Evaluation of a Multiple Goal Revision of a Physics Laboratory

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Abstract. This paper reports on the revision of the University Physics laboratory at Western Kentucky University. Multiple learning objectives were negotiated among faculty, and a curriculum was developed to address all of them. A full pilot was run in Spring 2012 with three experimental sections and two control sections. Data was collected using the Force and Motion Conceptual Evaluation, a self-efficacy survey, and performance on the laboratory final. Data from the pilot shows gains in conceptual understanding on certain topics, differences in a few laboratory skills, and improvement in technical writing ability as measured by both a writing sample and student perception.

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INTRODUCTION

A variety of goals exist for introductory physics laboratories, such as "the art of experimentation, experimental and analytical skills, conceptual learning, understanding the basis of knowledge in physics, and develop collaborative learning skills." [1] Research-based curricula often focus on one or a few goals. Examples include RealTime Physics, [2] Workshop Physics, [3] Investigative Science Learning Environment, [4] and cooperative problem solving laboratories. [5] This work addresses a broad set of goals negotiated among departmental faculty.

In 2000 (before the lead author joined the department) the department's introductory calculus-based physics laboratories were revised by faculty associated with the applied physics lab. A custom built interface box with industrial quality electronics and software written in National Instruments' LabVIEW were developed. The laboratories emphasized skills such as calibrating sensors, numerical calculations, propagation of error, professional quality graphs, and fitting data; the last two used a dedicated graphing package (Igor Pro). This initial exposure LabVIEW has often led students to take an advanced data acquisition course, opening up a variety of advanced study and employment opportunities. The pedagogical structure of the labs generally consisted of experimentally verification of physical laws following detailed, step-by-step instructions from the manual.

The current revision sought to maintain the current strengths while incorporating more pedagogical best practices. Learning outcomes for the curriculum were developed by an ad hoc committee of faculty and instructors involved in teaching the lecture and laboratory sections of the course (all taught by faculty members). The prioritized list of objectives in Figure 1 is the result of negotiations among a group of faculty that included an education researcher and a leader of the previous revision effort.

Learning Objectives

1. Measure physical quantities using tools from simple scales to sophisticated data acquisition (LabVIEW) employing proper procedures for the given tool and keeping good records.
2. Develop experimental procedures to carry out an investigation to test a hypothesis.
3. Identify the appropriate methods (e.g. equations, diagrams) for analyzing data and carry them out correctly, including producing and fitting graphs.
4. Write technical reports that use appropriate language and are structured in typical format, such as including an abstract, introduction, experiment/procedures, data/results and conclusion.
5. Demonstrate improved conceptual understanding of foundational physics concepts.
6. Identify, minimize and quantify uncertainty in measurements, estimate uncertainties in calculated results, and compare with other results.
7. Effectively function in teams to accomplish different tasks.
8. Report having a positive learning experience in the course.

FIGURE 1. Learning objectives for WKU University Physics Laboratory I adopted by the department.

An initial pilot of the new materials was carried out in one section in fall 2011. The focus of this paper is spring 2012 where an expanded pilot with revised material was taught in three sections by the first two authors and departmental chair, while two control sections used the old curricular materials and were taught by other experienced faculty. Other faculty taught the two calculus-based lecture sections that students took concurrently, which sometimes incorporated some research-based activities. Students in the course are primarily engineering, physics, a few other sciences, and gifted high school students from the state math and science academy on campus.

STRUCTRE OF THE REVISED LABS

The curriculum continues to emphasize careful measurement of physical quantities (goal 1). Students still calibrate sensors, acquire data, make graphs and carry out linear and non-linear fits of the graphs. The most significant change in this aspect is that a new version of the data acquisition program was written in LabVIEW to provide a cleaner user interface and more careful pedagogical design (see Figure 2). Configuration files that partially set up the program and scripted some steps in Igor Pro were used to spread learning of all the steps over the first third of the semester.

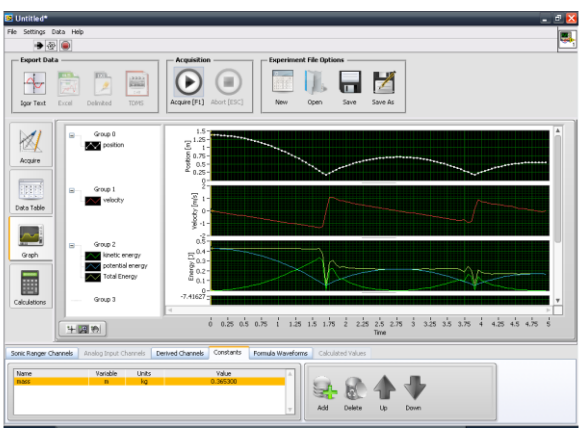

FIGURE 2. Data acquisition user interface. Buttons across the top are data acquisition and different file functions. Tabs down the left side control which graphs or data tables are displayed in the central area. In the lower panel the user defines data acquisition channels, calculation constants, derived and calculated data sets and statistics to calculate.

