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Crash Safety in the Introductory Physics Lab

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AC 2011-1651: CRASH SAFETY IN THE INTRODUCTORY PHYSICS LAB

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Dr. Daniel Ludwigsen pursued research in Musical Acoustics while completing the Ph. D. in Physics from Brigham Young University. After joining Kettering University in support of the acoustics specialty within Applied Physics, Dr. Ludwigsen has broadened his professional interests to include physics education research and instructional design. In addition to an overhaul of the introductory physics laboratories, partially supported by NSF CCLI funding, Dr. Ludwigsen has written two courses at the sophmore/junior level, and coauthored a senior level laboratory in acoustics. He is also interested in developing materials to help K-12 teachers with units on sound and waves, and to incorporate crash safety topics into their physics curriculum.

Janet Brelin-Fornari, Kettering University

Dr. Brelin-Fornari is a professor of Mechanical Engineering and the Director of the Kettering University Crash Safety Center. She began work as an engineer with General Motors and has spent the last twelve years in academia. Dr. Brelin-Fornari teaches in the areas of dynamics, systems, and controls. She also conducts research in pediatric mobility safety. And, she brings both the classroom and the research together for students at the undergraduate and K-12 levels.

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Graduate Research Assistant, Kettering University. Project Description - Coordination of research efforts between physics and the crash safety center to fulfill the obligations of the funding agency in the redesign of the PHYS-115 lab curriculum. Create, edit, and integrate data and multimedia for use in lab curriculum. Assess curricular materials and student feedback for improvement in lab activities. Perform research in Kettering University's Crash Safety Center

Crash Safety in the Introductory Physics Lab

Introduction

Introductory Physics labs would seem inherently to incorporate principles of active learning. However, informal program assessment within the Kettering University physics department indicated students moved through instructions, recorded results, and interpreted data only as much as was required to "get through the lab." Not surprisingly, lab skills did not carry over into a later lab course, and, similarly, students' understanding of physics concepts in the laboratory seemed superficial and temporary. A new laboratory curriculum has been created to utilize research-based pedagogy and leverage a relationship with the Crash Safety Center on campus. Both the pedagogical approach and topical context are intended to improve student engagement with activities in the lab and activities are designed to lead to greater ownership of the process of laboratory work.

The Crash into Physics program launched in fall of 2009 at Kettering University. The new lab curriculum is designed to bring real world applications into a setting accessible to students early in their studies, and to highlight Kettering's Crash Safety Center. The new curriculum explores active learning in the laboratory, utilizing computer acquisition tools and a set-up which mimics cutting edge testing in the field of vehicle crash safety. This led to a different style of teaching from the previously used expository lab curriculum.

Expository labs are designed to have a set procedure for the student to follow with a predetermined outcome. These types of labs have little instructional value in that, as is stated by, "virtually no meaningful learning takes place." [1] The previous physics laboratory employed these "cookbook" experiments; students would execute without generating work or procedures of their own, leading to an inadequate linking of physical laws with work performed outside of the classroom and poor retention of skills and concepts. This lead to the development of Crash into Physics using an inquiry/discovery laboratory style that is based on the lab structure of *RealTime Physics*.[2]

An alternative to the expository style that requires more student engagement might be described as a discovery or inquiry style. A discovery style laboratory has a predetermined outcome, inductive reasoning approach and the procedure is student generated. An inquiry style lab has an undetermined outcome, inductive reasoning approach and the procedure is student generated. The procedure is not fully student generated, but there is not a cookbook set of instructions either. The students are provided with the tools to be used, information about how to use these tools and is asked to report their outcomes and back up their findings. The students are instructed on what to accomplish without necessarily being instructed on how to accomplish it. *RealTime Physics* might fall into this category. From its introduction, the learning cycle of *RealTime Physics* "consists of prediction, observation, comparison, analysis, and quantitative experimentation."[2] This pattern is designed to engage the students more deeply than the expository style of laboratory activity.

