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ABSTRACT

This project focused on encouraging instructors at large universities to take advantage of the curricular materials and computer tools developed for two related programs funded originally by FIPSE. In particular, it involved reworking and integrating materials developed for the previously funded Workshop Physics and Tools for Scientific Thinking projects so they could be used more flexibly in large university settings. Both the Workshop Physics Activity Guide and the Tools for Scientific Thinking laboratory materials with instructor guides were revised and enhanced. Prototype interactive lecture demonstration materials were developed and tested, new conceptual examinations were developed for project evaluation, and the microcomputer-based laboratory software and hardware offerings were extended and enhanced. MBL and spreadsheet software tools were developed to allow students to undertake more sophisticated data analysis and do mathematical modeling. These new materials were tested, and student learning gains were assessed at a number of institutions. The project directors did extensive dissemination through public talks, teacher workshops, and on-site consultation. Appendixes include: "A New Mechanics Case Study" (P. Laws); "Using Large-Scale Classroom Research To Study Student Conceptual Learning in Mechanics and To Develop New Approaches to Learning" (R. Thornton); a Vernier Software brochure; "Engaging Students with Interactive, Microcomputer-Based Demonstrations" (R. Thornton and D. Sokoloff); Tools for Scientific Thinking question sheets; a list of talks given; and additional grants information. (AA)

FIPSE Interactive Physics Project
(October 1989-August 1993)
Final Report

Priscilla W. Laws
Ronald K. Thornton

COVER SHEET

Grantee Organization:	Department of Physics and Astronomy Dickinson College Carlisle, PA 17013
Grant Number:	P116B90692
Project Dates:	Starting Date: October 1, 1989 Ending Date: August 31, 1993 (includes an 11 month extension) Number of months: 47
Project Directors:	Priscilla W. Laws Department of Physics and Astronomy Dickinson College Carlisle, PA 17013 Telephone: (717) 245-1242
	Ronald K. Thornton Center for Science and Mathematics Teaching Tufts University Science Technology Building Medford, MA 02155 Telephone: (617) 381-3244
FIPSE Program Officer:	Brian LeKander
Grant Award:	Year 1 $133,024 Year 2 $139,045 Year 3 $147,275 Total $419,344

Project Summary

This project involved reworking and integrating materials developed for the previously funded Workshop Physics and Tools for Scientific Thinking projects so they could be used more flexibly in large university settings. Both the Workshop Physics Activity Guide and the Tools for Scientific Thinking laboratory materials with instructor guides were revised and enhanced. Prototype interactive lecture demonstration materials were developed and tested, new conceptual examinations were developed for project evaluation, and the microcomputer-based laboratory software and hardware offerings were extended and enhanced. MBL and spreadsheet software tools were developed to allow students to undertake more sophisticated data analysis and do mathematical modeling. These new materials were tested, and student learning gains were assessed at a number of institutions. The project directors did extensive dissemination through public talks, teacher workshops, and on-site consultation.

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The following project products are available from Vernier Software Co., 2920 S.W. 89th Street, Portland, OR 97225 Tel:(503) 297-5317

The Workshop Physics II Activity Guides (Calculus-Based and Non-Calculus-Based)
The Tools for Scientific Thinking Curricular Guide
Universal Lab Interface and Software Developer's Guide
Voltage Measurement Leads/Radiation Detector/Force Probe/Motion Sensor/Photogates/ Light Sensor/Microphone
MBL 4.0 Series Software for Macintosh and MS DOS Computers: MacMotion /Data Logger/Sound and Temperature
MBL 4.0 Series Software for the Macintosh:Event Timer/Event Counter

The following project software and hardware products are available in beta version from Dickinson College and Tufts University:

MS Excel Custom Tools (for use with Windows and Macintosh)–Dickinson
Video Analysis Tools and Movie Set (for the analysis of motion)–Dickinson
MBL Rotary Motion software and sensor–Tufts
MBL Two Force Probe Data Logger software–Tufts

The following curricular materials, articles and reports have resulted from the project:

"Achieving Global Scientific Literacy," **The 1993 Yearbook from the Charles A. Dana Awards for Pioneering Achievements in Health and Education,** November, 1993. Author: P. Laws.

"Tools for Scientific Thinking," **The 1993 Yearbook from the Charles A. Dana Awards for Pioneering Achievements in Health and Education,** November, 1993. Author: R. Thornton.

"Workshop Physics: Reflections on Six Years of Laboratory Based Introductory Physics Teaching," **Proceedings of the American Association of Physics Teachers Conference: Lab Focus '93**, August 1993. Author: P. Laws.

"RealTime Physics: Active Learning in the Introductory Laboratory," **Proceedings of the American Association of Physics Teachers Conference: Lab Focus '93**, pp. 98-101, 1993. Author: D. Sokoloff.

"Changing the Physics Teaching Laboratory: Using Technology and New Approaches to Learning to Create an Experiential Environment for Learning Physics Concepts," **Proceedings of the American Association of Physics Teachers Conference: Lab Focus '93**, pp. 86-89, 1993. Author: R. Thornton.

"Black Boxes and Automatic Data Collection: Exploring the Intelligent Use of Technology in the Teaching Laboratory," **Proceedings of the American Association of Physics Teachers Conference: Lab Focus '93**, pp. 82-85, 1993. Author: R. Thornton.

"A New Order for Mechanics," **Proceedings of the Rensselaer Polytechnic Institute Conference on Introductory Physics Courses,** May 1993. (In Press) Author: P. Laws.

"Microcomputer-based Labs and Interactive Demonstrations," **Proceedings of the Rensselaer Polytechnic Institute Conference on Introductory Physics Courses,** May 1993. (In Press) Author: R. Thornton.

"Using Large-Scale Classroom Research to Study Student Conceptual Learning in Mechanics and to Develop New Approaches to Learning." (To be published in **Proceedings of the NATO Advanced Research Workshop--Microcomputer-Based Labs**, Amsterdam, Nov. 9-13, 1992.) Author: R. Thornton.

"A New Mechanics Case Study: Using Collisions to Learn about Newton's Third Law," **Proceedings of the NATO Advanced Research Workshop on Microcomputer-Based Laboratories,** Amsterdam, Nov. 9-13, 1992, (In Press with Springer-Verlag) Author: P. Laws.

"RealTime Physics: Mechanics," preliminary version. **Vernier Software**, September, 1993, Portland, OR. Authors: P. Laws/R. Thornton/D. Sokoloff.

"Engaging Students with Microcomputer-Based Laboratories and Interactive Lecture Demonstrations," **Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers**, pp. 38-48, (August, 1993). Author: D. Sokoloff.

"Tools for Scientific Thinking--Heat and Temperature Curriculum and Teachers' Guide," **Vernier Software**, 1993, Portland, OR. Authors: D. Sokoloff and R. Thornton.

"Teaching Electric Circuit Concepts Using Microcomputer-Based Current and Voltage Probes." (To be published in **Proceedings of the NATO Advanced Research Workshop--Microcomputer-Based Labs**, Amsterdam, Nov. 9-13, 1992.) Author: D. Sokoloff.

Changing the Physics Teaching Laboratory: Using Technology and New Approaches to Learning to Create an Experiential Environment for Learning Physics Concepts, **Proceedings of the Europhysics Study Conference, *The Role of Experiment in Physics Education*,** Seta Oblak, Nada Razpet, ed. (Ljubljana, Slovenia, pp. 12-31, 1993)

"Tools for Scientific Thinking--Motion and Force Curriculum and Teachers' Guide," Second ed., **Vernier Software**, 1992, Portland, OR. Authors: D. Sokoloff/R. Thornton.

"Motion and Force: Student Activities (a guided discovery MBL curriculum) and Teachers Curriculum Guide" **Vernier Software**, Portland, OR 1992. Authors: R. Thornton/D. Sokoloff.

"Enhancing and Evaluating Students' Learning of Motion Concepts." Chapter in **Physics and Learning Environments**, A. Tiberghien and H. Mandl, eds. (Berlin-Heidelberg-New York, Springer Verlag, NATO ASI Series F: Computer & Systems Sciences, **86**, pp 265-283. Series, 1992). Author: R. Thornton.

"Constructing Student Knowledge in Science" (with Robert Tinker). Chapter in **New Directions in Educational Technology**, E. Scanlon and T. O'Shea, eds. (Berlin-Heidelberg-New York, Springer Verlag, NATO ASI Series F: Advanced Educational Technology, **96**, pp 153-171. Series, 1992). Author: R. Thornton.

"Calculus-Based Physics Without Lectures," **Physics Today,** Vol. 44, No. 12, December 1991. Author: P. Laws.

Using the Microcomputer-Based Laboratory to Improve Student Conceptual Understanding in Physics (In English). **Turkish Journal of Physics 15** (2), pp 316-335 (1991), Turkey.

"Heat and Temperature: Student Activities" (a guided discovery MBL curriculum), **Vernier Software**, Portland, OR 1991. Authors: R. Thornton/D. Sokoloff.

Using the Microcomputer-Based Laboratory to Improve Student Conceptual Understanding in Physics (In Italian). **La Fisica nella Scuola** (1990), Italy, Anno XXIII **2**, pp 81-92.

Executive Summary

Project Title: Interactive Physics

Grantee Organization: Department of Physics and Astronomy
Dickinson College
Carlisle, PA 17013

Project Contacts: Priscilla W. Laws at (717) 245-1242
Ronald K. Thornton at (617) 627-3658

A. Project Overview

This project focused on encouraging instructors at large universities to take advantage of the curricular materials and computer tools developed for two related programs funded originally by FIPSE. In particular, this project involved reworking and integrating materials developed for the previously funded Workshop Physics and Tools for Scientific Thinking projects so they could be used more flexibly in large university settings. Both the Workshop Physics Activity Guide and the Tools for Scientific Thinking laboratory materials with instructor guides were revised and enhanced. Prototype interactive lecture demonstration materials were developed and tested, new conceptual examinations were developed for project evaluation, and the microcomputer-based laboratory software and hardware offerings were extended and enhanced. MBL and spreadsheet software tools were developed to allow students to undertake more sophisticated data analysis and do mathematical modeling. These new materials were tested, and student learning gains were assessed at a number of institutions. The project directors did extensive dissemination through public talks, teacher workshops, and on-site consultation.

B. Purpose

The purpose of the project was to find ways to encourage Physics Departments at larger universities to engage in serious efforts to change the manner in which they teach introductory physics. We wanted the courses to be more interactive and to take better advantage of the new teaching methods and pedagogical materials developed for the FIPSE-funded Workshop Physics and Tools for Scientific Thinking programs. Since the Workshop Physics approach was developed at a small liberal arts college with a high faculty to student ratio and excellent resources, the abandonment of lectures that it required was hard to realize at larger institutions with high student enrollments. Although the laboratory materials created in the Tools for Scientific Thinking program gained widespread use in university laboratories, the lecture and recitation sessions were still being taught in the same way. We felt that by taking the special problems of larger institutions into consideration, we could revise the curricular materials and computer tools so that they could be used in university physics programs.

