NOTE

Case Study Experiments in the Introductory Physics Curriculum

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One of the major issues in physics education is the balance between hands-on, open-ended activities for students and more structured and directed approaches.[1] The goals of physics education include teaching problem-solving skills and addressing the application of physics to real-world situations. While open-ended student activities generally have the advantage of engaging students more directly in the methods of scientific research, they also introduce the risk that students will become frustrated when experiments don't work exactly as planned. This approach also places greater demands on faculty to oversee a wide range of activities in the laboratory that may require considerable amounts of time to develop and operate. However, the potential benefits resulting from student "ownership" of their work, the opportunity for students to study topics they feel are relevant within the physics curriculum, and the break from "canned" experimental activities can bring about an improved attitude of students towards physics, and greater comprehension and understanding.

There are several methods by which faculty have tried to integrate inquiry-based activities into courses.[2] *Workshop Physics*, for example, emphasizes inquiry-based activities within each class "lecture," integrating experimental work directly into the classroom activities.[3] This has the advantage of directly tying experiential learning into classroom learning, and temporally connecting hands-on work with classroom discussion. However, these activities don't necessarily invite maximum creativity on the part of students. Inviting students to design *their own* experiments meets this need. It is not, *a priori*, clear that this would improve student learning, but we could make the heuristic argument that students will take a greater interest, and learn more, from an activity they themselves develop. This is embodied in our *case-study* approach, where students select a real-world situation, propose, design, and conduct an experiment or series of experiments of their own design over the course of a semester.

Background

Carthage College introduced case studies into the first-semester introductory physics courses during the Spring 1999 semester, under CCLI funding from the National Science Foundation. The courses affected included both the calculus-based course populated by physics and chemistry majors as well as advanced biology majors, and the noncalculus course populated primarily by biology majors. The laboratory portions of these courses were modified to include two distinct sets of experiences. The first set, which we termed "capsules," were specific laboratory exercises designed to elucidate specific physics principles, such as measurement techniques and errors, one- and two-dimensional motion, etc. These are similar in scope and purpose to traditional laboratory exercises, and are each completed in one lab period. The second set, which comprised approximately two-thirds of the lab time over the semester, was devoted to student case-study projects.

Students were divided into teams of three to five students each. Each team was allowed to select its own case-study topic, and to propose an experiment to investigate that topic. The faculty tried to get each team to identify a testable question that could be addressed through an experiment. Gentle steering was needed to coax some groups to develop experiments that really tested physical principles, as opposed to merely making a measurement of some sort. For instance, a proposed project that might merely measure the drag created by different parachutes would be considered insufficient; however, a project aimed at determining a scaling law relating parachute geometry to drag would be acceptable. The teams adhered to a schedule that included a presentation of the experiment concept early in the semester and a second presentation on the experiment design one week later. These presentations enticed the other class members to critique each experiment and provide useful suggestions. Each team developed a parts list; faculty members shopped for the needed parts and materials. Each team then conducted its experiment, sometimes during the lab period but often outside of the regular lab time when their experiment required a quiet or dark period. The teams documented their work in formal laboratory reports (one per team), and gave a formal poster presentation at a colloquium held for the college

Fig. 1. Apparatus to crush aluminum cans in order to measure acceleration as a function of distance from the impact site. Steel posts mounted on lab stands serve as guide rails on which a wood board falls under gravity. Kilogram masses are affixed to top of wood board; hard metal surface applied to bottom of board creates a rigid impactor.

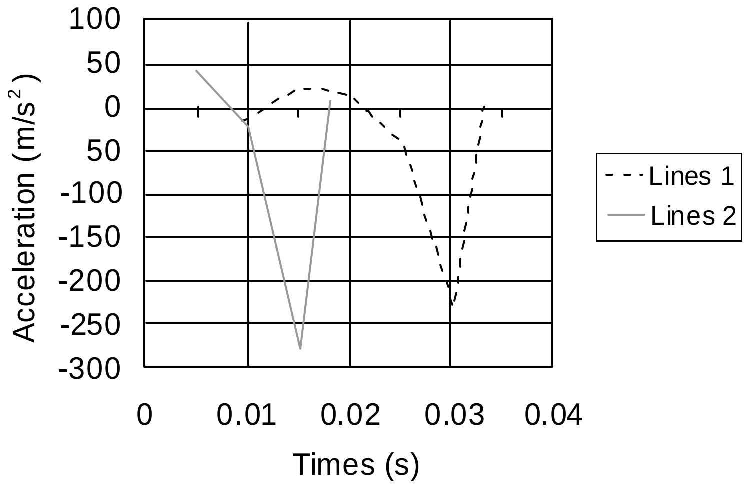

Fig. 2. Acceleration profiles for two adjacent "hash-mark" reference lines on "car-collision."