Goal 2 required no longer providing detailed instructions to students; instead laboratory manuals provide students with goals and some guidance on tasks. In compensation, detailed instructor notes are provided to help instructors implement the much interactive curriculum. Students make more experimental design choices as the semester progresses, for example what sensor to use for oscillatory motion. A series of pre-lab questions due in advance of each session helps ensure students are prepared, through summarizing the relevant physics for a lab, making predictions, reading up on procedures in the data acquisition or graphing software they will need to use that week, and thinking in advance about design choices. Each laboratory section has an undergraduate assistant to help support students during the laboratory period.

Analyzing data through calculated quantities and graphs (goal 3) continues to be emphasized; an important improvement is the ability to define and graph calculated quantities such as kinetic energy in the data acquisition program itself.

Formal laboratory reports continue to be the principle means of evaluating student performance (goal 4). Several activities were added to intentionally help students learn technical writing. First they evaluated two sample reports of very different quality using the grading rubric and discussed them in the second class. Then each week over the first half of the semester a different report section was discussed in pre-lab questions and in class; only after this discussion were those sections required in the reports.

The new curriculum has several laboratories that include tasks focused on conceptual understanding (goal 5). During the sessions on constant motion and acceleration, students were asked to predict and then qualitatively explain position, velocity and acceleration graphs and motion diagrams. During the introduction to force lab, students predict the motion diagrams and velocity and acceleration graphs of a hovercraft experiencing a constant force, and then carry it out in the hall, using bean bags to mark its position at two second intervals to construct a real-life motion diagram of hovercraft motion.

Statistical analysis and handling uncertainty (goal 6) are taught through specific activities introduced as students have need. For example, the initial activity in the free fall lab has student measure *g* using stop watches and meter sticks, resulting in a wide spread of data that are collected as a class for a discussion about systematic and random error, and understanding how to use the standard error to estimate the latter.

Elements of team work (goal 7) are introduced through assigning partners and carrying out several tasks as teams, such as pulling the hovercraft and dividing up different combinations of surfaces to test in the friction lab. Finally, the structure of the activities is designed to have students more engaged in the laboratory, using activities like the hovercraft to capture interest. Effort is made to provide real-world situations; the friction lab is couched in working as a research division of a new company.

EVALUATION OF THE REVISED LABS

Data on the pilot of the new curriculum was collected through three means. The department has routinely collected pre/post assessment of introductory physics laboratories using the Force and Motion Conceptual Evaluation (FMCE). [2] In addition, a survey of student self-efficacy and a common laboratory final exam were given to both groups.

Conceptual learning

The FMCE measures understanding of mechanics concepts. At WKU it is administered in all first semester physics laboratories in paper format during the first meeting the semester, and again one or two weeks before the end. Student performance does not count for a grade, but they are asked to take it seriously. The results of the assessment are shown in Table 1 with average of raw pre- and post-scores along with gain for the both groups, along with data for the previous two years. One control section did not complete the post test due to scheduling issues.

The experimental group gained more than the control although the small numbers limit confidence. Gains on the test as a whole were similar to the historical data, but there were significant trends on individual questions. The five questions on which the experimental group scored highest compared to the historical group on the post test (15 to 23 percentage points) were questions 2, 5, 22, 24 and 26, which all deal with the force or acceleration of an object that is either speeding up or moving at a constant speed. In contrast, the five questions in which they scored the lowest compared to the historical group were 32, 39, 44, 45, and 46, which deal with Newton's third law when one object is stationary or velocity/kinetic energy of an object going down a slope.

TABLE 1. FMCE Results.

Measure	Experiment	Control	Previous
Pretest score	14.6	11.3	13.7
Posttest score	22.3	16.6	21.3
Hake gain	24%	15%	23%
Sample size	29	16	115

Self Efficacy

During the tenth week of the semester, students in all sections were asked to fill out a self-efficacy survey at the beginning of the lab. Five questions asked students to rate on a scale of 1 to 5 how much they felt they had developed their ability over the semester to write technical reports, to make accurate measurements, to determine and handle uncertainty, to develop experimental procedures and to work as a team. They were also asked to rate how positive the experience had been for them, and provide demographic data. The results are shown in Figure 2. Error bars represent one standard error.