To complement the change in pedagogy, topics related to vehicle crash testing are essential to the new curriculum. The Crash Safety Center at Kettering University is a unique facility serving the needs of industry, academic research, and fully committed to education. The main test apparatus is the Deceleration Sled, which uses a controlled acceleration pulse to model the effect of crumple zones and other features of a full vehicle on the dynamics of interior parts and occupants. Using lab tools already available on the market, students can create experiments similar to a collision event. The link to real activities of vehicle or component testing is ubiquitous, and therefore creates a lasting impression of relevance and applicability on the students . The work of crash testing and analysis of results, includes the topics of motion and kinematics, forces and torques, momentum, and energy that are encountered in the typical introductory physics course.

This paper presents the current state of the curriculum development project, roughly one year after initial full-scale deployment. The first section discusses the background and motivation for the change. The middle of the paper outlines the content of the set of laboratory activities, and describes how topics from crash safety are incorporated into the curriculum. Finally, preliminary assessment data are presented from established surveys: Force Concept Inventory (FCI) for conceptual understanding, and the Maryland Physics Expectations Survey (MPEX) for student attitudes about physics. Additionally, informal student opinions of the new curriculum used in continued refinement of the materials are discussed.

Crash into Physics

The name of the curriculum development project, Crash into Physics, describes both the partnership with the Crash Safety Center, and a new approach to learning physics. By leveraging this partnership and drawing from research-based approaches to learning, the project has two goals. First, students will leave the lab with a better fundamental understanding of the physical world and the laws governing it. They will also realize a deeper link from lab activities and real life, especially in their work in engineering. This connection to the real world helps drive a deep understanding of physical laws for practical-minded students.

The foundation of Crash into Physics relies on the computer based measurement interface to connect mechanical lab tools with immediate computer display of results. This is the origin of the *RealTime Physics* approach, and enables the learning cycle; prediction, observation, comparison, analysis, and quantitative experimentation. The emphasis is moved from tasks like recording and plotting, to reflection on the results and their interpretation. This permits time multiple runs, trials, and exploration before pursuing more rigorous quantitative experimentation. Students can also be expected to confront concerns related to higher-level laboratory skills such as basic error analysis. Students must read the laboratory material prior to arriving at the lab, even planning ahead to think about how he or she is going to run the test, and collect the data. After the lab session, students present a report based on sound physical principles related to the project.

This cycle of weekly work is accomplished with three parts. Preliminary Questions are provided to the student and are expected to be turned in at the beginning of class. The Preliminary Questions focus on the concepts covered in the lab and the activities students will perform. In evaluating these submissions, more consideration is given to whether the student put serious thought into the answers than whether they are correct.

The second part of the curriculum is written documentation regarding specific session accomplishments and instructions. This "Lab Activity" is laid out sequentially for the students to follow during the lab session, and includes a discussion section with topics for reflection by the entire class, led by the instructor. The Lab Activity ends with the third part of the curriculum, a set of Follow Up questions, designed to reinforce concepts through reflection on the results of the students' work. These are typically treated as homework to be turned in later.

The body of the Lab Activity contains information needed to execute the activity and tips throughout the document to help the student set up the experiments to obtain good results. These are written in the spirit of sharing best practices, rather than mandatory, precise instructions. For example, students use a camera and software to perform a video analysis of a crash event. Instead of stating directly where it physically set up the camera, the Lab Activity explains what parallax is and how it causes an increase in error. The idea is to lead the students to place the camera in a spot that minimizes this error.

The first half of the term consists of labs that are meant to prepare the student in using the equipment and familiarize the students with the lab instruments. The goal of these weeks is to guide the student through performing the lab activity and provide them with the tools necessary to complete more complex labs. The instructions are given in paragraphs rather than numbered items or bullet points, forcing the student to read the information carefully and extract what is needed to execute the experiment. The idea is to encourage the student to think about what they are doing and also why they are doing it.

Half way through the term, students individually take a Certification Test. At the superficial level, the Certification Test evaluates how well the student is able to perform laboratory tasks with the apparatus and analysis, but also incorporates physics concepts as context for the questions. Because it falls in the middle of the term, students are aware that they are individually accountable from the very beginning of the course. The Certification Test is an important part of the course design because it informs the instructor of the progress of a student and identifies those who still need help learning how to use the equipment and understanding the data.