C. Background and Origins

This interactive program grows out of the previous development of two highly related approaches to the teaching of Introductory Physics–the Workshop Physics project at Dickinson College[1] and

[1]The Workshop Physics Project began officially in October 1986 with a three-year FIPSE grant at Dickinson College. It is described more fully in a pending paper by Priscilla Laws entitled

the Tools for Scientific Thinking project at Tufts University[2], both funded by FIPSE (Oct. 1986-Sept. 1989). These programs addressed major problems affecting the teaching and learning of introductory physics students – the failure to deal effectively with students' profound misconceptions about physical phenomena and the absence of contemporary tools for the construction and communication of scientific knowledge. The educational approach in both of these projects is *interactive* and *learner-centered*. Both programs share the use of inquiry methods of instruction and the use of the microcomputer as an active tool for learning, and both share a common educational philosophy: that the acquisition of scientific literacy as defined by Arnold Arons[3] is more important than engagement with the traditional textbook problem solving that currently dominates introductory physics. At the completion of the funding period for each program there were still many challenges ahead. Refinement of materials and evaluation methods were still ongoing and questions were being raised as to how to best convince colleagues at larger institutions to adopt the new approaches.

D. Project Description

In year one the Interactive Physics project began with dialog and visits by instructors to large universities seeking ways to expand the number of interactive laboratory experiences available to students and to integrate activities developed in the two programs into the lecture and recitation portions of introductory physics courses. Formal collaboration was initiated with colleagues at the University of Oregon and Boise State University. In addition, informal collaboration took place with faculty members at dozens of institutions, including Ohio State University, Rutgers at New Brunswick, University of Nebraska. Meetings were held with project collaborators during the 1989, 1990, and 1991 winter meetings of the American Association of Physics Teachers and at Dickinson College during the corresponding summers.

We began to appreciate first hand the difficulties that large departments have in implementing effective changes in classroom practices. We saw that our existing curricular materials and computer tools needed refinement and enhancement. We also realized that we needed to expand our efforts in several other areas: (1) to expand our program of classroom testing and evaluation both to inform the refinement of the materials and to convince our skeptical colleagues of the viability of our approach; (2) to develop ways to integrate the experiences students have in lectures with their experiences in the new interactive laboratories; and (3) to continue an active

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"Workshop Physics–Replacing Lectures with Real Experience", Proceedings of the Conference on Computers in Physics Instruction (Addison Wesley, Reading MA, 1989).

[2]The "Tools for Thinking" project under the direction of Ronald Thornton of Tufts University has been funded by the FIPSE program to create MBL tools and curricula that will allow introductory physics students to understand physical concepts, seldom learned in standard courses, through hands-on activities in laboratories. The project has done major testing and revision of materials at eight colleges and universities. Some project results are summarized in two recent papers and a book chapter by Ronald Thornton: (1) "Tools for Scientific Thinking-Microcomputer Based Laboratories for Physics Teaching", Physics Education Vol. 22 (1978), (2) "Tools for Scientific Thinking: Learning Physics Concepts with Real-Time Laboratory Measurement Tools", Proceedings of the Conference on Computers in Physics Instruction (Addison Wesley, Reading MA, 1989), (3)Constructing Student Knowledge in Science (with Robert Tinker). Chapter in *New Directions in Educational Technology*, E. Scanlon and T. O'Shea, eds. (Springer Verlag, Nato Science Series, in press). The second paper is reproduced in Appendix I of this proposal.

[3]A. Arons, "Achieving Wider Scientific Literacy", *Dædalus*, Spring 1983

program of reaching colleagues at larger institutions through conference talks, departmental colloquia, hands-on workshops, and publications.

By securing additional grants from the National Science Foundation for curriculum development and in-depth faculty workshops, we were able to add David Sokoloff of the University of Oregon as a full partner in the development, testing, and dissemination of curricular materials. He and Ron Thornton worked on the development and testing of prototype interactive lecture demonstration materials. In addition, all three of us are working on a new set of interactive laboratory materials called RealTime Physics which are intended to provide larger universities with sets of interactive lab activities centered on a single field of physics (i.e. mechanics, circuits, thermodynamics, etc.) that can span a whole quarter or semester of time. Although this project is funded by the NSF ILI program, the idea for the project was catalyzed by the FIPSE Interactive Physics project.

Obviously by combining funding from FIPSE and the National Science Foundation, we have been able to accomplish much more that we originally expected. In fact, our grants and program goals were so highly related that it became impossible in many cases to say definitively that a given source of funds could be credited for a given outcome.

E. Project Results

Project outcomes include: (1) adaptation of our materials and teaching methods for a growing number of university environments; (2) demonstration of improvements in conceptual learning at universities and other types of institutions; (3) revision and extension of written and computer-based curricular materials for commercial distribution to colleagues at other colleges and universities; (4) continuation of a sequence of teacher workshops at professional meetings and in other settings on how to organize and teach introductory physics interactively using integrated computer tools and; (5) provision of information and support to hundreds of colleagues at other institutions who are interested in modifying their introductory teaching; (6) publication of numerous articles and reports on the project; (7) delivery by P. Laws, R. Thornton, and D. Sokoloff (of the University of Oregon) of over 100 talks at professional meetings and physics colloquia; (8) receipt of several additional national awards for curricular innovation during the time period covered by this grant; and (9) receipt of additional grants from NSF, the U.S. Department of Education, IBM, and Apple Computer to continue with the development and dissemination of the program.

F. Summary and Conclusions

This Interactive Physics grant from FIPSE has allowed individuals at three different institutions to significantly promote the adaptation of microcomputer-based interactive teaching methods to university environments. Even more significantly it has served to establish the Workshop Physics, Tools for Scientific Thinking, and the new RealTime Physics programs as ongoing enterprises which promise to continue making significant contributions to reforming of introductory physics teaching for years to come.

REPORT NARRATIVE

A. Project Overview

This project focused on encouraging instructors at large universities to take advantage of the curricular materials and computer tools developed for two related programs funded originally by FIPSE. In particular, this project involved reworking and integrating materials developed for the previously funded Workshop Physics and Tools for Scientific Thinking projects so they could be used more flexibly in large university settings. Both the Workshop Physics Activity Guide and the Tools for Scientific Thinking laboratory materials with instructor guides were revised and enhanced. Prototype interactive lecture demonstration materials were developed and tested, new conceptual examinations were developed for project evaluation, and the microcomputer-based laboratory software and hardware offerings were extended and enhanced. MBL and spreadsheet software tools were developed to allow students to undertake more sophisticated data analysis and do mathematical modeling. These new materials were tested, and student learning gains were assessed at a number of institutions. The project directors did extensive dissemination through public talks, teacher workshops, and on-site consultation.

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[4]The Workshop Physics Project began officially in October 1986 with a three-year FIPSE grant at Dickinson College. It is described more fully in a pending paper by Priscilla Laws entitled

project at Tufts University[5], both funded by FIPSE (Oct. 1986-Sept 1989). These programs addressed major problems affecting the teaching and learning of introductory physics students – the failure to deal effectively with students' profound misconceptions about physical phenomena and the absence of contemporary tools for the construction and communication of scientific knowledge. The educational approach in both of these projects is *interactive* and *learner-centered*. Both programs share the use of inquiry methods of instruction and the microcomputer as an active tool for learning, and both share a common educational philosophy: that the acquisition of scientific literacy as defined by Arnold Arons[6] is more important than engagement with the traditional textbook problem-solving which currently dominates introductory physics. At the completion of the funding period for each program there were still many challenges ahead. Refinement of materials and evaluation methods were still ongoing, and questions were being raised as to how best to convince colleagues at larger institutions to adopt the new approaches. We have summarized the status of the two programs since the beginning of the Interactive Physics project (fall, 1989) in the paragraphs that follow.

1. Tools for Scientific Thinking, Tufts University (Oct. 1986-Sept 1989)

This project, described in several publications[7], utilizes the microcomputer equipped with sensors, a special interface, and software to collect and display real scientific data instantaneously in graphic form. Such a setup is commonly known as a Microcomputer Based Laboratory or MBL. The graphs on the computer screen might represent the change of a measured quantity such as

"Workshop Physics–Replacing Lectures with Real Experience", Proceedings of the Conference on Computers in Physics Instruction (Addison Wesley, Reading MA, 1989).

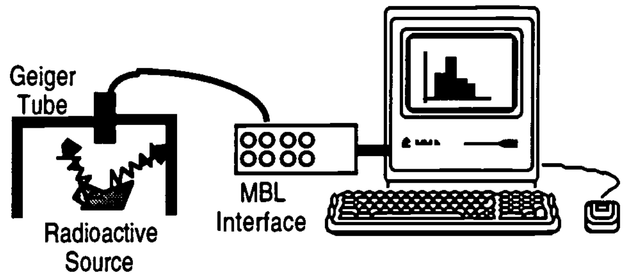
[5]The "Tools for Thinking" project under the direction of Ronald Thornton of Tufts University has been funded by the FIPSE program to create MBL tools and curricula that will allow introductory physics students to understand physical concepts, seldom learned in standard courses, through hands-on activities in laboratories. The project has done major testing and revision of materials at eight colleges and universities. Some project results are summarized in two recent papers and a book chapter by Ronald Thornton: (1) "Tools for Scientific Thinking-Microcomputer Based Laboratories for Physics Teaching", Physics Education Vol. 22 (1978), (2) "Tools for Scientific Thinking: Learning Physics Concepts with Real-Time Laboratory Measurement Tools", Proceedings of the Conference on Computers in Physics Instruction (Addison Wesley, Reading MA, 1989), (3)Constructing Student Knowledge in Science (with Robert Tinker). Chapter in *New Directions in Educational Technology*, E. Scanlon and T. O'Shea, eds. (Springer Verlag, Nato Science Series, in press). The second paper is reproduced in Appendix I of this proposal.

[6]A. Arons, "Achieving Wider Scientific Literacy", *Dædalus*, Spring 1983

[7] See footnote 12 for detailed references to articles about the Program on Tools for Scientific Thinking. An additional article for another edited volume is also in press: R.F. Tinker and R.K. Thornton, "Constructing Student Knowledge in Science", *New Directions in Educational Technology*. The reader may also want to refer to the FIPSE proposal submitted by the Tufts University Center for the Teaching of Science and Mathematics to the U.S. Department of Education in 1986 under the title "Tools for Scientific Thinking."

the distance of a student from a motion detector, the counting of a beta particle for a radioactive nucleus, or the temperature of a cooling object as time passes. An MBL setup is illustrated in Figure 1 below.

Fig 1: An MBL setup to display beta particle counts from a radioactive source.



Using microcomputer-based laboratory (MBL) sensors and software, students can simultaneously measure and graph such physical quantities as position, velocity, acceleration, force, temperature, light intensity, sound pressure, nuclear radiation, current, and voltage.

MBL stations give students immediate feedback by presenting data graphically in a manner that students can learn to interpret almost instantly. This provides a powerful link between real events that can be perceived through the senses and the graph as an abstract representation of the history of those events. Thus, MBL tools provide an ideal medium to support the development of physical intuition through direct inquiry – an approach strongly recommended by cognitive scientists and physics educators.

Originally inquiry-based curricular materials and MBL tools were developed for seven topics covered in traditional introductory physics courses:

1. motion (kinematics)
2. force and motion (dynamics)
3. heat and temperature
4. simple harmonic oscillations (including energy)
5. sound
6. visible light
7. electricity

Seven colleges and universities were involved in the primary testing of the materials, including California State Polytechnic University, Dickinson College, Massachusetts Institute of Technology, Muskingham College, the University of Oregon, Tufts University, and Xavier University.

