ACTIVITY BASED PHYSICS: ENHANCING STUDENT LEARNING USING THE OUTCOMES OF PHYSICS EDUCATION RESEARCH AND EMERGING TECHNOLOGIES

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Abstract
For over twenty-five years Priscilla Laws (Dickinson College), David Sokoloff (University of Oregon), Ronald Thornton (Tufts University), Robert Teese (Rochester Institute of Technology) and others have developed and conducted research on the efficacy of *Activity Based Physics* curricular materials designed for introductory physics courses.[1] These materials combine Physics Education Research findings with emerging technology. The project began in 1986 when Professors Laws and Thornton were each awarded grants from the US Fund for Postsecondary Education (FIPSE). In this paper the evolution of the Activity Based Physics curricular materials, teaching methods and technology use is described. These materials include: *Workshop Physics*, [2] *RealTime Physics* Laboratory Modules,[3] *Interactive Lecture Demonstrations*,[4] *Explorations in Physics*,[5] *Physics with Video Analysis*,[6] and a set of *Interactive Video Vignettes* currently under development. The outcomes of research on the effectiveness of these materials and associated technologies for the teaching of Newtonian Mechanics and DC Circuits is presented.

Keywords: Physics Education Research (PER), Curriculum Development, Emerging Technologies

1. Introduction

Physics instructors who teach at the secondary and post-secondary level often realize that many students complete introductory courses without mastering basic concepts. In the past twenty-five years, many researchers in the emerging field of Physics Education Research (PER) have concentrated on identifying learning difficulties encountered by secondary school and university students who enroll in introductory physics courses.[7,8]
The growth of Physics Education Research (PER) occurred in parallel with the onset of the personal computer in the early 1980s and the discovery by Bob Tinker and colleagues at the Technical Education Research Centers (TERC)[9] that devices such as thermistors and ultrasonic Polaroid camera range finders could be attached to microcomputer game ports to detect temperatures and motions. A thermistor plunged into ice water could cause a cooling curve to be displayed in real time on a computer screen. Similarly a student walking back and forth in front of an ultrasonic range finder connected to a computer could see an instantaneous graph of her motion. Subsequent studies show that when someone walks back and forth front of an ultrasonic

motion detector while looking at a real-time graph of the motion he or she can acquire an immediate understanding of position, velocity and acceleration graphs.[10,11] These early computer-based sensors and, if needed, interfaces became known as Microcomputer Based Laboratory or MBL devices.

The Activity Based Physics Group's curriculum development efforts began in 1986 when Principal Investigators at Dickinson College (Priscilla Laws) and Tufts University (Ronald Thornton) each received grants from the U.S. Department of Education's Fund for the Improvement of Postsecondary Education. They were asked to collaborate because Laws and Thornton both proposed to use educational research outcomes and MBL devices in the development of curricular activities. Laws led the creation of the calculus-based *Workshop Physics* introductory physics courses at Dickinson College[12,13] while Ronald Thornton along and David Sokoloff from the University of Oregon proposed to co-develop MBL-based *Tools for Scientific Thinking* laboratory manuals for Motion[14] and Heat & Temperature.[15]

As a result of recent advances in computer, sensor and digital video technology, three vendors now provide electronic interfaces, up to 50 sensors and software packages such as Logger *Pro*, Coach 6 (used in Europe) or the new PASCO Capstone software that allow for the instantaneous collection, graphical display and analysis of data for a full range of physical phenomena.[16-18] In addition, all of these suppliers have included video analysis modules in their data collection software that allows for two-dimensional motions and other laboratory and real world phenomena to be studied though the capture and analysis of video images. So it is now possible to synchronize sensor data with video analysis data, if the video is taken while corresponding sensor data is collected.

The purpose of this paper is threefold: (1) To describe how the outcomes of Physics Education research and the use of emerging technologies such as MBL and video analysis tools have influenced the development of the Activity Based Physics Group's curricular materials; (2) To explain how pre/posttest evaluations based on Physics Education Research findings can be used to refine and improve curricular materials; and (3) To discuss how emerging video and web-based technologies can be used to create activity based distance learning materials that, at present, place students in a passive role.

2. Activity Based Curricular Materials that Use MBL Tools for Data Collection

The curricular materials developed by the Activity Based Physics Group since 1988 have been designed to provide instructors with materials that can be used in many contexts.