The second half of the class expects the student to have a technical understanding of the equipment and can therefore allow greater flexibility in the students' approach to the lab objectives. The activities gradually increase in difficulty, and less time is spent training the students. The students can now focus more on setup and developing how they want to run their test. This setup puts the student in the driver's seat and gives them ownership of the work.

The equipment for the lab is minimal and fairly consistent from week to week, which allows the student to become comfortable with using it. Centered around the Vernier, Inc. Dynamics System, the main apparatus is a 1.2 m track and a low-friction cart with a spring-loaded plunger. The first sensor encountered, an ultrasonic range finder ("motion detector") is used in most weeks' activities as a means of tracking position. A USB interface and software acquires data with a rapid learning curve, so that students can immediately explore position and velocity of the cart on the track. In subsequent weeks, activities introduce accelerometers and force sensors, and video analysis of position is made possible through low cost web-cams with 720p resolution at

30 frames per second. Toy dolls are used to simulate a vehicle occupant on the cart, mimicking the more sophisticated crash test dummies that are used in actual vehicle crash testing.

During the first few weeks of the course, students tour the Crash Safety Center facility. Ultimately, it is hoped that the Crash into Physics curriculum would be distributed to other institutions, so this tour of the Crash Safety Center will be virtual, through a video presentation including clips from tests run as well as a presentation provided by an expert in the field. A library of videos is also being assembled for the project website for dissemination and general public interest.

Table 1 is a brief overview of the lab titles and topics covered in the lab

Table 1: List of Laboratory Titles and the Physical Concepts Covered

Lab #	Title	Concepts Covered
1	Motion I	Mathematical and conceptual relationships between position and velocity, in one dimension
2	Motion II	mathematical and conceptual relationships between position, velocity, and (time-varying) acceleration in one dimension
3	Accelerometers	Strengths and limitations of sensors; Acceleration
4	Video Analysis	2-d motion and trigonometry; techniques and requirements of video analysis
5	Passenger Projectile	Newton's 1st and 2nd Laws; Analyze the trajectory of a projectile in 2-d
6	Passenger Restraint	Force sensor; Consider *g* as a gravitational field strength
7	Stopping Sled	Impulse-Momentum theorem; momentum as a motion variable changed by force integrated through time
8	Accelerating Sled	Work-Energy theorem; kinetic energy changed by force integrated through distance
9	Head-Neck	Rigid Body Motion; Statics
10	Dummy Calibration	Energy; Test development from standards

Assessment

Two instruments have been identified and employed by the physics department to measure student conceptual understanding and attitudes toward physics. The Force Concept Inventory (FCI) measures the students' conceptual understanding of physics. The Maryland Physics Expectations (MPEX) survey[3,4] measures students' attitudes about physics using 34 Likert-scale statements about physics, with five choices from strongly agree to strongly disagree. These statements separate into six different clusters: independence, coherence, concepts, reality link, math link, and effort. While the overall score is important, this project focuses on the four questions designed to test the reality link. Responses from our students are compared with those of recognized experts; if they match it is considered "favorable." For example, if the experts disagree or strongly disagree with a statement, and a student agrees, that is recorded as an unfavorable response. Neutral responses are ignored. The survey is administered once at the end of the term and the students' answers are compared to the experts' answers.

The Force Concept Inventory was developed to measure students' understanding of how the physical world works. [5] The inventory consists of 30 questions designed to test the conceptual understanding of forces in the physical world. The FCI is used here to evaluate the instruction materials, not the performance of individual students, and as with MPEX results, only aggregate data is recorded. The intended use for this paper is as a diagnostic tool to measure the effectiveness of the past and present curriculum. The FCI presents the students with physical situations and multiple choice options that relate to either the "favorable" answer in line with Newtonian concepts or commonsense alternatives/misconceptions.[5] These alternatives may seem correct but distract students from choosing the description that aligns with Newtonian thinking. The FCI survey was administered during the first and last weeks of the term.