In order to assess student learning gains, pre- and post- tests were administered after each unit. In some cases the persistence of the learning was tested several months after the original intervention. These tests focused on major concepts and misconceptions identified by researchers. Data show dramatic and persistent learning of physical concepts, not easily learned in lectures, by students who use the MBL curricular materials. (A preprint of a recent article by Thornton along with a compendium of recent results are reproduced in Appendix C.) For example, university students who were given two kinematics labs each lasting between 2 and 3 hours were able to reduce error rates on questions aimed at interpreting velocity graphs from a pre-test average of 65% to a post-test average of about 12% as shown in Figure 2.

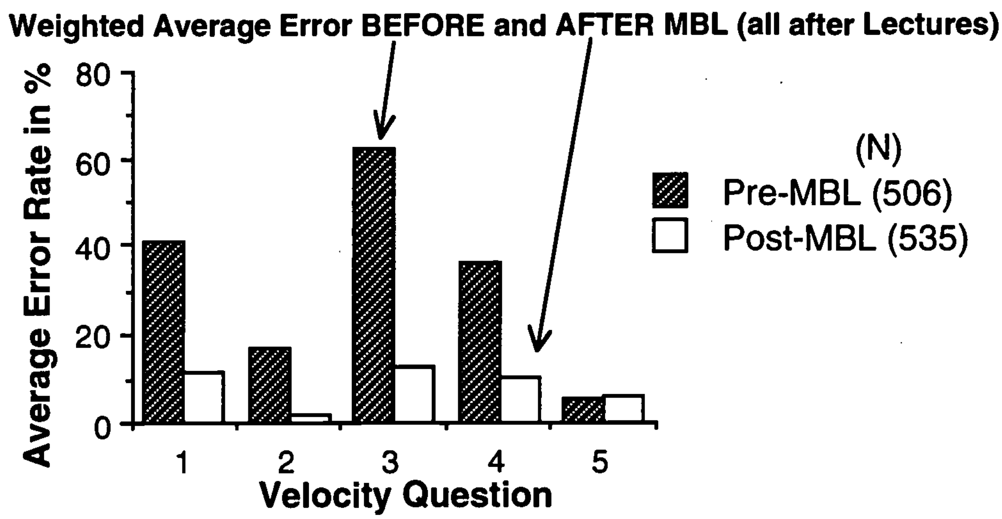


Figure 2

On the other hand, *students from Tufts University and the University of Oregon receiving lectures on the same topic only reduced their average error rates to 50% and thus, had much smaller learning gains.* Additional research with high school populations indicates similar pre- and post-test patterns that appear to be independent of ethnic origin, intended major, or sex. One student at Tufts after using the MBL motion detector and figuring out the meaning of linear acceleration for herself exclaimed, "Look at me, I'm a scientific humanist!"

By 1989 the Tools for Scientific Thinking materials had been widely disseminated and adopted. At least twenty additional colleges and universities used parts of the curriculum even before it was officially disseminated. Project staff have offered six oversubscribed workshops at the national meetings of the AAPT and eight international workshops. The project director has given many invited talks in the United States and in six foreign countries.

2. Workshop Physics, Dickinson College (Oct. 1986-Sept 1989)

In the Workshop Physics program the normal distinction between lecture and laboratory has been abandoned. Students and instructor meet for three two-hour sessions each week in which they can move freely between guided activities and discussions[8]. Workshop Physics' curricular materials were created for a

[8] In addition to reading the article about the Workshop Physics program reproduced in Appendix C, the reader may also want to refer to the FIPSE proposal submitted to the U.S. Department of Education by the Dickinson College Department of Physics and Astronomy in 1986 under the title "Workshop Physics."

range of activities that cover most of the traditional introductory physics topics. Among other things students pitch baseballs, whack bowling balls with twirling batons, attempt pirouettes, construct digital circuits, ignite paper by compressing gas, design engine cycles with rubber bands, and use an MBL system to monitor radon on campus. Students experience physical phenomena directly whenever possible. Macintosh SE computers are used extensively by students to collect, display, and analyze data as well as for solving numerical problems, modeling, and graphic simulations. This allows students to perform and analyze many more qualitative observations and quantitative experiments than is typically possible in an introductory physics laboratory.

The design of learning activities in each unit is adapted from a learning sequence suggested by Kolb[9] and others[10]. The sequence begins with student predictions of the outcome of casual, qualitative observations of a phenomenon of interest. Students proceed to actual observations and reflect on the results of these observations. With the help of the instructor, the outcome of the observations is often the basis for the development of a formal mathematical description of a phenomenon. The sequence culminates in providing the students with an opportunity to apply their new understandings to the solution of a novel experimental or theoretical problem or to perform a quantitative experiment that verifies the predictions of the formal theory. The content of the courses was cut by about 30% to allow students a longer time to begin mastering important physics concepts. Preliminary assessments of learning gains in covering the subset of MBL units adapted from the Tools for Scientific Thinking Project indicate that content should be cut even more, if maximum educational benefits are to be realized.

During the 1986-87 academic year five members of the Department of Physics and Astronomy at Dickinson College drafted Student Activity Guides for both the calculus and non-calculus sections of the course. Development of hardware and software for MBL photogate timing and nuclear counting was started, and new apparatus was designed to aid students in direct observations. The Workshop Physics courses were introduced to about 70 students at Dickinson College during the fall of 1987. The courses have undergone a second full year of classroom testing, and the Activity Guides were revised for the second time by Profs. P. Laws, J. Luetzelschwab, and R. Boyle. The four major objectives of Workshop Physics are to: (1) develop a positive attitude toward science, (2) enhance scientific literacy, (3) reduce misconceptions, and (4) retain traditional text book problem-solving skills. This latter objective was included with some

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[9] D.A. Kolb, Experiential Learning: Experience as the Source of Learning and Development (Prentice Hall, Englewood Cliffs, 1984)

[10] Osborne and Freyberg summarize several three stage teaching sequences suggested by Renner, Karplus, Nussbaum and Novick, and Erickson for teaching science. These sequences are similar to that proposed by Kolb. [R. Osborne and P. Freyberg, Learning in Science (Heineman, Portsmouth, 1985)].

reluctance, because it was deemed important to those at other institutions who might be interested in adopting the Workshop Physics approach.

A range of instruments have been used to evaluate the program starting with pre-workshop physics baseline tests using the Mechanics Concepts test developed at Arizona State University[11], selected portions of the AP Physics examination, the standard Dickinson College Course Evaluation form, and a special questionnaire asking students to rate how various course activities contributed to their learning, to estimate how much time they spent on the course, and to describe what changes they would most like to see made. Each of these tests has been administered one or more times to students who have taken Workshop Physics along with post tests for MBL activities developed in the Tools for Scientific Thinking project.

Early assessments indicated that students had fewer misconceptions after taking Workshop Physics. Although there is no standard measure of scientific inquiry skills, three different physics instructors teaching approximately 10 students who have taken the calculus-based Workshop Physics courses report that the group is significantly above average in motivation, lab skills and problem-solving skills.

The most dramatic gain in the early assessment of the impact of Workshop Physics on students is an improvement in their attitude toward the study of physics. In comparison with the time spent on other courses, the average student reported working far harder on the Workshop Physics course. In spite of this fact, the written comments on the course evaluation forms indicated that the vast majority of the students in the calculus-based course and more than half the students in the non-calculus based course preferred the workshop method to the lecture method. On a nine point quality-of-course scale one calculus section in the spring of 1988 gave the course an average rating of 7.6 and a median rating of 8.0 in spite of the fact that this was the first trial of the second semester calculus-based course. *This was the second highest combined rating given to any of the 117 laboratory science course sections taught at Dickinson in the past three years and thus placed it in the top 2% of the lab science courses offered.* One freshman who enrolled in physics to fulfill the science requirement commented–

> "The intellectual challenge and quality of this course were excellent. Some days after doing an experiment that worked out really well, I would feel as if I accomplished so much. Even after struggling over an experiment for the whole period, finally getting it was a great feeling. I received a lot more from the course than an understanding of physics. The "hands-on" experience was great. . . Besides the physics I learned, just the experience with the computers and equipment have helped me a lot. I have stayed away from computers and been afraid to

[11] A.H. Halloun and D. Hestenes, "The Initial Knowledge State of College Physics Students," Am. J. Phys. Vol 53, No. 11 (1985) pp. 1043.

play around with equipment before, but now I'm not and I can just "dig in". . . .Workshop Physics is Phun!

D. Project Description

The goal of the project was to extend and improve the early versions of the Tools for Scientific Thinking and Workshop Physics programs just described. In year one the Interactive Physics project began with dialog and visits to instructors at large universities seeking ways to expand the number of interactive laboratory experiences available to students and to integrate the new activities into the lecture and recitation portions of introductory physics programs. Formal collaboration was initiated with colleagues at the University of Oregon and Boise State University. In addition, informal collaboration took place with faculty members at dozens of institutions, including Ohio State University, Rutgers at New Brunswick, and University of Nebraska. Meetings have been held with project collaborators during the 1989 , 1990, and 1991 winter meetings of the American Association of Physics Teachers and at Dickinson College during the corresponding summers.

We began to appreciate first hand the difficulties that large departments have in implementing effective changes in classroom practices. We saw that our existing curricular materials and computer tools need refinement and enhancement. We also realized that we must expand our efforts in several other areas: (1) expand our program of classroom testing and evaluation both to inform the refinement of the materials and to convince our skeptical colleagues of the viability of our approach; (2) develop ways to integrate the experiences students have in lectures with their experiences in the new interactive laboratories; and (3) continue an active program of reaching colleagues at larger institutions through conference talks, departmental colloquia, hands-on workshops, and publications.

By securing additional grants from the National Science Foundation for curriculum development and in-depth faculty workshops, we were able to add David Sokoloff of the University of Oregon as a full partner in the development, testing, and dissemination of curricular materials. He and Ron Thornton worked on the development and testing of prototype interactive lecture demonstration materials. This approach to the integration of laboratories and lectures show tremendous promise in our efforts to effect significant change in introductory physics teaching at large universities. In addition, all three of us are working on a new set of interactive laboratory materials called RealTime Physics which are intended to provide larger universities with interactive lab activities centered on a single field of physics (i.e. mechanics, circuits, thermodynamics, etc.) that can span a whole quarter or semester of time. Although this project is funded by the NSF ILI program, the idea for it were catalyzed by the FIPSE Interactive Physics project.

Obviously by combining funding from FIPSE and the National Science Foundation, we were able to accomplish much more that we originally expected to. In fact, our grants and program goals were so highly related that it became impossible in many cases to say definitively that a given source of funds could be credited for a given outcome.

E. Project Results

We have described nine major project outcomes in the following section.