Workshop Physics is a calculus-based introductory physics curriculum designed to replace traditional lectures and laboratories. In a typical 2-hr Workshop Physics class, students use equipment, and computer tools (e.g. MBL and spreadsheets) for data acquisition, visualization, analysis, and mathematical modeling. There are four modules that span a full year course: two on Mechanics, one on Heat & Temperature, and one on Electricity & Magnetism. These modules are distributed by John Wiley & Sons for use in university level courses and by Vernier Software & Technology under the name Activity Based Physics High School e-dition for use in secondary school courses.[14]

Tools for Scientific Thinking Guides use microcomputer-based laboratory materials to help student develop concepts and intuition in the laboratory. Guides for the study of Motion or Heat & Temperature are suitable for either high school or introductory college lab students. They are distributed by Vernier Software & Technology.[14,15]

RealTime Physics Modules use MBL materials to help student develop lab skills and enhanced conceptual understanding. The Four Modules on: 1-Mechanics; 2- Heat & Thermodynamics; 3-Electricity&Magnetism, and 4-Light&Optics are suitable for either high school or introductory college students. They are distributed by John Wiley & Sons for use in university level courses and by Vernier Software & Technology for use in secondary school courses.

Interactive Lecture Demonstrations (ILDs) are worksheet-based guided demonstrations that focus on fundamental principles and specific naive conceptions. The demonstrations use MBL tools to collect and display data in real time. Each ILD sequence is designed for delivery in a single lecture period. The demos help students build concepts through a series steps involving prediction, discussion with peers, viewing the demonstration and reflecting on its outcome. The ILD collection includes sequences in mechanics, thermodynamics, electricity, optics and more. Instructors can obtain a complimentary copy of the ILD book from a regional John Wiley & Sons representative.

Explorations in Physics is an award winning* hands-on curriculum that integrates the use of guided-inquiry with self-directed projects to help students acquire a fundamental understanding of the nature of science. The modular design provides flexibility for instructors to adapt the materials to their environments. Each of eight modules can be downloaded at no charge at
http://physics.dickinson.edu/~eip_web/resources.html
* http://www.aaas.org/news/releases/2012/0127sp_ibi.shtml

Physics with Video Analysis is a collection of 32 assignments that require students to make predictions, perform a short video analysis (sometimes synchronized with sensor data), and draw conclusions. The assignments can be completed individually or collaboratively. The book and CD, distributed by Vernier Software & Technology contain videos, assignment sheets and answer keys.

As noted some of these materials are free. However, other the materials are softcover workbooks published by John Wiley & Sons. College and university students must purchase these books. By special arrangement with the publisher, secondary schools can purchase a license from Vernier Software and Technology and reproduce materials for dissemination to their students.

3. Formative and Summative Evaluation of ABP Curricular Materials

Educational research has been used to inform the development of new Activity Based Physics curricular materials as well as revisions of older materials. This research uses feedback from colleagues who use materials in professional development workshops and with their own students, feedback from students based on classroom testing, and pre- /post-test results based on evaluation instruments designed to gauge student learning in key areas. This cycle is shown in Fig. 1.

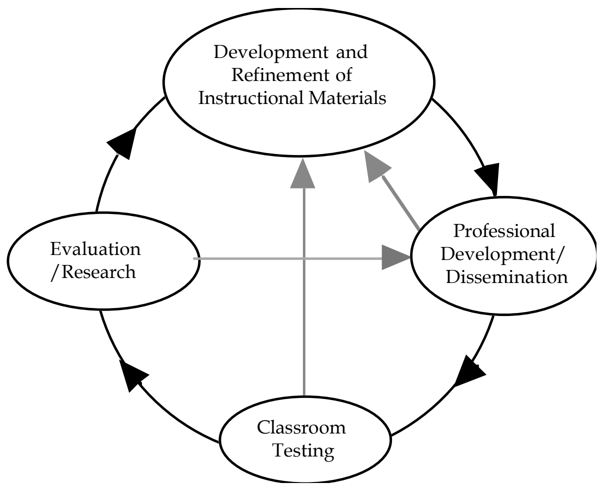

Fig. 1: Testing and Evaluation Cycle for Activity Based Physics Curricular Materials

Using interview techniques, pre- and post-testing and classroom observations, PER researchers have identified a number of learning difficulties students bring to the study of physics. Examples of learning difficulties drawn from Newtonian mechanics include:

(1) Failure to relate simple one-dimensional graphs of position, velocity or acceleration vs. time to the motion of the object or the forces that it is experiencing;
(2) Belief that an object will come to rest eventually even when no net forces are present or that whenever an object collides with a less massive objects it exerts more force on that object;
(3) Belief that a moving object that experiences no forces will come to rest;
(4) Belief that a constant net force on an object will cause that object to move at a constant velocity; and
(5) Belief that when two objects moving in opposite directions at the same speed collide, the more massive object will exert more force on the less massive object.