Natural Sciences Division near the end of the semester.

Case-Study Examples

The following experiments were conducted by the teams in the course:

- Design Considerations for Roller Coaster Construction
- Construction of a Wind Tunnel to Study Airfoil Dynamics
- Sound Attenuation by Different Materials
- Aerodynamics of Various Nose Cones
- How Does the Tilt Angle of an Indy Car's Rear Wing Affect the Ratio of Down-Force to Drag?
- Forces on Structures during an Avalanche
- Dependence of Terminal Velocity on Parachute Parameters
- Relative Performance of Javelins under Prior and Current NCAA Rules
- Measurements of Traction on Various Surfaces with 4-Wheel and 2-Wheel Drive Vehicles
- Accelerations during High-Speed Car Collisions
- Forces on Joints during Running

Three of these are discussed in more detail below to elucidate some of the key aspects of conducting case studies as part of an introductory physics curriculum.

Accelerations during High-Speed Collisions. This team wanted to determine the *g*-forces felt by a passenger in a car subject to a head-on collision. Rather than crashing a real car (somewhat outside of our budget), the students smashed 12-ounce aluminum soda cans. Their apparatus, shown in Fig. 1, allowed them to drop a plate backed with a known mass onto a fixed can. An open-shutter camera and a strobe centered on the can recorded the position of a series of "hash marks" painted on the side of each can. During their experiment the team discovered a number of important factors needed to conduct a successful measurement. First, they had to modify the apparatus to hold the can rigidly in place; any play allowed the can to move or bounce during the impact. Second, they had to adjust their apparatus so that the impact occurred more or less square to the upper surface of the can. Third, they had to change their original marking system on the can to make the hash marks visible in the camera; this involved painting the cans black first, then applying white lines with correction fluid. Finally, although the initial experiment was to have been conducted with a digital camera, downloading each image to computer and measuring positions with graphics/drawing software, they found that film and a conventional 35-mm camera were easier to use, and gave better images. Digitizing the images then allowed the students to make the necessary measurements. Their results are quite interesting and are shown in Fig. 2. They analyzed the position of each hash mark as a function of time, using the strobe rate as a time marker. From this they were able to determine the acceleration and velocity of each point during the impact, as well as the dynamics of the impactor.

The students on this team learned a number of valuable lessons. From a purely physics standpoint, in a first-semester course they were able to directly apply kinematic relations and Newton's laws to a real, physical situation. They were forced to challenge and ultimately reinforce their understanding of these concepts. They experienced the trials and tribulations of experimental physics. The sequence of experiment modifications and changes needed until the apparatus produced useful results was quite comparable to that required in any laboratory effort. They also came to recognize that an experiment does not, in any way, end when the data is taken; rather, the analysis and interpretation of the results is the biggest and most significant part of the effort. For example, the team noted that they had no fiducial time mark on the film, and the time "zero" for the motion of each hash mark is therefore different. This prevented them from finding time intervals between the motions of different positions of the can; only the individual motions could be determined. Thus, their experiment could not determine how long after an automobile impact a passenger begins to feel an effect. The students also had to make estimates of the duration of the impact to determine a suitable strobe rate to obtain data. They were thus forced to learn to estimate using scaling laws.

Forces on Joints during Running. Another case-study example was the experiment performed by a group of biology majors studying the kinematics of walking and running. The objective was to determine the forces on the lower limb, and thus to understand the cushioning provided by running shoes. The students videotaped an individual running on a treadmill. The subject had marks attached to the knee, ankle, and hip joints. Using *VideoPoint*® software[4], the students were able to locate each of these points frame-by-frame, and thus develop a measure of the displacement, velocity, and acceleration of each joint as a function of time. As in the previous example, students developed an appreciation for the interpretation of data in terms of physical principles, and went through a series of experimental trials before obtaining useful results. They were challenged by the conceptual difficulty of distinguishing between velocity and acceleration, and by several aspects of their experimental technique. The latter included maintaining a steady camera position, accounting for the relatively "soft" surface of the treadmill, positioning the runner in the frame in a way that allowed implementation of a fixed coordinate system, and the difficulties associated with diagnosing the impacts, having only the 30-frame-per-second rate of the video camera. To determine the forces acting on the joints, the students were forced to identify the acting masses that experienced the measured accelerations, requiring the team to develop a model for each limb as a set of coupled free-bodies. The necessity of converting complex systems into manageable models amenable to experiment was thus learned.