(1) Materials and teaching methods are being adopted at a growing number of universities. For example, in the fall of 1993 Penn State University reestablished a laboratory program after a five year hiatus by combining laboratory activities from the Tools and Workshop programs. For the past three years Moorhead State University has abandoned lectures in favor of using Workshop Physics activities for about 300 students enrolled each year in introductory physics courses. For several years Ohio State University has been using the Tools for Scientific Thinking labs in Mechanics in the first quarter of its 1400 student introductory calculus-based physics course. Recently they expanded their computer capabilities to add the Tools for Scientific Thinking Heat and Temperature labs to the second quarter curriculum. In consultation with Ron Thornton and Priscilla Laws they have experimented with cutting back on lectures on some of their sections. One of the best know lecturers at the University of Texas at Austin is testing the Interactive Lecture demonstrations in his large calculus-based physics lecture section. Faculty members at North Carolina State University are developing an integrated engineering program including physics, math, and chemistry based partially on the adaptation of materials from both the Tools and the Workshop programs. Workshop Physics style activities are being used at Rutgers University where lectures have been scaled back in a 700 student introductory course of allow more time for hands-on computer-based activities in an innovative science learning center. Materials from the workshop program are also being used at the University of Utah and in an honors class at Arizona State University.

(2) Improvements in conceptual learning at universities and other institutions over those achieved in traditional introductory physics courses have been demonstrated. A great deal of effort has gone into the design of conceptual examinations for assessment purposes. Current versions of three of the most often used examinations are included in the Appendix. Among the most interesting results related to the special goals of this project involve the use of Interactive Lecture Demonstration prototypes at the University of Oregon to help students learn force concepts. The following description of results is excerpted from an article prepared for an upcoming NATO science series book based on a conference held in November 1992 in Amsterdam.

The data from the Oregon non-calculus course displayed in Figures 1 and 2 from 1989 and 1990 show that standard instruction resulted in an additional 7% of the students in the class answering the conceptual questions on force and motion in a Newtonian manner.

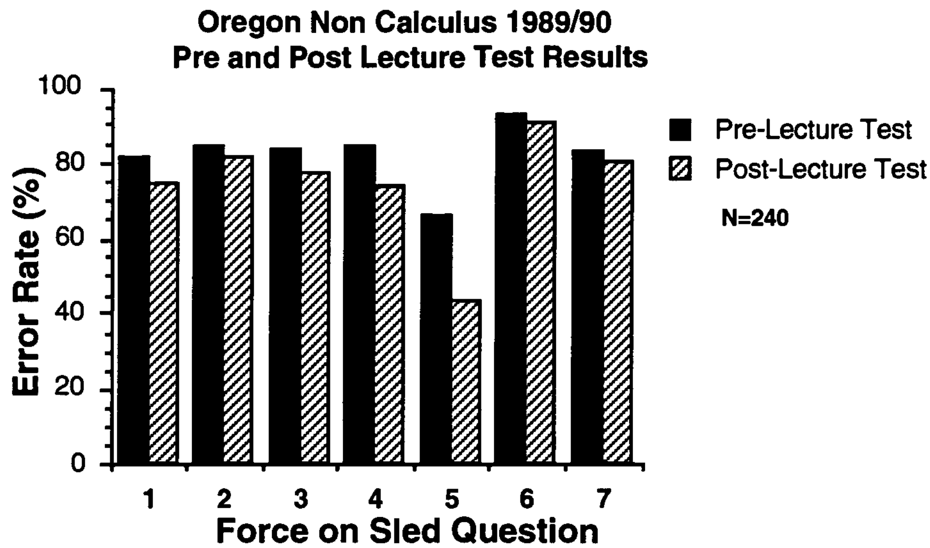


Figure 1: Error rates of 240 University of Oregon students in first year algebra-based physics on the simple dynamics questions shown in Figure 7. The dark bars show results before instruction and the striped bars after traditional instruction.

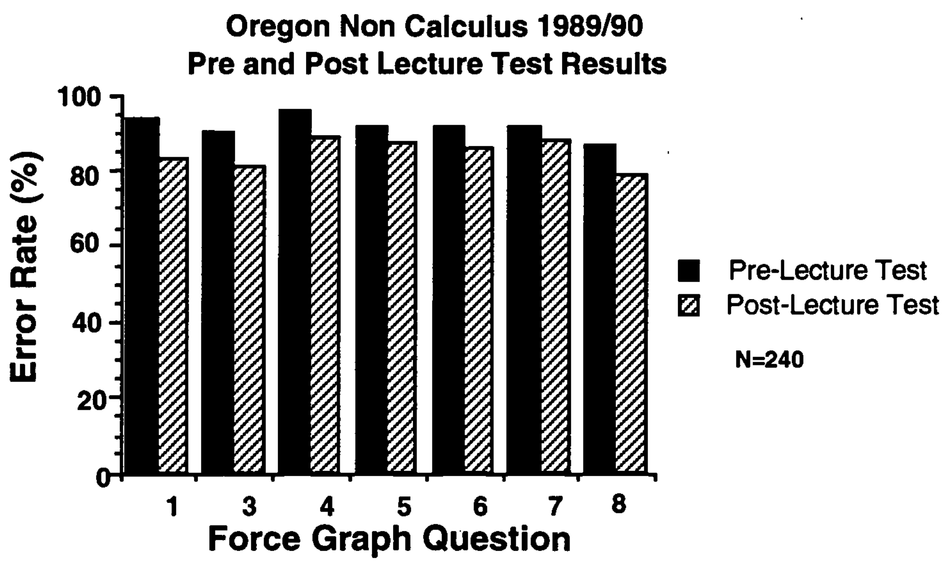


Figure 2: Error rates of 240 University of Oregon students in first year algebra-based physics on the simple dynamics questions shown in Figure 8. The dark bars show results before instruction and the striped bars after traditional instruction. Question 2 in this sequence from the Force and Motion Conceptual Evaluation was not asked.

The disappointing result becomes somewhat more understandable in light of the hierarchy presented above. At the end of all traditional kinematics and dynamics instruction, a given acceleration question was answered correctly (on average) by 28% of the students. (It is probable that this number was somewhat lower during the time the dynamics lectures were being given.) Since only students who understand acceleration concepts are likely to learn dynamics, the traditional instruction on dynamics could be of benefit to very few and partially accounts for the small number of students who develop a Newtonian view.

In an effort to improve learning of dynamics concepts by students who did not have access to MBL laboratories, David Sokoloff and I developed further an interactive MBL lecture demonstration that had shown some promise in smaller scale experiments in previous years. In the fall of 1991, students in non-calculus lecture course were given 40 minutes of interactive lecture demonstration on kinematics, based on the learning sequence used in the MBL motion labs. A protocol developed for effective implementation of the interactive lecture demonstrations is shown in Figure 3. The protocol encourages students to become actively engaged in the learning.

Interactive Lecture Demonstration Protocol

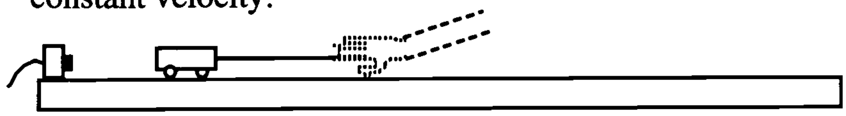
1. Describe the experiment/demonstration and do it for the class without MBL measurements.
2. Ask each student to record an individual prediction on the handout sheet.
3. Ask the class to engage in small group discussions in order to decide on a group prediction.
4. Ask each student to sketch a final prediction on the handout sheet (the group prediction if they came to an agreement). The prediction sheet will be collected at the end of the class.
5. Carry out the experiment/demonstration with MBL measurements displayed.
6. Ask a few students to describe the result and discuss results in the context of the demonstration. Students fill out results sheet which they keep.
7. Discuss analogous physical situations that produce a similar physical result but have different "surface" features.

Figure 3: This is the procedure to follow for each of the lecture demonstration/experiments such as the ones shown in Figure 4. The students are given two sheets, a prediction sheet to hand in so they don't lose credit and a results sheet to fill out for their own use. (Filling out the results should also improve the learning). The students are reminded that there are no wrong predictions.

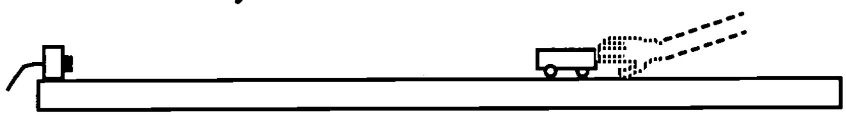
As a result of this series of interactive demonstrations of kinematics, which were given after kinematics lectures, the acceleration questions were answered correctly by 63% of the students before the traditional lectures on dynamics. This is in contrast to previous years where approximately 25% of the students understood the acceleration concepts. After this preparation, the traditional lectures on dynamics resulted in a 28% (± 6%) average improvement in the force graph questions compared to the 7% (±2 %) from the previous years. We attribute this improvement to the fact that more students understood kinematics, since nothing else was changed. The 40 minutes of time invested was well worthwhile since four times as many students benefited from the traditional dynamics instruction. On the other hand, 72%, on average, of the students still answer these question from a non-Newtonian point of view. Even with the enhanced learning of kinematics, attributable to the interactive demonstration, the traditional lectures were not very effective at teaching a Newtonian point of view. The students who used the Tools for Scientific Thinking lab curricula did considerably better and only 15% of the students answer these questions in a non-Newtonian way. We employed further interactive lecture demonstrations on force and motion after the traditional lectures. The results were gratifying. Approximately 65% of the non-laboratory students answered the force graph questions from a Newtonian point of view in contrast to previous years where only 15 to 20% did so (see Figure 2). We are examining the efficacy of interactive lecture demonstrations at other universities and high schools.

Interactive Motion Demonstrations

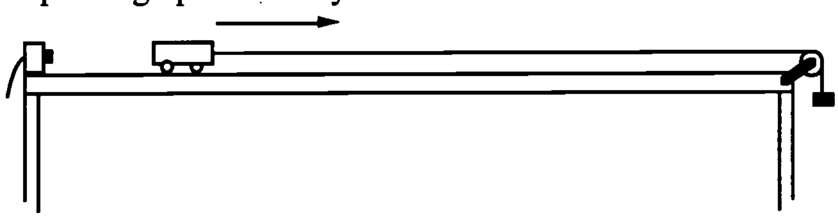
Demonstration #1: Pull cart away from motion detector at constant velocity.



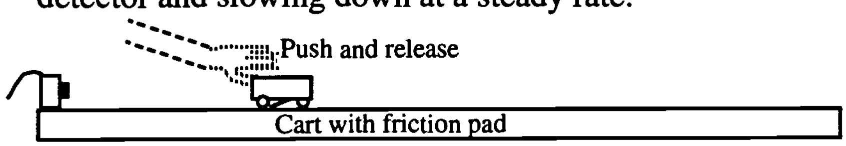
Demonstration #2: Push cart toward motion detector at constant velocity.



Demonstration 3: Cart moving away from the motion detector and speeding up at a steady rate.



Demonstration #4: Cart moving away from motion detector and slowing down at a steady rate.



Demonstration 5: Cart moving toward the motion detector and slowing down at a steady rate.