Researchers have proposed various of strategies for helping students overcome common learning difficulties identified by PER. Over the past twenty-five years, members of the *Activity Based Physics Group* and others have developed various conceptual evaluations to determine student beliefs about physics phenomena. These evaluations can be used as ungraded pre- and post- tests for introductory physics students. Several pre/post tests have been created to assess the viability of *Activity Based Physics* curricular materials. In addition, instructors at many institutions want to know what alternative conceptions about topics their own students bring to the study of physics. Also, instructors who plan to use alternate materials and approaches can assess how effective their own approaches to introductory physics teaching, have often asked to use our Group's evaluation tools. The following evaluations are available on the *Activity Based Physics* website:[19]

The Quadratic and Linear Conceptual Evaluation (QLCE)
There is a growing awareness that introductory physics students should learn how to "read" equations that describe physical phenomena and understand the role that functional relationships and coefficients play in modeling physical situations and in determining the nature of graphs based on data.

The Vector Evaluation Test (VET)
A 31 item multiple-choice and short-answer survey testing vector analysis skills including addition and subtraction, component analysis, and comparing magnitudes.

The Force-Motion Concept Evaluation (FMCE)
A survey containing 47 items in a multiple-choice multiple-response format. This evaluation covers a wider variety of topics than the Force Concept Inventory (FCI), including many more questions on kinematics.[20]

The Heat and Temperature Concept Evaluation (HCTE)
A 28 item survey on concepts of heat, temperature, and heat flow. Should take about 30-40 minutes to complete. All but one of the items are machine gradeable. One item requires drawing a graph and writing a sentence.

The Electric Circuits Concept Evaluation (ECCE)
A 45 item multiple-choice survey probing student understanding of direct and alternating current circuits. Some items include capacitors and inductors or request explanations. Should take about one hour to complete.

The Maryland Physics Expectations Survey (MPEX)
A 34-item Likert scale (5-point agree-disagree) survey that probes student expectations about the nature of learning in physics classes. The MPEX items fall into 5 clusters:

independence/authority, concepts/formulas, coherence/pieces, reality link, and math link. The Survey takes about 20-30 minutes to complete. A spreadsheet for the construction of favorable/unfavorable response diagrams is included.

4. Using Conceptual Evaluations to Enhance Activity Based Physics Teaching

Here we present two case studies demonstrating how conceptual evaluations were used to help authors of the *Workshop Physics* and *RealTime Physics* materials improve the curricular materials to make them more effective. One involves testing student comprehension of Newtonian Mechanics in courses where Workshop Physics was being implemented and comparing it to students were Workshop Physics had been used for several years. The second case study involves assessing learning associated with the behavior of simple DC circuits when students completed early versions of *Workshop Physics* and *RealTime Physics* laboratory activities, modifying the activities based on PER research done at the University of Washington and then retesting students who completed the modified activities.

Case Study 1: Newtonian Mechanics

There are two popular evaluations used to gauge learning in Newtonian Mechanics: The Force Concept Inventory (FCI) I. Halloun and D. Hestenes, The Initial Knowledge State of College Physics Students, *Am. J. Phys.* **53**: 1043-1055 (1985) and the Force Motion Conceptual Evaluation (FMCE)[20] discussed in the previous section of this paper. Success on these two evaluations is often reported as "normalized gain" or g. This is a measure of the fraction of the way a student has gone from his/her pretest score to a perfect score. A gain of 0 signifies that the pretest and posttest scores are identical while a gain of 1 signifies that the student has answered all the posttest questions perfectly and has mastered Newtonian mechanics. Reporting the average gain for a class is a gauge of how successful an instructor is. Or if an instructor is trying a new approach, the success of the new methods can be assessed.

