Inquiry-Based Honors Physics Labs

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Abstract

We report on a new set of laboratories for our Freshman Honors Physics Course. The new labs are inquiry-based, and allow students to design, execute and analyze their own experiments. The students usually analyzed their experiments by simulating them, using realistic motion techniques in python or spreadsheets. Students presented their finished analyses to the rest of the class with Microsoft PowerPoint. The labs were quite successful, though we did not do any rigorous assessment.

Introduction

There has been a lot of progress on inquiry-based science classes in K-12 education [NRC, 1995; NRC 2001], but they are still rather novel at the undergraduate level. An inquiry-based class is one in which students are allowed to find their own questions to work on, then guided by the instructor as they explore their chosen topic. We feel that inquiry is a very natural way for Honors students to do science, so we have recently replaced a set of conventional labs with inquiry-based labs in our Honors Freshman Physics class. We give our students a topic, after which they design their own experiments, take whatever data they want in their own way, do their own simulations and analyses, and finally present their results to the rest of the class. Inquiry-based labs move more slowly than conventional ones, but the students learn the subjects in a much deeper and more meaningful fashion, which we feel is appropriate for the Honors program. After one semester the new labs are quite successful, and we intend to continue with the program.

Honors Freshman Physics

The Honors program at the University of Minnesota Institute of Technology is a semi-residential program for extremely well-prepared students. Honors students take special, advanced, science and math courses for their first two years, with smaller sections and rigorous treatments of topics. Physics 1401 is the Freshman Honors course on mechanics. There are about 100 students, who meet for three lectures, one discussion section and a lab each week. Labs are 2 hours long, and usually have about 18 students. Our students usually have a great deal of experience with computers before they come to the University.

The canonical set of Freshman physics labs were designed for Physics 1301, a large (1200 students in 5 lecture sections) course for engineering students. The 1301 labs are quite pedantic, with procedures spelled out in detail in the lab book. Students analyze experiments with a computer program that is very intolerant of error; for example there is no way to "undo" a bad data point, and students must start over if they make a mistake. We felt that Honors students did not need the step-by-step hand-holding of the usual labs, so we decided to start over with a completely different approach. Rather than have labs in which students are given a set of instructions, we decided to have a much more open-ended approach, and to let the students decide what they wanted to do, coached and guided by the best teaching assistants (TAs) we could find.

In our new labs, students are given a topic, then spend the first week brainstorming and designing their experiments. The TAs have a list of potential experiments, which they may show to students who need some inspiration. Students must hand in an experimental proposal by the end of the first week. Two weeks of data-taking and analysis follow, and finally the students spend the last week giving presentations of their experiment and analysis to the class. Students work in groups of three or four, which are occasionally rearranged between experiments.

Technology

The budget for this project was quite low, so we had to be very careful with technology choices. We purchased three digital video cameras for students to take data with, which worked very well. Students used the cameras to film moving objects for the first two labs, then used the same cameras as audio recorders for the oscillations lab. We also borrowed liberally from existing apparatus for the other Physics labs in the department, and acquired some function generators, mechanical oscillators, and so forth. The lecture demonstration people were also very generous about loaning us equipment.

Almost all of our software was open-source (Microsoft Office was available under the University site license, so we used it for a spreadsheet and word processor). Simulations too complex for Microsoft Excel were done with vpython, a free 3D visualization/physics programming environment from Sherwood and Chabay at NCSU [Sherwood and Chabay, 2001]. Students moved their videos from camera to computers with JMStudio from Sun Microsystems, then analyzed them with a free Java-based analyzer called LabAnalysis. LabAnalysis shows students a video one frame at a time, and allows them to measure an object's position by clicking on it in each frame. LabAnalysis outputs a text file of position-vs-time measurements, which can be imported into a plotter or spreadsheet for further analysis. Audio analysis was done with Audacity. We used gnuplot for plotting and some mathematical fitting. We had no problems with our free software, and were impressed that the software end of things worked so smoothly.