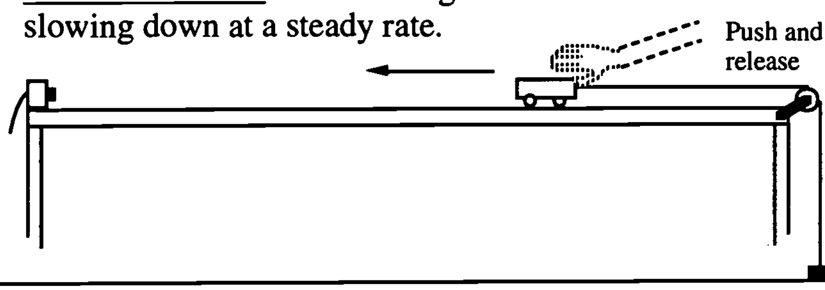


Figure 4 : First 5 of 8 demonstration/experiments for Interactive motion demonstrations as examples. Student sheets which are not shown, often ask students to predict both the velocity and acceleration graphs for each demonstration/experiment.

(3)Written and computer-based curricular materials have been revised and prepared for commercial distribution to colleagues at other colleges and universities. Most of these materials are available from Vernier Software in Portland, OR:

1. The Workshop Physics II Activity Guides
2. The Tools for Scientific Thinking Curricular Guide
3. Universal Lab Interface and Software Developer's Guide
4. Voltage Measurement Leads/Radiation Detector/Force Probe/Motion Sensor/Photogates/Light Sensor/Microphone
5. MBL 4.0 Series Software for Macintosh and MS DOS Computers: MacMotion/Data Logger/Sound and Temperature
6. MBL 4.0 Series Software for the Macintosh:Event Timer/Event Counter

Some of the materials which are being disseminated informally for testing include–

1. MS Excel Custom Tools (for use with Windows and Macintosh)–Dickinson
2. Video Analysis Tools and Movie Set (for the analysis of motion)–Dickinson
3. MBL Rotary Motion software and sensor–Tufts
4. MBL Two Force Probe Data Logger software–Tufts

(4) A sequence of teacher workshops have been offered at professional meetings and in other settings on how to organize and teach introductory physics interactively using integrated computer tools. One-day long workshops have been given every six months at the semiannual national meetings of the American Association of Physics Teachers throughout the three years of the Interactive Physics grant. These workshops were consistently over-subscribed and many individuals had to be turned away. In addition, as a result of NSF funding in its Faculty Enhancement program, Ron Thornton and Priscilla Laws have been giving two-week long summer workshops at Dickinson College along with Pat Cooney of Millersville University. For the past four years approximately 30 college and university teachers have attended these workshops each year. Although most of the attendees come from small institutions, several come each year from larger universities. This has led to a significant increase in the number of universities adopting interactive teaching methods.

(5) The project directors have provided information and support to hundreds of colleagues who are interested is improving their introductory teaching.

(6) Numerous articles and reports on this project have been published. These are listed in the project summary at the beginning of this report.

(7) P. Laws, R. Thornton, and D. Sokoloff (of the University of Oregon) have delivered over a 100 talks at professional meetings and physics colloquia. A list of just the talks and colloquia given at universities is included in the Appendix.

(8) During the past three years Ron Thornton and Priscilla Laws received national awards for curricular innovation from the American Association of Physics Teachers, the Charles A. Dana Foundation, EDUCOM/NCRIPTL, and Computers in Physics.

(9)Additional grants have been secured from the National Science Foundation and the Department of Education to continue with the development and dissemination of the program. These are summarized in the Appendix.

F. Summary and Conclusions

We have learned by hard experience that the process of reform is long and slow. It takes patience, and the work will never end. However, this Interactive Physics grant from FIPSE has enabled individuals at three very different institutions to enhance significantly the adaptation of microcomputer-based interactive teaching methods to university environments. In fact materials from both projects have been adapted for use at hundreds of high schools, two and four year colleges, and universities throughout the United States and a number of foreign countries.

Other funding agencies at the state and federal level are now contributing in important ways to new development efforts and to dissemination of curricular materials. The work of both the Tools for Scientific Thinking and Workshop Physics projects have national and international reputations as evidenced by national awards, attendance at workshops, and distribution of curricular materials and computer tools by Vernier Software. The new RealTime Physics program has gained a significant following less than a year after the first draft module on mechanics was introduced in January 1993. All three projects have proven track records and when combined are in a unique position to continue the development of learning materials that can have an important impact on science education at all levels.

In many significant ways this Interactive Physics grant from FIPSE has been vital in helping to establish the Workshop Physics and Tools for Scientific Thinking programs as well as the new RealTime Physics program as viable enterprises which promise to continue making significant contributions to the reform of introductory physics teaching for years to come. Thank you FIPSE!

G. Appendices

The written materials appended to the full report include:

(I) Two articles (either published or pending) based on work undertaken as part of the Interactive Physics Project.

(II) A Vernier Software flyer describing commercial availability of materials developed with the help of project funds.

(III) Sample materials demonstrating the Interactive Lecture Demonstration approach

(IV) Copies of the current conceptual examinations developed by Ron Thornton and David Sokoloff for assessment of learning gains.

(V) A list of talks and colloquia given at *universities* by Priscilla Laws, Ron Thornton, and David Sokoloff. **Note**: Many other talks and workshops were given at colleges, high schools, and as part of conferences.

(VI) A list of additional grants secured for the continuation of Workshop Physics, Tools for Scientific Thinking, and RealTime Physics activities.

A New Mechanics Case Study: Using Collisions to Learn about Newton's Third Law

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A New Mechanics Case Study: Using Collisions to Learn about Newton's Third Law

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Abstract: Several researchers have reported on conceptual difficulties students encounter in the study of Newton's Laws, especially Newton's Third Law. This paper describes a project to restructure the introductory physics mechanics curriculum to present Newton's Laws in a more logical sequence. This curriculum is based on the use of direct experience coupled with Microcomputer-Based Laboratory (MBL) tools. This paper gives particular attention to the sequence of learning experiences developed to improve student understanding of Third Law concepts applied to collision processes. The results of pre- and post-testing show significant gains in student ability to apply the Third Law to different types of interactions.

1. Introduction

In the study of introductory mechanics, acquiring a conceptual understanding of Newton's Laws has proven to be one of the most difficult challenges faced by students. Recent surveys by Hestenes, et. al.,[1] of student conceptual gains before and after traditional instruction have been disappointing. Arons and Rothman[2] have observed that many popular textbooks have treatments of Newtonian dynamics that are logically inconsistent. In addition a number of science education researchers have discovered that many students begin the study of mechanics with misleading conceptions about the nature of motion which are extremely hard to overcome[3].

Research has shown that microcomputer-based laboratory tools are effective in enhancing student learning in kinematics and dynamics.[4] Recent improvements in

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[1] David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher*, Vol. 30, 141-158. (March, 1992).

[2] Arons, Arnold. *A Guide to Introductory Physics Teaching*, (John Wiley, New York, 1990) Chapter 3; and Rothman, Milton A. *Discovering the natural laws; the experimental basis of physics*, (Doubleday, New York, 1972) Chapter 2.

[3] Lillian McDermott, "Research on conceptual understanding in mechanics," *Physics Today*, 2-10. (July, 1984); and David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher*, Vol. 30, 141-158. (March, 1992).

[4] c.f. The article in this volume by Ronald K. Thornton; and Ronald K. Thornton and David Sokoloff, "Learning Motion Concepts Using Real-Time Microcomputer-Based Laboratory Tools," *Am. J. Phys. 58* (9) 858-867 (Sept., 1990).

microcomputer-based laboratory systems for the study of force and motion[5] and the availability of new low friction dynamics carts[6] have made it possible to design new activities in which students can observe relationships between force and motion quickly and easily.

David Sokoloff, Ronald Thornton and the author outlined a sequence of laboratory activities to be used for teaching mechanics concepts in the Workshop Physics program[7] and the RealTime Physics project[8] involving the adaptation of curricular materials from the Workshop Physics and Tools for Scientific Thinking Programs[9] to introductory laboratory sequences in Mechanics, Heat and Temperature, and Circuits. In the summer of 1992 a small conference attended by individuals active in physics education research and curriculum development[10] was held at Tufts University. Participants were asked to critique the ideas for the new mechanics sequence. Thus, the outcomes of research on student learning, insights offered by Arons and Rothman on logical development, new MBL tools, activities designed for Workshop Physics and Tools for Scientific Thinking programs, and ideas generated by participants in the new mechanics conference were used as a basis for the development of a new activity-based mechanics curriculum. During the 1992-93 academic year this curriculum was tested in the Workshop Physics programs at Dickinson College and Gettysburg High School and in activity-centered RealTime Physics laboratories at the University of Oregon and Arizona State University.

2. The New Mechanics Sequence

The New Mechanics sequence differs from the traditional sequence in several ways:

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[5] A motion detector, force probe, interface and motion software for Macintosh and MS Dos computers can be purchased from Vernier Software Company, 2920 S.W. 89th Street, Portland, OR 97225.

[6] Low friction dynamics carts can be purchased from PASCO Scientific Company, 10101 Foothills Blvd., PO Box 619011, Roseville, CA 95678-9011.

[7] Priscilla Laws, "Calculus-Based Physics Without Lectures," *Physics Today*, Vol. 44, No. 12, (Dec. 1991); and Priscilla Laws, "Workshop Physics--Learning Introductory Physics by Doing It," *Change*, 20-27 (July/Aug. 1991); and Priscilla Laws, "Workshop Physics-Replacing Lectures with Real Experience," *Proceedings of the Conference on Computers in Physics Instruction*, Addison-Wesley, Reading, MA, 1989.

[8] The RealTime Physics project, directed by David Sokoloff, is funded by the National Science Foundation ILI Laboratory Leadership program, #USE-9054224, at the University of Oregon.

[9] FIPSE Comprehensive Program Grant #'s: 1) G008642149, *Tools for Scientific Thinking -- Microcomputer-Based Laboratories;* 2) G008642146, *Workshop Physics* from 10/86 - 9/89; and 3) P116B90692, *Interactive Physics: Using Workshop Physics and MBL in the University Classroom and Laboratory* from 10/89-9/92; and NSF Undergraduate Curriculum Development Program, USE-9150589, *Student-Oriented Science (SOS): Curricula, Techniques & Computer Tools for Interactive Learning* from 9/91 to 2/93.

[10] The New Mechanics conference which was held on August 6-7, 1992 in Medford, MA was attended by Pat Cooney, Dewey Dykstra, David Hammer, David Hestenes, Priscilla Laws, Suzanne Lea, Lillian McDermott, Robert Morse, Hans Pfister, Edward F. Redish, David Sokoloff, and Ronald Thornton.

(a) The order in which Newton's three laws are presented is based on the difficulty students appear to encounter in understanding them. Students begin with Second Law activities before they consider First Law phenomena. [11] Finally they work with Third Law concepts which appear to be the hardest to master.[12]

(b) Activities using MBL force and motion sensors and low friction dynamics carts are designed to enable students to make direct observations of basic elements of Newtonian dynamics without recourse to textbooks.

(c) Extra efforts are made to help students look at the elements of Newton's laws and be able to distinguish definitions such as acceleration, force, and inertial mass from observed phenomena,; for example, more "pull" causes more acceleration and more "stuff" causes in less acceleration.

(d) Concepts in kinematics and dynamics are initially developed for one dimensional horizontal motion with visible applied forces (pushes or pulls) with little friction present.