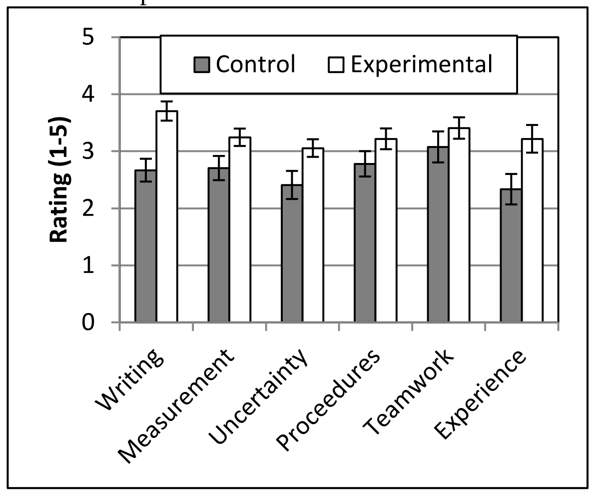

FIGURE 2. Student self rating of learning in five areas and general experience; only "Writing" was significant when previous laboratory experience was accounted for.

T-tests found no significant difference in self efficacy due to gender or major. There was a confounding variable in that the students in the control sections had, on average, taken more lab courses. When this was included as a factor in a linear regression, there were no significant differences between the two curricula except for the writing question, which were significant at the $p < 0.005$ level.

Laboratory Final

A final exam focused on specific laboratory skills, developed by the first two authors to address different learning outcomes, was reviewed and approved by all laboratory instructors (face validity). The questions focused on skills students should have developed during the course: calibrating a motion sensor, measuring the lengths of a set of rods with a Vernier caliper and determining the average and standard error, graphing position/velocity data and determining the acceleration by fitting a specified region, determining the spring constant of a spring, and writing an abstract for a provided sample report.

Student results on the tasks except the spring were analyzed using copies of exams with names removed. Some results naturally lead to numerical analysis, like the precision to which rods were measured and the length of the abstract. Others were analyzed using an emergent coding scheme developed by the first and third authors in consultation with each other, and then counts were made of the different codes. A total of twenty different measures were obtained.

The most significant differences related to the writing of the abstract. While no differences were observed in spelling/grammar errors or length of abstract, those of the experimental group were more complete and more consistent in use of voice. Figure 3 shows the percent of abstracts with acceptably complete descriptions of the purpose, the experimental procedures, the results, the combination of all three, and did not change voice (e.g. third person passive) throughout. There is a potential complication in that two different sample reports were used; the report for the experimental group read a report on the lifetime of batteries compared to Newton's second law, though it is not clear what difference this would make.

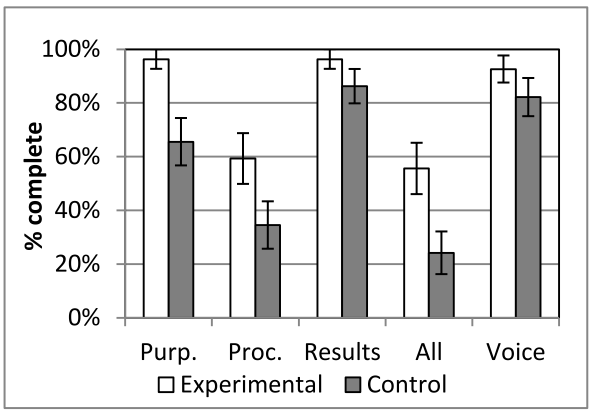

FIGURE 3. Quality of abstract writing, showing thee percentage of abstracts with complete purpose, procedures, results, the three combined, and consistent use of voice.

Two other areas where differences were found were the precision that the students reported measurements of rods lengths and formatting graphs. The experimental group reported data with a precision averaging 0.007 cm compared to 0.03 cm for the control group, calculated from the average of the logs of the precision. A t-test of the logs of precision gives $p < 0.01$. 78% of the control group properly labeled the graph and both axes compared to only 38% of the experimental group, though in 2/3 of the cases the error was simply not titling the graph. All of the students who did not attempt to fit the graph to get the acceleration were from the experimental group, a total of five or 19% of group.

DISCUSSION AND CONCLUSION

Writing skills were the area with the strongest results. Although neither student self-assessment nor the abstract writing task have a particularly high level of validity, they do represent two independent measures that agree with each other and instructor impressions, providing us with confidence of improved writing skills. This is gratifying as the teaching and scaffolding of technical writing was one of the areas of the major change in the curricula.

The FMCE data shows improved conceptual understanding compared to the control group. The experimental group performed better than historical on questions relating to force and acceleration of objects moving at constant velocity or speeding up. These corresponded to early labs with explicit conceptual development (and a hovercraft) and had been piloted the previous semester. The experimental group performed worse on questions related to impulse and energy; the corresponding laboratories were being piloted for the first time and various difficulties were encountered, including needing a second week to complete. Both also wound up taking on more of a character of a verification lab then intended.

The difference in precision of rod measurements and graphing is consistent with specific activities over the course of the semester. The experimental group completed more activities involving reading Vernier calipers than the control group. On the other hand, the control group spent an entire laboratory period learning to use the graphical software, including labeling and fitting, while the experimental group learned it as needed as the semester progressed. The process of learning the laboratory software had already been identified by the instructors in the experimental sections as an area where the new curricula needed improvement even before this analysis was carried out.

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