The Labs

The students spent the first week on Lab 0, an introduction to simulating kinematics. First they did a pencil-and-paper simulation of a racing game, then they simulated the same game with a spreadsheet. Lab 0 was very simple, but it introduced the students to the basic ideas of simulating kinematics and using formulas in a spreadsheet. It is very helpful to have students do a simulation on pencil-and-paper, then move into a spreadsheet and do the same thing with formulas on columns of data.

Lab 1 was more complex and much more interesting. The topic was "do an experiment about air resistance", and the students were given a 2-page write-up of the various effects air resistance can have on a trajectory (terminal velocity, Magnus or "curveball" effects, dependance on shape and smoothness, etc.). They were also given a large assortment of objects to use in their experiment: styrofoam balls of various sizes, water-guns, washers, popguns, frisbees and so forth. The TAs introduced the students to the cameras, and the students were encouraged to take the cameras and tripods outside of the classroom. Most students opted to study air resistance by throwing the styrofoam objects in various ways and filming their trajectories, then comparing the analyzed trajectories to simulations. A large open, windless, quiet, empty space was clearly needed, and eventually some students realized that the entrance hall of Northrop Auditorium next door was perfect (it is 3 stories high with balconies and usually empty during the day). Styrofoam objects dropped from the top balcony clearly reached terminal velocity, which was thoroughly studied by several group of students. Other groups studied shape effects, scaling, spin effects, and so on. About half of the groups simulated their experiments, while others relied on curves fitted to their data. The experimental results varied quite a bit, with some groups finding results that were clearly wrong, but others did remarkably well, especially considering the time limits involved.

The topic for Lab 2 was to "do an experiment about inelastic collisions", and the students were again given a list of interesting effects and a table full of equipment to play with. Several groups of students decided to study pool ball collisions with their cameras. The student union has a pool hall, and the management proved to be quite cooperative about people standing on chairs filming breaks and strange shots. Other groups worked on tracking energy dissipation in a "Newton's cradle" apparatus, and found the ratio of energy lost to air resistance/ball elasticity/sound energy for the device. Still others attempted to measure the energy lost to cork bumpers in a cart-collision device. A few groups simulated an ideal gas with vpython. Again, the quality of the results varied, but the students all learned quite a bit.

The topic for Lab 3 was to "do an experiment about oscillations". Many students opted to study sound waves, using the cameras as sound recorders and Audacity to study the results. Students studied beat frequencies, Doppler shifts, resonant cavities, and so on. One group did simulations of standing sound waves by simulating the motion of 50,000 air atoms, and observed resonanace by looking at energy absorption. Others simulated sound waves in taut strings, and compared their observed results to simulations.

Results

Our opinion of the new labs is very favorable, especially compared to the canonical labs. We did not do a rigorous assessment, since this was our first time, and we were changing things as we went. Students had no trouble dealing with the wide array of software, and were quite comfortable with the idea of designing their own experiments. We regard the new labs as a marked improvement over the old ones. It is especially interesting to see the presentations, and to hear students talk about how they tried one approach, found it didn't work, tried another, and wound up with something that works fairly well, but has some problems. The students are probing their conclusions, finding errors, devising improvements, and finally admitting where they are still puzzled. This is exactly how real experimental science works, and our students have clearly learned something valuable by doing such wide-open labs.

Inquiry-based labs are much slower than conventional ones, and they require very high quality TAs, who must be able to do much more than in the usual labs. The faculty also need to show their belief in inquiry-based labs, and to demonstrate their interest by attending presentations, mentioning the labs in lecture, writing up the theory sheets, and so on. We believe that the payoff is worth it, and that, especially for advanced students, inquiry-based labs are much more interesting and appropriate.

Future Work

As of this writing, we are continuing the inquiry-based labs in Physics 1402, which is the Honors Freshman Electricity and Magnetism course. We envision another three labs; one on gravitation, one on circuits and finally one involving fields. Clearly simulation will be very important this semester, since it is hard to actually do an experiment on gravity, for example. Next year we hope to do another set of inquiry-based labs for 1401-2, and perhaps introduce them in another course as well. Decisions on next Fall's classes have not been made at the time of this writing, and the final decision rests with the primary professor.

References

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