(e) Students are then asked to make additional observations which lead them to invent invisible forces (i.e., friction forces, gravitational interaction forces, normal forces, and tension forces) in order to maintain the viability of the Newtonian schema for predicting motions. This process of modifying mental schema to apply to new situations is labeled by cognitive scientists as accommodation.[13]

(f) The study of kinematics and dynamics is finally extended to two dimensional phenomena such as projectile motion, circular motion and motion on inclines.

(h) Students work with the impulse-momentum theorem, forces in collisions, the Law of Conservation of Momentum, and center-of-mass concepts before dealing with the conservation of energy. The inversion of momentum and energy topics was suggested by Arons[14] on the basis that (1) the momentum concept is simpler than the energy concept, in both historical and modern contexts and (2) the study of momentum conservation entails development

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[11] James Minstrell, "Teaching for the Development of Understanding of Ideas: Forces on Moving Objects" from the *1984 Yearbook of the Association for Supervision and Curriculum Development*, Editor Charles W. Andersen, December 1984

[12] David Hestenes, Malcolm Wells, and Gregg Swackhamer, "Force Concept Inventory," *The Physics Teacher*, Vol. 30, 141-158. (March, 1992).

[13] David Ausubel, "Learning as Constructing Meaning," from *New Directions in Educational Psychology: 1–Learning and Teaching*, D. Entwhistle, Ed. (Falmer Press, London, 1985)

[14] Private Communication with Arnold Arons, "Preliminary Notes and Suggestions," August 19, 1990; and ________, *Development of Concepts of Physics* (Addison-Wesley, Reading MA, 1965)

of the concept of center-of-mass which is needed for a proper development of energy concepts.

Although this paper focuses on elements of the sequence designed to help students acquire an understanding of Newton's Third Law and collision processes, key elements of the New Mechanics Sequence are summarized in Table 1 below. A more detailed description of the activities developed to help students understand these elements will be published in the near future in an article currently being prepared by the author in collaboration with David Sokoloff and Ronald Thornton.

3. Helping Students Understand the Third Law

3.1 Overview

One of the most challenging and interesting parts of the New Mechanics sequence involves the application of Newton's Third Law to one-dimensional collision processes. Many students can apply Newton's Third Law to the construction of free body diagrams when two interacting objects are in equilibrium. Virtually all introductory physics students can recite Newton's Third Law in the form "for every action there is an equal and opposite reaction" or "forces are always equal and opposite". However, the majority of students who complete introductory mechanics either do not understand the meaning of these phrases or don't really believe them when considering contact forces in collisions. For example, traditional instruction in two high school classes in Arizona, one regular and one honors, reduced average error rates from 90% to only 72% on conceptual questions requiring an understanding of Third Law concepts.

The existence of common misconceptions about interaction forces in collisions is not surprising for two reasons. First, when students observe elastic collisions between a rapidly moving object (i.e. an active agent) and a stationary object having the same mass, a dramatic momentum transfer seems to take place. Pretest scores indicate that about 80% to 90% of students begin the study of introductory physics with the belief that in a collision there are circumstances under which one object exerts more force on another. Second, when students observe a head-on collision between a heavy object and a light one moving at the same speed, the light object undergoes a more dramatic acceleration than the heavy one. This leads to the belief that the object with the greatest mass exerts the most force in a collision. Only students with good physics training and intuition recognize that Newton's Second Law reveals that momentum changes are essential to determining relative magnitudes of interaction forces.

Arons asserts that an understanding of Newton's Third Law requires students to recognize that "*all* interacting objects exert equal and opposite forces on each other *instant by instant*, and this applies to widely separated gravitating bodies as well as to those exerting contact forces on each other, and that zero time elapses between a change occurring at one body and the effect of the change being felt by the other."[15] From the perspective of modern physics, we now understand that the requirement that zero time elapse between a change in one body and a change in another cannot be met. Thus, although Newton's Third Law does hold for mechanical contact forces between objects, modern physics ultimately gives primacy to Conservation of Momentum in the

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[15] Arons, Arnold. *A Guide to Introductory Physics Teaching*, (John Wiley, New York, 1990), p. 67.

hierarchy of physical law. In fact, one of Newton's many brilliant insights was that the experimental fact that momentum (quantity of motion) is conserved in collisions implies that the interaction forces between two objects must have the same magnitude.

3.2 The Sequence of Activities on Collisions and the Third Law

A major goal of this sequence of activities is to help students understand how Newton's Laws lead naturally to the Law of Conservation of Momentum in the description of collision processes. As we explained in section 2 we decided to introduce momentum and its conservation before exposing students to energy concepts.
The sequence of activities was designed to help students to: (1) understand the relationship between forces experienced by a single object and its change in momentum, (2) consider mutual interaction forces between two bodies undergoing a collision, and (3) realize that the Law of Conservation of Momentum is a consequence of Newton's Second and Third Laws. Students perform the following activities:

3.2.1. Recasting Newton's Second Law in Momentum Form

a. Using a Thought Experiment to Define Momentum: Students perform a thought experiment and try to predict at what speed, V, a small car of mass m must move in order to stop a truck of mass M moving at a slower speed, v. The outcome of this discussion is used as a basis for defining momentum as $\vec{p} = m\vec{v}$.

b. Deriving Newton's Second Law in terms of momentum: Students show mathematically that

$$\sum \vec{F} = m\vec{a} = \frac{d\vec{p}}{dt}$$

3.2.2. The Impulse-Momentum Theorem

a. Reviewing the mathematical definition of p-change: Students need help realizing that a super ball undergoes more momentum *change* than a clay blob. They are asked to practice calculating momentum changes.

b. Gaining intuition about impulse, average force and momentum change: Students discuss why they tend to catch raw eggs more slowly than a ball. This discussion makes the definition of impulse as the time integral of force a bit more plausible.

c. Measuring Impulses: Quantitative data on forces during a collision is performed using the MBL system set up with motion software and a force probe. A force probe is attached to a cart and allowed to collide gently with a wall or another object. The data analysis feature of the motion software is used to determine the impulse resulting from the collision. A sketch of the apparatus is shown in Figure 1.

c. Deriving the Impulse-Momentum Theorem from Newton's Second Law: Students are asked to perform a mathematical derivation to show that

$$\int_{t_i}^{t_f} \Sigma\vec{F}\,dt = \int_{t_i}^{t_f} \frac{d\vec{p}}{dt}\,dt = (\vec{p}_f - \vec{p}_i) = \Delta\vec{p}$$

d. Verifying experimentally that the impulse-momentum theorem holds: A quantitative experiment is performed using the MBL system set up with motion software, a force probe, and a motion detector. A force probe is attached to a cart so that it can undergo a relatively slow collision with something soft such as a piece of foam rubber. Force readings are taken during the collision while the motion detector is used to determine the velocity of the cart just before and just after the collision. Students find that the quantitative verification of the impulse-momentum theorem is good to within 5 or 10% if they take careful measurements.

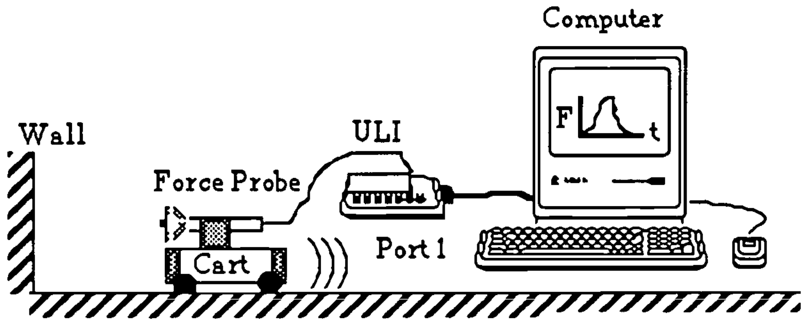


Figure 1: MBL apparatus set up for measuring collision forces on a force probe mounted on a cart

3.2.3 Mutual Interaction Forces

a. Predicting relative force magnitudes in a collision: Students are presented with several collision scenarios such as two cars of equal mass undergoing a collision, a moving car hitting a stationary truck, and a school bus smashing a fleeing mosquito. They are asked to predict the relative forces and discuss the circumstances under which one object might exert a greater magnitude of force on another object.

b. Observing interaction forces in "real time": Students are given two low friction carts with force probes mounted on them and some extra masses. The force probes are hooked into an MBL system, and they are provided with a special version of the motion software which can record data from two probes simultaneously. Students are then asked to use this equipment to investigate the circumstances under which one object exerts more force on another. A typical setup is shown in Figure 2. When these observations are carefully done, students discover that contact forces of interaction are equal in magnitude and opposite in direction on an instant-by-instant basis for all circumstances including that of a heavily loaded cart bearing down on a light cart which is at rest. Many students are surprised to see the force vs. time graphs for the two force probes looking equal and opposite! Sample graphs from these types of experiments are shown in Figures 3 and 4 for slow and fast encounters respectively.

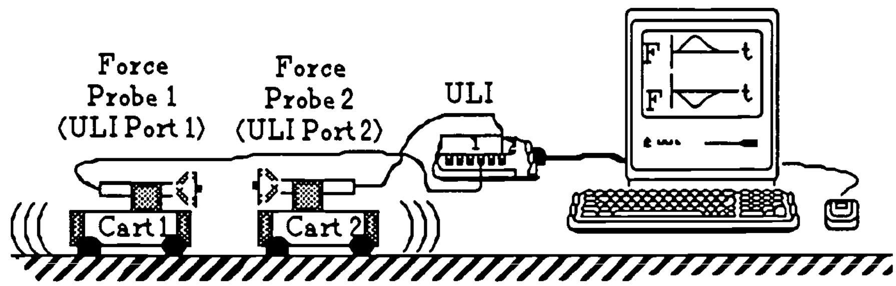


Figure 2: MBL set up for reading two forces at once during a gentle collision

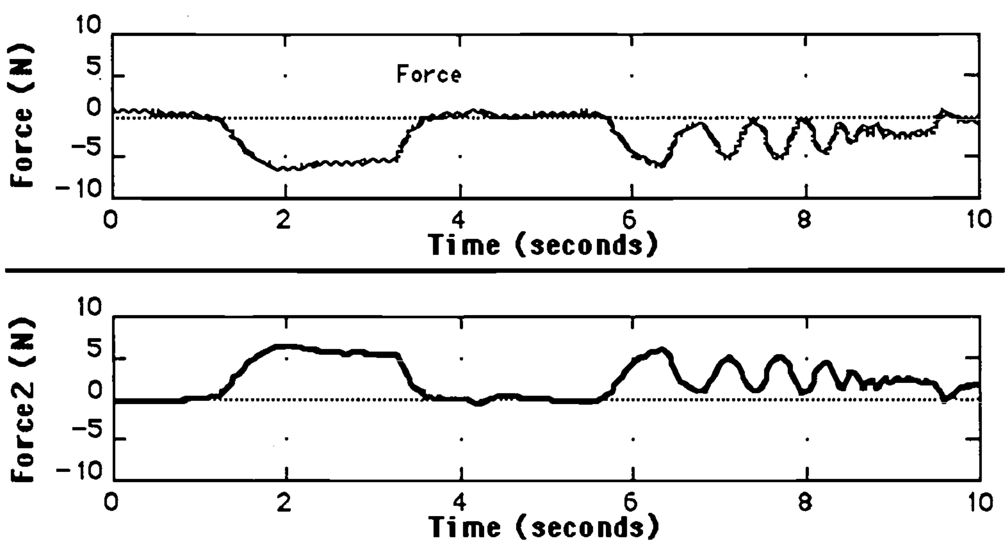


Figure 3: Two carts undergo slow collisions. Sometimes the first cart does the pushing and other times the second cart does the pushing. These graphs are made with MBL software, a ULI, and two force probes.

