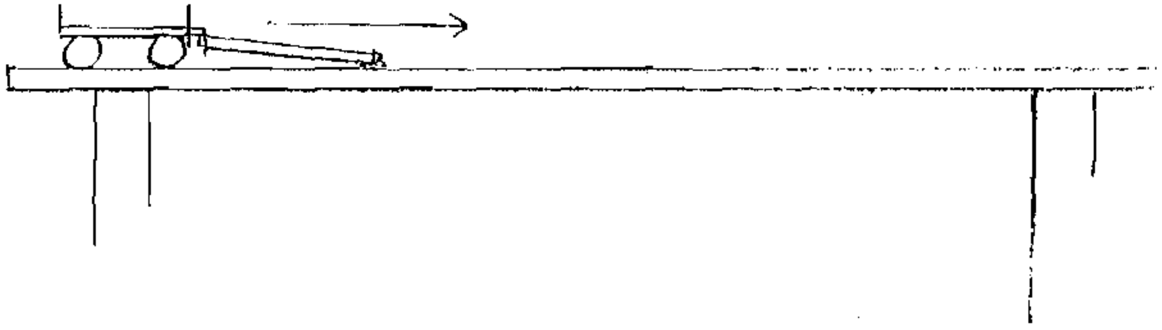
9) Draw an approximate graph of acceleration vs. distance or acceleration vs. time.

10) Describe intuitively how you think inertia or momentum might play a role in the motion. (1 to 3 sentences). (If they change during the motion, you might try to graph them.)

Important: It is not necessary to make numerical measurements (although you may if you like). In this laboratory we are more interested in the general shapes of the graphs and in conclusions like: "the more weight we add, the further it goes;" or, "acceleration is at a maximum when the speed is zero."







The Instructor's Role

In practice, students seemed to spend much of their time following **their** own path of inquiry rather than answering questions from the **list in** order. During the lab the instructor:

1) helped students find equipment they needed;
2) asked individual groups to verbally describe what they were doing; (this often had the effect of causing students' ideas to become more precise).
3) listened to discussions and observed experiments; (a major part of the instructor's work consisted of trying to understand typical non-Newtonian views of students).
4) encouraged students who were asking questions of their own, designing experiments to test conjectures, or discussing differences in point of view;
5) proposed related thought experiments (ie., "what would happen if there were no friction?" ; "Is this like an automobile accelerating?")
6) verbally labeled heuristic strategies students used ("When you think about sliding the coin on a vertical track that's called thinking about an extreme case"; "when you changed weights on the pendulum keeping the length and initial displacement constant, that's called controlling variables")
7) Communicated conjectures between groups - "Some people argue that the maximum speed of the quarter is reached just as you release it on the track, because that's where it's the highest above the table -- others say it's on the horizontal run-off section because the speed takes a while to "build up" -- others say it's somewhere else -- what do you think?")
8) encouraged students to make predictions;
9) Provided a standard label for a concept that a student used when it was perceived that the student's concept was probably a Newtonian one ("When you say 'A sharp increase in speed', the physicists says, 'The acceleration is large there'.")
10) answered students' questions about the Newtonian definitions for the various concepts;
11) it was found that the instructor tended to underestimate what students could learn on their own.

The instructor found it necessary to make a conscious effort to not spend time giving extended explanations of the "correct" point of view. Rather he found it most effective to circulate and spend less than two minutes at a time with each pair of students, returning to each pair several times during the lab period. The instructor provided information to students when they asked for it, but the role with the greatest payoff was seen to be that of stimulating and extending student-student and student-apparatus interactions. Thus for example, the instructor would often ask a pair what they had found, suggest a related question, and then move on to another group without waiting to work through to the answer with them.

## Transcript Exerpts

The following are some sample (condensed) conversations between students and the instructor in the lab:

C1) Two students are trying to decide where the cart launched across the table from the elastic band reaches it's maximum speed. One of them accepts the idea that the speed will be at a maximum at the moment of release where the band is pulling hardest, the other argues that the speed will continue to increase after release as long as the band is still stretched:

VTHS5 (640)

1) I) And why do you think the band being stretched means that it, the speed of the cart, was still increasing --

2) S1) The minute it, the cart, is gone from the rubber band -- I think that's the maximum speed -- it is making force on the cart until it's slack.

3) S2) That's like -- a baseball -- 'cause you throw the ball, right, and it picks up all the speed as soon as you leave with your hand -- as soon as you release it.

4) S1 A bullet reaches it's maximum speed as soon as it leaves the cannon, right?

5) I) (Nods) I's at a maximum right, when it comes out.

6) S2) Same thing as this (the cart) -- it's at a maximum right when it comes out.

7) I) Other people say it, maximum speed, is where it (the band) is stretched the most.

8) S1) It's zero there.

9) I) Some say it's the maximum.

10) S2) I see it -- I see it.

(Instructor leaves)

11) S2) It's maximum at this point (near the release point) right when it starts.

12) S1) You think so -- I don't know.

13) S2) Because there's no more force to it -- everything is opposite now -- as soon as you let it off -- gravity and a, friction and everything else.

14) S1) Yeah, but how about here? (holds car with band half stretched)

15) S2) I got an idea -- it's like the pendulum!

16) They spend some time looking for maximum speed in their notes on the pendulum, but decide that it won't answer the question about the cart.

(Instructor returns)

17) S1) I think from here (holds cart so band is fully stretched) to here (band slack) it increases -- and then it starts decreasing.

18) S2) So you're saying -- once the elastic has been stretched and then released is when it stops, right?

19) I) You mean the car stops?

20) S1) No, it gains to there --

21) S2) No the force -- there's no longer any horsepower.