For example in 1997 Jeff Saul and E.F. Redish carried out an independent evaluation of student learning in *Workshop Physics* at seven colleges and universities that were implementing *Workshop Physics* for the first or second time as part of a grant project. Student learning was evaluated with Pre-Post FCI or FMCE questions.[Refs: J.M. Saul and E.F. Redish, "Final Evaluation Report for FIPSE Grant #P116P50026:Evaluation of the Workshop Physics Dissemination Project," University of Maryland Preprint, 1997].

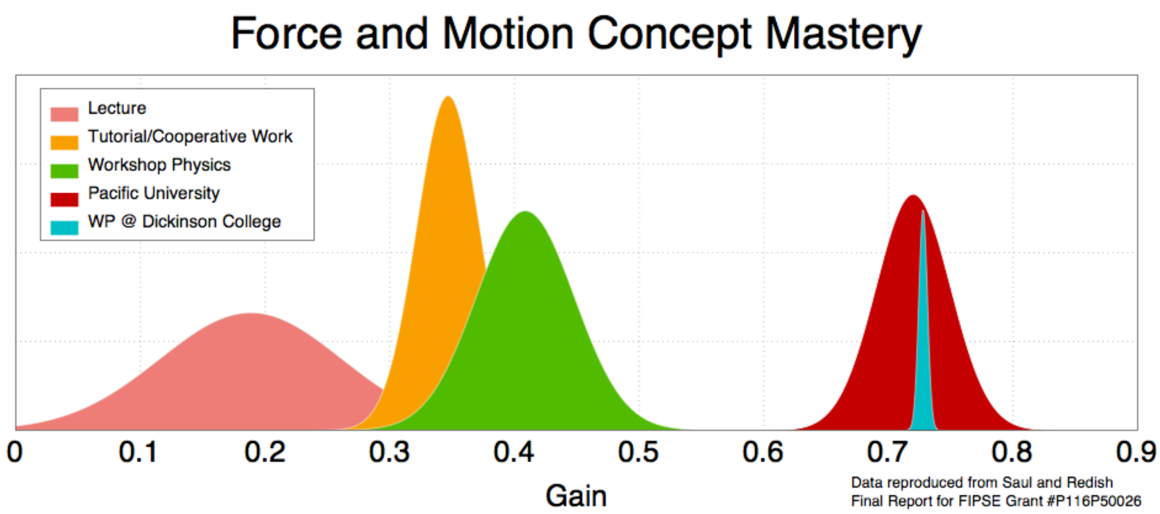

Fig. 2: Distribution of fractional gains or pre-post FCI and FMCE for traditional instruction, traditional instruction enhanced weekly tutorial/recitation sessions, early adopters of Workshop Physics, and experienced *Workshop Physics* adopters at Pacific University and Dickinson College where the staff already had eight years of experience with using the *Workshop Physics* method. Except for the single spike for the WP @ Dickinson on the right, histograms for each group are fit with a normalized Gaussian.

Clearly learning gains from new *Workshop Physics* adoptors are superior to those obtained by other, more traditional approaches to teaching. But student mastery of force and motion concepts is far superior when *Workshop Physics* students have taken courses from experienced instructors.

Case Study 2: DC Circuits with Batteries and Bulbs

Between 1988 and 1992 the Workshop Physics materials on simple DC Circuits used at Dickinson College were derived from early studies of conceptual development in middle school students. During that period David Sokoloff was adapting some of the early Workshop Physics activities for introductory physics laboratories at the University of Oregon. He devised a pretest on circuits that eventually served as the basis for the Electric Circuits Conceptual Evaluation (ECCE). When he administered it to students who were taking his lecture course at the University of Oregon, but had not yet enrolled in a laboratory course, the pretest and posttest scores on the early version of evaluation were disappointing. Before lectures, students scored 33% on the pretest and 38% on the posttest. When he introduced students taking the lab course to some workshop physics wiring exercises, the posttest scores rose to 50%. The Workshop Physics students at Dickinson College were also getting about 50% correct on his posttest. But in 1992 both Sokoloff and Laws heard a presentation by Peter Shaffer on an extensive project completed at the University of Washington to identify learning difficulties encountered by students in their study of circuits.

Using preprints of two landmark papers published by McDermott and Shaffer on DC Circuits, Laws and Sokoloff revised the curricular materials on simple DC circuits used in Workshop Physics courses at Dickinson College and the early RealTime Physics labs at the University of Oregon. [Ref. P.S. Shaffer and L.C. McDermottt, "Research as a guide for curriculum development; An example from introductory electricity. Part II: Design of an instructional strategy," Am. J. Phys. 60- 1003-1013 (1992)] We are proud to report that both sets of students got over 80% mastery of DC Circuit questions as shown in Figure 3.