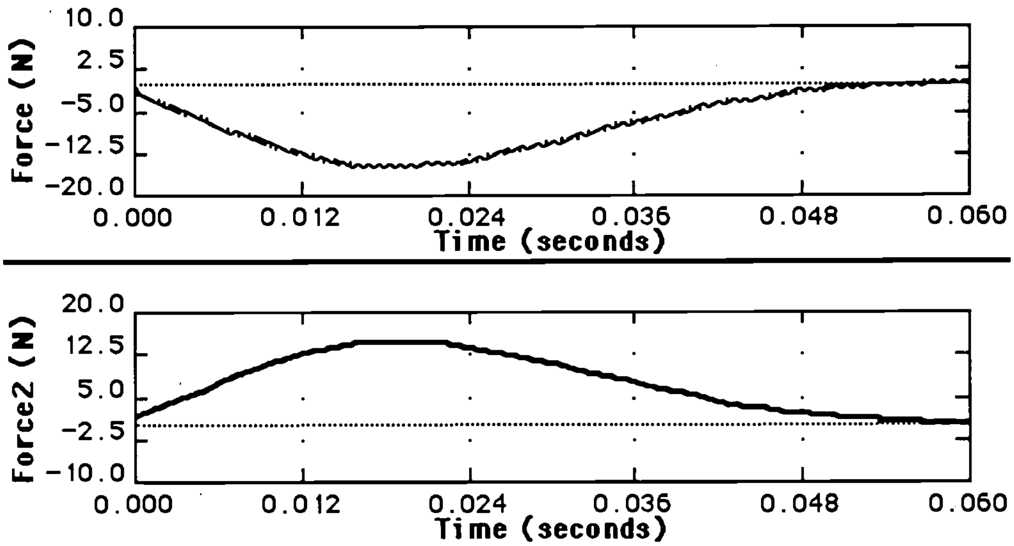


Figure 4: A 1.0 kg cart which is moving collides gently with a 0.5 kg cart which is at rest. These graphs are made with MBL software, a ULI, and two force probes. The data rate was set for 1000 readings per second.

3.2.4 Momentum Conservation

a. Deriving Momentum Conservation as a Consequence of the Second and Third Laws: Students combine the impulse-momentum theorem which is a form of the Second Law and the Third Law to predict mathematically that momentum ought to be conserved for collision processes.

b. Observing Momentum Conservation Qualitatively for Simple Situations: Students watch carts of the same mass interact in elastic collisions involving both contact forces and magnetic action-at-a-distance forces. They also observe inelastic collisions and "explosions".

c. Deriveing the Equivalence between Momentum Conservation and Constant Center-of-Mass Motion: The idea of center-of-mass is introduced and students show mathematically that the center of mass of an isolated system always moves at a constant velocity.

d. Observing Center-of-Mass motion in 1D and 2D Collisions: Collisions between low friction carts having different masses and of pucks on an air table enable students to verify momentum conservation in 1D and 2D.

4. Assessing Learning Gains for Third Law Concepts

4.1 Initial Use of the Sequence at Three Institutions

Activity-based student worksheets using New Mechanics sequences were prepared in two slightly different formats, one for the Workshop Physics program and one for the RealTime Physics laboratory program. Preliminary versions of the New Mechanics curriculum were then tested at Dickinson College, the University of Oregon, and Arizona State University in the fall of 1992. the author introduced activities to three sections of the Workshop Physics calculus-based physics course at Dickinson College with a total enrollment of 71 students. These students had no formal lectures and met for three sessions of two hours in length each week for the semester. At the same time a RealTime Physics Laboratory program using the New Mechanics sequence was used under the direction of David Sokoloff in an algebra-based introductory laboratory course taken by 257 students. These students met in the laboratory once each week for three hours. In addition, the University of Oregon students were enrolled in a parallel lecture course which included recitation sessions in addition to lectures. Finally, Cheryl Claussen, a graduate teaching assistant at Arizona State University, introduced the new RealTime Physics Laboratory materials to students in one laboratory section of algebra-based physics at Arizona State University which met for two hours each week for a semester.

From an instructor's perspective the trials went as well as could be expected for a first time through. However, many changes are being made as a result of the classroom testing. For example, the preparation for the activities involving the Third Law was quite labor intensive because the software was so new that there was insufficient time to test it and some of the older force probes didn't work properly with the new software. Thus, while many of the students made observations on colliding carts that convinced them that forces between carts were always "equal and opposite", some students encountered technical difficulties. We expect that with fully tested software and procedures the reliability of the MBL observations made throughout the sequence will be improved significantly.

4.2 The Results of Pre and Post Testing on Third Law Concepts

The Force Concepts Inventory examination was administered to students in the calculus-based sections of Workshop Physics in the Fall of 1992 both before and after students worked with the New Mechanics activities. At the University of Oregon students were given a related Force and Motion Concepts Test[16] after completing the New Mechanics sequence as part of the RealTime Physics laboratory program. Since the testing of the curriculum at Arizona State University was done only on a pilot basis, no formal analysis of the ASU results was performed.

Three of the questions covering Third Law concepts on the Force and Motion Concepts Test were based on questions developed for the Force Concepts Inventory. Each of these three questions tests several important elements in student misconceptions about forces in collisions: (1) the notion that an object with a greater mass exerts a greater force even if the objects are moving at the same speed when they collide head on, (2) the notion that a larger active agent with more mass will exert more force on a smaller passive agent, and (3) the question of whether more force is exerted during contact by a small active agent or by a large passive agent. In this article the error rates are reported for these three

[16] For more information on the test, contact Ronald K. Thornton, Center for Science and Mathematics Teaching, Lincoln-Filence Building, Tufts University, Medford, MA 02155.

questions at both Dickinson College and the University of Oregon after students completed the New Mechanics activities. In addition, Hestenes, et. al.[1] have reported results for those questions for some other groups including two high school classes, one honors and one regular, that had received traditional instruction and two high school honors sections that had received special instruction. The results are summarized in Table 2.

Table 2: Percentage Error on Post (Pre) test questions involving the application of Newton's Third Law to contact forces

Misconception	FCI	FMT	Traditional Instruction **HS honors & regular** %Error	Special Instruction **HS honors** %Error	RTP New Mechanics **N=257 Univ of Oregon** %Error	WP New Mechanics **N=71 Dickinson College** %Error
1. Greater mass results in greater force when truck and car collide head on	Q2	Q36	65 (88)	08 (85)	11 (–)	14 (100)
2. Active agent w/ more mass exerts more force as a student pushes another	Q11	Q45	61 (89)	03 (86)	09 (–)	11 (73)
3. Active *or* most massive agent exerts more force when car pushes truck	Q13	Q42	89 (93)	22 (89)	39 (–)	30 (78)
Average Error Rate %			*72 (90)*	*11 (87)*	*20 (–)*	*18 (84)*

4.3 Comments on the Results

Some conclusions can be drawn from the data in Table 2. Based on pretest error rates at Dickinson College and in the high school groups tested by Hestenes, et. al., between 80 and 90% of any class have significant misconceptions about interaction forces in collisions. After traditional instruction error rates are only reduced at best for the "easiest" of the questions to about 60%. The post instruction error rates on Third Law concepts for students using the New Mechanics sequence were very similar for students at Dickinson College and the University of Oregon. The lowest error rates were achieved for question 2 and were about 10% in each case with the average error rate on all three questions being about 20%.

Question 3 in which a small car was pushing a large truck with its engine turned off remained the hardest for all the classes tested. If students thought either that the more active agent exerts more force or that the more massive object exerts more force they could answer the question incorrectly. However, essentially all of the students at Dickinson and University of Oregon who still answered the question incorrectly after instruction did so because they believed that the small car as an active agent would exert more force on the large truck which was passive and pushed in the direction of the car.

This overall result for error reduction in Third Law concepts, although quite impressive, is not quite as impressive as the 11% post test error rate achieved by a high school honors class taught by Malcolm Wells. No details are reported on how Wells achieved the learning gains in this particular class. There are several possible factors that might explain the difference between his results and those obtains by students completing the New Mechanics activities. It could be that difficulties (which we expect to overcome) in keeping the equipment calibrated and working smoothly in the MBL based force probe collisions prevented a few students groups from discovering the Third Law for themselves. It may be that there are a larger proportion of students in classes at the University of Oregon and Dickinson College who were very slow learners than in the high school honors class. It may be that differences of 10% in error rates are simply not statistically significant when the unreported sample size in the high school honors class is probably quite small.

5. Conclusions

As a result of the pilot testing in the fall of 1992, instructors generally agreed that the New Mechanics sequence shows promise in helping students develop a deeper conceptual understanding of Newton's Laws. The curriculum needs further refinement and more classroom testing. We must do much more careful analysis of learning gains for elements of all three of Newton's Laws before reaching firm conclusions about the impact of the new curriculum on learning. By examining the teaching of Third Law concepts in more detail, perhaps some light has been shed on the educational potential of the New Mechanics activities.

6. Acknowledgments

This work would not have been undertaken without the help of David Sokoloff and Ronald Thornton, who played a major role in the development and implementation of the New Mechanics sequence. As collaborators we owe a debt of gratitude Arnold Arons for consulting with us over a period of a year and a half to suggest better ways to present mechanics. Dewey Dykstra spent time early in the conception of the new sequence helping us refine our ideas and reminding us that teaching mechanics to students requires much work prior to the presentation of logical sequences and quantification. We would especially like to thank participants in the New Mechanics Conference who served as sounding boards for our ideas. Special mention should go to Cheryl Clausen who is cooperating with us in the testing of the activities at Arizona State University and to Bob Morse of St. Albans School who was typically several steps ahead of us in the conceptualization and classroom testing of a number of activities we have incorporated into the New Mechanics curricula.

APPENDIX

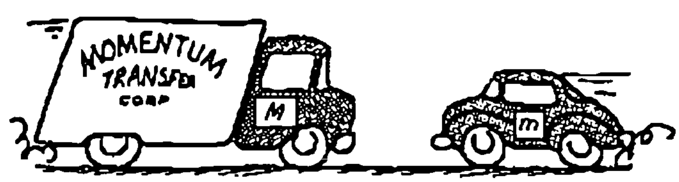
Conceptual Questions on Newton's Third Law

Questions 36, 42, and 45 from Force and Motion Concepts Test developed by David Sokoloff and Ronald Thornton are reproduced below. These questions are adapted from Force Concepts Inventory[1] questions 2, 13, and 11 respectively.

Questions 36-40 refer to collisions between a car and a truck. For each description of a collision (36-40) below, choose the one answer from the possibilities **A** though **J** that best describes the forces between the car and the truck. You may use a choice more than once or not at all.