22) S1) It -- stops gaining speed.

23) S2) Yeah, that's what -- it stops <u>gaining</u> speed -- that's what you're trying to say I think.

24) I) Another way to say that is it stops accelerating.

25) S2) That's what -- it stops accelerating.

26) S1) Then it starts - -

27) S2) It's still accelerating though, isn't it?

28) I) You mean down here? (Where cart slows down)

29) S1) Minus acceleration --

30) S2) Minus acceleration -- you know what I mean?

31) I) Aha! Ok., good point -- is that like something else?

32) S1) Let's see -- say

33) S2) It's like going 60 miles an hour -- all of a sudden you hit -- you know, slow -- get off the gas.

34) I) You must have been talking about acceleration because you couldn't do this last week --

35) S1 + S2) Yeah. (laughs).

C2) (About the Launched Cart)

1) I) Find out anything yet?

2) S1) I was trying to measure, like when you stretch the band -- how far it goes.

3) I) Can you make a graph of stretch (of the band) vs. how far it goes?

4) S1) It's not a rule; like, the more you stretch, the more power you get -- right here (small stretch) there's no power at all -- up here (large stretch) it's more than double.

5) I) Could you draw a rough graph of that?

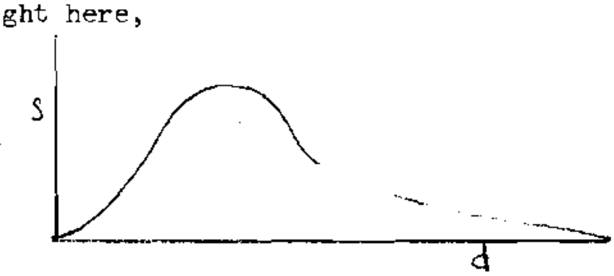
(Instructor leaves)

C3) (About Penny on Track) H 16A (200)

1) I) Find out anything?

2) S6) The maximum (speed) is right about here -- before the level (part of the track) -- and the minimum point. (refering to graph he is drawing of speed vs. distance) would be, I'd say somewhere right before it stops -- it gets slower till it stops. And right here,

3) I think it gets -- It goes -- it picks up speed faster than it loses speed (referring to graph he is drawing of speed vs. distance).




4) I) So -- it climbs faster than it drops

5) S6) Yeah -- the way it looked -- all of a sudden it was fast and then right here (level part of track) it just slowed down.

C4) (About the Launched Cart) H 16 A ( 50)

1) S3) (asks instructor) What happens if you increase weight -- the momentum is greater? Like a bigger truck has a greater momentum than smaller vehicles -- like going down a hill maybe -- same amount of force?

2) I) OK., this is good -- how do you think about what happens to the momentum?

3) S3) OK., -- it picks up, accelerating on the flat surface and the momentum it would have -- is by thrust, force caused from the elastic -- Let's say you added more weight to the carts -- and the same amount of force -- the momentum would be greater -- but would the cart go further?

4) I) Good question! I think I follow your thinking on that -- if there's more weights -- it should have more momentum and what would that do? That might cause it to go further, wouldn't it?

5) S3) I'm gonna try it out and see what happens; use a smaller amount, greater amount

C5) (Two Students Working on Pendulum) H 16 A (93)

1) I) Finding out anything?

2) S4) Well, we're just starting out trying to set up control factors like, you know, how far this way and that way (to start it from), and then we're gonna add more weight and change the length, -- that kinda stuff and see how it changes.

3) S5) The angle at which it started (would be another factor).

4) I) What would you predict?

5) S4) I think they're all gonna make some kinda difference.

6) S5) If you have more weight (starting it on the left) it will swing at a bigger angle (on the right) -- go up higher (on the right) -- as you add weight, (starting it on the left) it'll go up higher (the height it rises to on the right) keeping everything else the same.

7) I) What about length?

8) S4) If you change it, it'll go faster -- shorten it.

9) I) And will (starting the weight from a higher point) make a difference in how long it takes?

10) S4) I guess it's gonna take longer for it to get all the way back over there and come back here -- more distance.

(instructor leaves and returns 5 minutes later)

11) I) Did anything come true?

12) S4) (Concerned tone) The weights really don't make any difference (in how high the pendulum rises on the side opposite the release point).

## Distinctive Features of This Laboratory Format

Several features that made this laboratory unusual in contrast to traditional physics laboratories are:

1) The collection of quantitative data was not emphasized. Students were asked to describe how certain variables changed and to graph relationships between these changes. But they were asked to strive for qualitative accuracy rather than quantitative accuracy. Students who wished to look for quantitative relationships were able to do so on their own. In this early stage of the course we felt that the deemphasis on measurement allowed students to focus on understanding the new concepts and the causal relationships between factors in the experiment, rather than on whether their data fit some particular formula from the textbook.

2) Students were given a choice of equipment to use on the theory that this might increase the level of their investment and involvement in the lab.

3) Students were given a choice of questions to work on (beyond the first two) so that: a) students could become more involved by following their own interests; b) the lab was individualized in that more advanced students could choose more difficult questions.

4) The lab was open-ended in that students could "branch out" and investigate questions of their own, or invent experiments of their own. We were encouraged that a good number of students took advantage of these options, and that we began to see students proposing a greater number of "thought experiments" both inside and outside of the lab.

5) The apparatus used was extremely simple.

6) There were no specific directions given as to what experiments to do.

7) The lab was a valuable learning experience for the instructor because it gave him the change to circulate and talk to one or two students at a time as they were involved in describing the motion of a concrete system. This provided him with an opportunity to observe students' initial concepts of motion and to increase his understanding of typical discrepancies between Newtonian and intuitive points of view.