The average normalized gain $<g>$ describes, in a single value, how the sample group's performance changed.[6] This is calculated by dividing the gain $<G>$ (the increase in percentage of favorable answers) by the maximum gain possible—that is, an increase to 100% favorable, expressed mathematically in Equation 1,where $<S_f>$ and $<S_i>$ are the final (post) and initial (pre) class averages on the Force Concept Inventory.[6]

$$< g > \equiv \frac{\%\langle G \rangle}{\%\langle G_{\max} \rangle} = \frac{\%\langle S_f \rangle - \%\langle S_i \rangle}{100\% - \%\langle S_i \rangle} \tag{1}$$

Hake classifies courses as "high-*g*" if they show normalized gains greater than or equal to 0.7, "medium-*g*" courses have normalized gains between 0.3 and 0.7, and "low-*g*" courses, which tended to use traditional lecture classroom methods, were lower than 0.3[7]

Table 2 provides data about the groups and summarizes survey results. In labeling the groups of students who completed surveys, lower case letters denote those exposed to the previous expository curriculum and upper case letters denote those involved in Crash into Physics. Group b and c are the same set of students that were administered both tests; otherwise, the groups are different sets of students.

Table 2: Sample Group Sizes, Background and Scores

	a	b	c	d	E	F	G
Sample Size	96	47	47	25	28	32	56
% Never Taken Phys 114	95.8	93.6	91.5	68	89	84	94.5
% Taken Phys 114	1	4.3	4.3	20	11	16	3.6
% Taken Phys 114	3.1	0	2.1	4	0	0	1.8
% Left Space Blank	0	2.1	2.1	8	0	0	0
Surveys used	MPEX	MPEX	FCI	FCI	FCI	FCI	MPEX
MPEX Score	35.7	30.1	N/A	N/A	N/A	N/A	47
FCI Normalized Gain	N/A	N/A	31.2	37.3	21.6	24.9	N/A
Curriculum	Expository				Crash into Physics		
Term	Spring '08	Summer '08	Summer '08	Fall '08	Winter '10	Summer '10	Fall '10

The MPEX was administered to three sets of students after the curriculum had been changed. The groups all took the class in the same semester and had different instructors. Students in all groups tended to disagree with the experts on average, but these means also showed a relatively wide spread. Groups a and b had average favorable scores of 35.7% and 30.1%. Group G, exposed to the Crash into Physics curriculum, had an average favorable score of 47.0%. These data are shown in Figure 1 to place them in context, on an Agree-Disagree plot in the style of Ref. 3. The renormalized standard deviations for Groups a, b, and G were 7%, 10%, and 13%, respectively. (Renormalization accounts for the change from a trinomial to a binomial distribution when neutral responses were ignored.) A shift greater than twice the renormalized standard deviation may be interpreted as significant.[3]

The reality link cluster of the MPEX consists of the following four statements: #10: “Physical laws have little relation to what I experience in the real world.” (with which experts disagree) #18: “To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.” (experts agree) #22: Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.” (experts disagree) #25: Learning physics helps me understand situations in my everyday life.” (experts agree). Students’ rate of favorable responses is presented in Figure 2.