Measurements of Traction on Various Surfaces. A third group wanted to determine the effectiveness of two-wheel versus four-wheel drive on vehicles. They constructed a short track of plywood that served as a roadbed. Filling the track with sand, wetting the track, or filling it with crushed ice provided a variety of different test surfaces. One of the students volunteered a radio-controlled toy truck to act as the vehicle, which nominally had all four wheels driven through a gear train by a single motor. Using PASCO's *Science Workshop*[5] software, photogates, and motion detectors, the students measured the dynamics of the truck's motion as it traversed the track. By cannibalizing the truck, and removing a gear that linked the front and rear wheels, the team created a rear-wheel-only drive vehicle. They were then able to repeat their experiment, and compare the dynamics of rear-wheel and four-wheel drive. In this case, the students had to consider the weight balance of the vehicle, since this affects the distribution of the vehicle weight on the wheels, and thus the contact forces at the road surface. While this experiment produced some interesting results, the students could have conducted a more extensive study by varying the weight distribution of the vehicle in a controlled manner, thereby introducing a parameter that could have been used to model the expected behavior of the truck. Nevertheless, the students had to apply kinematic relations among position, velocity, and acceleration, and develop an understanding of frictional forces at interfaces.

Results and Assessment

The authors have found case studies to be an effective means of engaging students in physics. By implementing these activities in the first-semester course, students could address key elements of mechanics at the introductory level—kinematic relations and Newton's laws. As seen in the examples, these issues can be observed, addressed, and studied through a variety of different case-study topics. Most students considered these activities "fun," especially in contrast to the conventional exercises conducted during typical laboratory sessions. Our course evaluations and assessment process, which do not yet specifically address the case studies, were unusually positive, relative to results in previous years. While these could be anomalous, informal oral feedback from students causes us to believe that the students' positive attitudes are attributable in part to the case-study activities, and that their more positive attitudes resulted in better study and greater understanding, as evinced in results of our assessment exam. Approximately 80% of the students who took part in the case-study activities participated in the second semester of our introductory sequence in the fall. The instructor of that course (Crosby) observed that students had gained, *and retained*, greater comprehension of basic physics principles in comparison with students in previous offerings of this course. More material was covered at greater depth in the second-semester course than was possible previously.

The case-study projects could be equally well applied in a high-school physics class. Indeed, the basic approach can be used at higher college levels as well, though the experiments will need to be more complex. While it might be necessary to have greater instructor intervention in case studies at the high-school level, the fact that high-school courses are often conducted over a full academic year (as opposed to a quarter or semester) may give the class a greater opportunity to conduct a meaningful experiment, and perhaps to study more areas of physics in class prior to applying them in their experiments.

Recommendations and Concerns

The use of case studies in the introductory physics course was, in our view, successful. However, we must be sensitive to the difficulty students face in developing and executing meaningful experiments when their exposure and understanding of physics is in the initial stages. This is particularly evident as students propose their case-study experiments; without an understanding of physics principles they have difficulty devising experiments that actually test hypotheses, rather than merely observing or recording a phenomenon. The initial rough proposals thus represent an opportunity to discuss the scientific method and the connections between theory and experiment in a meaningful way.

Time-phasing the case-study experiences into the first-semester course is difficult, and requires substantial faculty involvement. For example, case studies often involve physics topics that are not taught until a point in the semester long after a student group might require the concept. Students were much more receptive to learning new material "out-of-phase" when it was relevant to their projects. Much time was spent in lab working with case-study teams doing directed tutorials on necessary concepts. We see this as an advantage to the approach, rather than a drawback. In addition, our student schedules are relatively complex, and scheduling additional laboratory time when all team members can work together is often problematic.

A reasonable inventory of small parts and materials must be developed, requiring a small budget for such things as camera film or styrofoam sheets. It is frustrating for students on tight schedules to not have needed supplies available immediately.

Finally, faculty should be capable of basic construction techniques, and be reasonably adept at on-the-fly experiment debugging, since students require regular assistance in conducting their experiments. When working with students who are just developing experimental skills, it is often difficult to interpret their descriptions of "failures" in their experiments, and to provide useful guidance. The instructor who is experimentally oriented may provide guidance on some experiments with greater ease.

Acknowledgment

Carthage College gratefully acknowledges the support of the National Science Foundation through ILI Grant DUE-9851068.

*Presently at The Bakken Museum, 3537 Zenith Ave. South, Minneapolis, MN 55416.

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