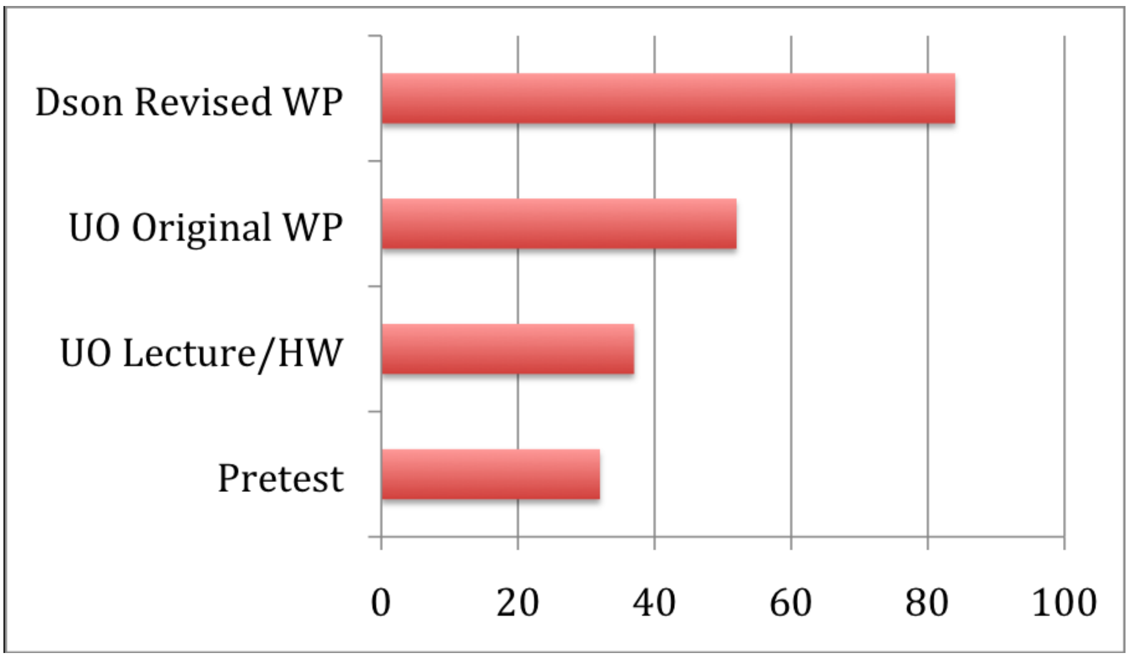

Fig. 3: ECCE scores at the University of Oregon and Dickinson College in 1992.

5. Designing and Testing Interactive Video Vignettes --A New Use of Emerging Technology

As reported earlier in this paper, one key to facilitating active learning is to take advantage of new technologies in ways that facilitate "learning physics by doing physics." Distance Learning is one of the new educational technologies that is currently in the news. In the United States people are talking about MOOCs an acronym stands for Massively Open Online Courses. The proponents of MOOCs seem excited about the idea that a number of lecture series can be

developed for which experts give "perfect lectures." This is supposed to obviate the need for classrooms, laboratories and discussion sessions. Learning that centers on listening to ideal lectures eliminates the no need for brick and morter universities or schools. Nevertheless thus belief seems to ignore a large body of research findings about the importance of active engagement.
Several authors of the *Activity-Based Physics* curricular materials described in this paper are participating in a new project supported by the U.S. National Science Foundation [Ref. DUE 1122828 & 1123118] to create a set of Web based Interactive Video Vignettes. The group is developing a series of about 25 short single-topic expositions as ungraded out of class activities for introductory physics students. A typical Vignette combines narration, real-world video, and video analysis tools that enable students to master concepts or learn data collection and analysis techniques. Currently, several Vignettes have been produced and are being tested. These include 6 minute to 10 minute long expositions in topics such as Projectile Motion, Newton's Laws, and Momentum and energy.

6. Conclusions

Members of the Activity Based Physics Group remain excited about new opportunities to create, test and evaluate curricular materials that use technologies that are designed in accordance with the latest findings of Physics Education Research. In this way they can help students continue "learning physics by doing physics".

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