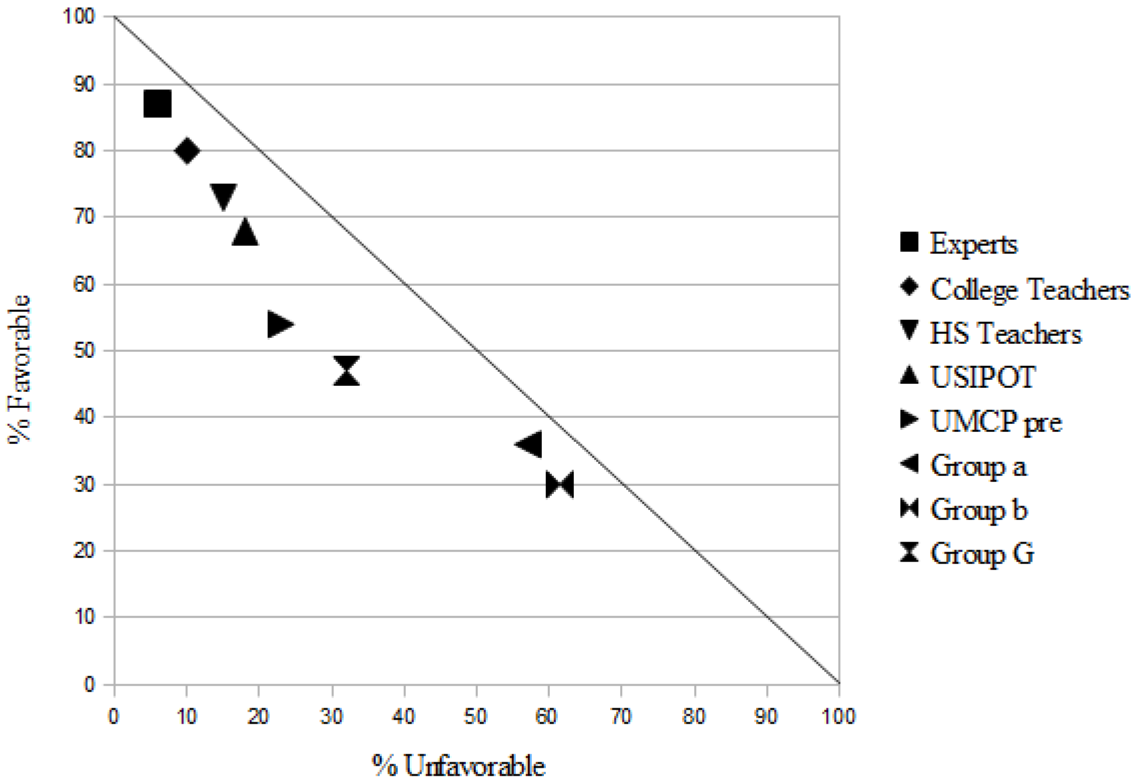

Figure 1: A-D plot as in Ref. 3, including their published data. (Experts are college teachers involved in Workshop Physics; USIPOT is one of the US International Physics Olympiad Teams, and UMCP pre are students entering the University of Maryland calculus-based physics course.)

Discussion

The goals of the curriculum development project were ambitious in the context of a two hour weekly lab. By incorporating a recurring theme of crash safety and vehicle testing, the project aimed to improve the perception of students that introductory physics is relevant to a career in engineering, in an area that benefits the general population. Also, the emphasis on active student engagement in a discovery/inquiry style lab is intended to provide deeper learning of concepts in physics. While this project revamped the laboratory, the structure and style of the lecture portion of the introductory course were not changed or affected by Crash into Physics.

During the initial year of deployment, the new curriculum has continued to be refined with the input of students and faculty. Structured focus groups led by external facilitators identified areas for improvement—primarily in facilitation, and clarifying expectations and grading. Overall, comments on student evaluations and midterm feedback have been positive regarding aspects such as the tour of the Crash Safety Center, using the lab apparatus as scaled-down models of test apparatus in that facility, and the flexibility in designing their own experimental methods in the later weeks.

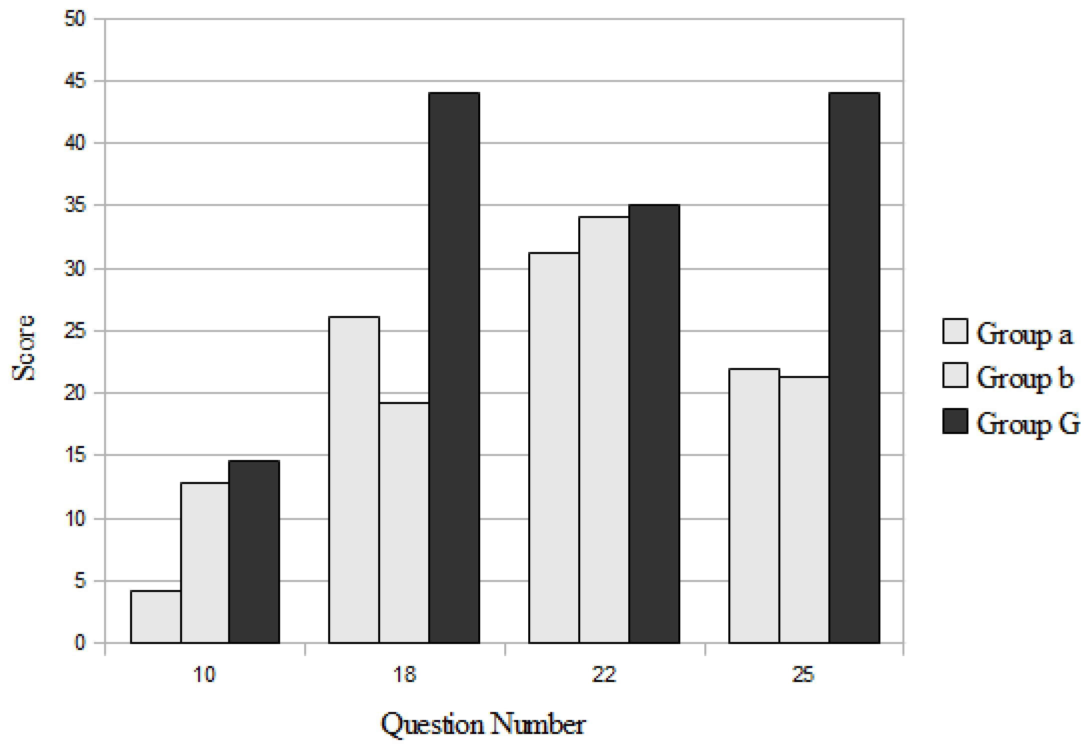

Figure 2. Percentage of favorable responses for statements in the reality link cluster. Groups a and b were students in the previous curriculum, and Group G was exposed to Crash into Physics.

The survey strategy intended to assess the effect of the change in laboratory curriculum was intermittent rather than consistent in every academic term, due in part to participation of instructional faculty and assessment needs of the greater physics degree programs. The four groups who completed the FCI, two groups before and two groups after the curriculum change, were drawn from lecture and laboratory sections with different instructors and different styles. All four sections' normalized gain is typical for teaching methods using traditional lecture rather than interactive engagement in the lecture hall. Both sections after the curriculum change produced lower gains on the FCI than the sections before the curriculum change, but this may indicate that many factors are involved in student conceptual knowledge beyond the scope of the laboratory curriculum. A successful lab curriculum, facilitated artfully, would contribute to improvements in the normalized gain on the FCI, but it might not cause much effect on its own.

Overall, the data collected to date from the MPEX survey might appear to show an improvement in the rate of favorable responses. Again, though, the mechanism behind this increase is not clearly tied to the laboratory curriculum effort. Additionally, calculation of the 5% probability level of random spread in the data, using renormalized standard deviations indicates that a statistically significant shift must be at least around 20% in the favorable response.

The reality link cluster of the MPEX, on the other hand, would more likely show an effect if reported attitudes are formed or affected through experiences such as those in laboratory. Focusing to the level of individual statements on the survey, Statements #18 and #25 appear to show statistically significant improvements in the rate of favorable responses.

This survey data is interpreted as preliminary, given that assessment has been sporadic (with relatively small *N* in each group), the facilitation best practices of the course are gradually being introduced to instructional faculty, and, of course, the materials and activities themselves are continually being refined.

Conclusion

Topics from vehicle crash safety have been integrated into the laboratory associated with the mechanics portion of the calculus-based introductory physics course. Used as more than examples of applications of mechanics topics, aspects of the Crash Safety Center facility are modeled on a small scale. The activities are designed with principles from physics education research, and engage students with increasing responsibility throughout the term, and on a weekly basis take students through a cycle that mirrors work done in research: predict, observe, compare, analyze, and then probe more deeply with quantitative experimentation. These resources will be shared via the project website.

The curriculum development project is ongoing, but preliminary assessment through a variety of means indicates students exposed to "Crash into Physics" may have improved attitudes about the link between physics in the classroom and situations in everyday life. For ongoing work, future assessment efforts will need to more precisely measure the effect of the laboratory activities, perhaps through carefully designed qualitative assessment instruments.

Acknowledgement

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