- **A.** The truck exerts a greater amount of force on the car than the car exerts on the truck.
- **B.** The car exerts a greater amount of force on the truck than the truck exerts on the car.
- **C.** Neither exerts a force on the other; the car gets smashed simply because it is in the way of the truck.
- **D.** The truck exerts a force on the car but the car doesn't exert a force on the truck.
- **E.** The truck exerts the same amount of force on the car as the car exerts on the truck.
- **F.** Not enough information is given to pick one of the answers above.
- **J.** None of the answers above describes the situation correctly.

In questions 36 through 38 the truck is much heavier than the car .



→36. They are both moving at the same speed when they collide. Which choice describes the forces?

37. The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?

38. The heavier truck is standing still when the car hits it. Which choice describes the forces?

36

Questions 41-43 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

Pick one of the choices **A** through **J** below which correctly describes the forces between the car and the truck for each of the descriptions (34-36). You may use a choice more than once or not at all.

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.

B. The force of the car pushing against the truck is less then that of the truck pushing back against the car.

C. The force of the car pushing against the truck is greater then that of the truck pushing back against the car.

D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.

E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.

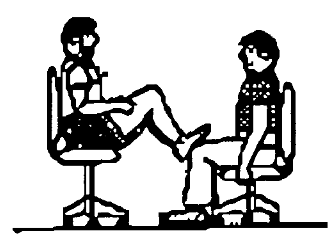
J. None of these descriptions is correct.

41. The car is pushing on the truck, but not hard enough to make the truck move.

→42. The car, still pushing the truck, is **speeding up** to get to cruising speed.

43. The car, still pushing the truck, is at cruising speed and continues to travel at the same speed.

→ 45. Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,


Bob Jim

A. Neither student exerts a force on the other.

B. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.

C. Each student exerts a force on the other, but Jim exerts the larger force.

D. Each student exerts a force on the other, but Bob exerts the larger force.

E. Each student exerts the same amount of force on the other.

J. None of these answers is correct.

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USING LARGE-SCALE CLASSROOM RESEARCH TO STUDY STUDENT CONCEPTUAL LEARNING IN MECHANICS AND TO DEVELOP NEW APPROACHES TO LEARNING[1]

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Abstract: Microcomputer-based laboratory (MBL) tools and guided discovery curricula have been developed as an aid to all students, including the underprepared and underserved, in learning physical concepts. To guide this development, extensive work has been done to find useful measures of students' conceptual understanding that can be used in widely varying contexts. This paper focuses primarily on the evaluation of student conceptual understanding of mechanics (kinematics and dynamics) with an emphasis on Newton's 1st and 2nd laws in introductory courses in the university. Student understanding of mechanics is looked at before and after traditional instruction. It is examined before and after MBL curricula that are consciously designed to promote active and collaborative learning by students. The results show that majority of students have difficulty learning essential physical concepts in the best of our traditional courses where students read textbooks, solve textbook problems, listen to well-prepared lectures, and do traditional laboratory activities. Students can however learn these fundamental concepts using MBL curricula and Interactive Lecture Demonstrations which have been based on extensive classroom research. Substantial evidence is given that student answers to the short answer questions in the Tools for Scientific Thinking Force and Motion Conceptual Evaluation provide a useful statistical means of evaluating student beliefs and understandings about mechanics. Evidence for the hierarchical learning of velocity, acceleration, and force concepts is presented.

I. Introduction

For about six years we have been studying how students in universities, high schools, and middle schools learn to understand the physical world. We have used our understandings of student learning to design environments where students have been able to learn fundamental physical concepts that were seldom learned in more traditional environments. Our intention has been to create an environment where closer to 90% of the students learn fundamental concepts rather than one where only the top 20% succeed ([7] and see discussion below). In addition, we have intended to develop materials and methods that will be successful in widely varying contexts for students of different ages, different cultural heritages, and preparation. Results from research in cognitive science and education substantiate the importance of basing development of scientific concepts and skills on concrete experience [4,11]. To these ends the "Tools for Scientific Thinking" project [15-19] at the Center for Science and Mathematics Teaching at Tufts University has developed microcomputer-based laboratory (MBL) tools and curricula that can help students make connections between the physical world and the principles which constitute scientific knowledge. The computer tools (which are being used in middle school, high school and colleges including college teacher preparation and enhancement programs), provide a convenient and effective means for students to collect and display physical data in a form that they can remember, manipulate, discuss and think about. The tools have enabled the development of curricula, based on research in science learning, that allow students to take an active role in their own learning.

To guide our work we needed to develop a practical means of assessing student conceptual knowledge in physics that would serve our many goals. This paper will identify the goals, discuss methods of assessing student learning in force and motion (kinematics and dynamics), use actual classroom research results, motivate the form of assessment chosen in light of the goals, discuss problems raised about the assessment methods, and provide evidence for validation of the assessment.

Although the evidence that students have not been learning fundamental physics concepts seems convincing to most physics education researchers, practicing physics teachers seem to require either high statistics or even measures of their own students to be convinced. It is useful to teachers involved in course design and modification to be able to evaluate student understanding of concepts that form a foundation for further learning in the subject. To satisfy these needs, we designed a short answer conceptual evaluation that can be easily used in many different contexts, and which provides reliable information about student beliefs about motion and how those beliefs are being changed (or not) by the instruction.

One of the purposes of this paper is to show that the conceptual evaluation we have been using provides a useful measure of student understanding of mechanics concepts. We have been conducting studies of the effectiveness of traditional methods of teaching motion concepts in addition to those curricula that use MBL tools. As a result, we have much information to bring to bear on the question of evaluation. We have explored student understandings of physics concepts in middle schools, high schools, colleges and universities in calculus and algebra-based introductory physics courses, and in teacher preparation and enhancement programs. Substantial work on curriculum development and evaluation was done at the college and university campuses that are part of the "Tools for Scientific Thinking" project [3]. Professors Sassi of the University of Napoli and Professor Borghi of Pavia have done research (some of which are reported in this publication) involving the use MBL curricula with Italian university students (including future teachers), and high school teachers and their students. The Workshop Physics Program [8, 9], under the direction of Priscilla Laws at Dickinson College, has provided a more ideal college learning environment into which the MBL tools have been adopted and some of the curricular pieces have been adapted. In more usual environments, we have used pre- and post-testing and other forms of evaluation to examine the understandings of thousands of college and university physics students under the Student-Oriented Science project (funded by the National Science Foundation). We have also collected data for a large sample of secondary and middle school students. All of these contexts have provided strong evidence for significantly improved learning and retention by students who used the MBL materials, compared to those taught in lecture [14-19] and these data also provide evidence to support the usefulness of our method of evaluation.

One learning environment, however, has provided the kind of information about student learning of mechanics that is of particular value in the context of this paper. David Sokoloff of the University of Oregon, a co-author of the curricular materials, has provided opportunities for extensive research on student learning [18] and the opportunity to experiment with new methods of teaching large classes (see Section IV of this paper). A six year collaboration with David Sokoloff has provided data on thousands of students. The university offers an introductory non-calculus physics class with two large lecture sections of between 150 to 200 students. The lectures are high quality traditional instruction. The laboratory is offered as a separate course, taught by graduate teaching assistants. Approximately one half of the students take the laboratory. We have had the opportunity to do very detailed evaluations of the students in this course some of whom experienced only traditional instruction and some who have experienced the Tools for Scientific Thinking Motion and Force Laboratory Curriculum. The conclusions about student learning we have come to by working with Oregon students have been consistent with research results from other similar and even from very different learning environments. However, the research at Oregon has been distinguished by the opportunity to take repeated measures on large numbers of students over many years. For this reason, the discussion that follows will focus upon student learning of motion and force at Oregon. To illustrate the generality of evaluation methods, however, the following section on kinematics concepts will use data from many universities.

II. Evaluating Student Learning of Motion (Kinematics) Concepts in Traditional and MBL Environments

One of the foundations for understanding force and motion (dynamics) is understanding kinematics which is the description of motion. The learning of dynamics depends on a knowledge of kinematics (see Section IV). While most physicists would agree with this statement, few courses provide an effective environment for students to learn kinematics.

Student Understanding of Kinematics Concepts after Traditional Instruction

If all students were learning the fundamental concepts associated with motion and force, there might be less reason to consider changing the ways we teach kinematics and dynamics and less reason to explore effective means of evaluation. Unfortunately, students are not learning these concepts in traditional courses, at least in the United States. Figure 1 shows the result of asking more than two thousand students, mostly future engineers in calculus-based courses at major universities and colleges, the 10 simple conceptual questions about velocity and acceleration.

These questions, which test concepts and not just graphing are shown in Figures 2 and 3. Note that error rates are shown. Physics professors unfamiliar with the results of this research predict error rates for their students of less than 5 to 10% while the actual error rates can be 40% or above for velocity concepts and 70-95% for acceleration concepts. The sample of students shown in Figure 1 show such an error rate. Our research also shows that students who cannot answer these simple questions will in general be at a great disadvantage in their subsequent study of kinematics and dynamics. Some evidence for this point of view will be presented in Section IV later in this paper.

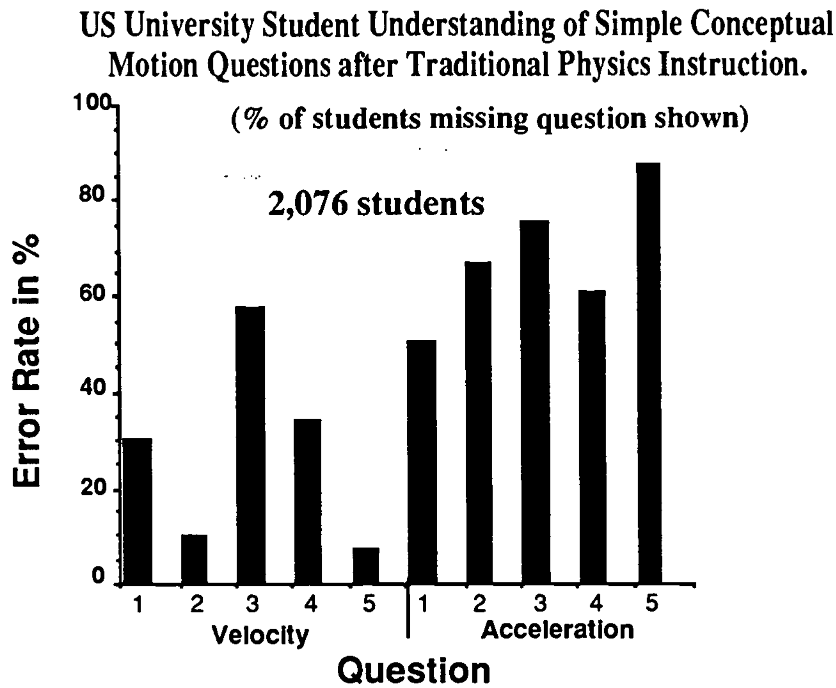
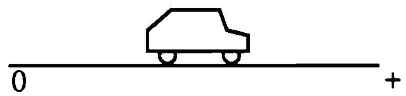


Figure 1 Percentage of US university students missing simple conceptual questions on kinematics after traditional instruction in first year calculus and algebra-based physics courses. The questions asked are shown in Figures 2 and 3. Note that velocity questions 2 and 5 require little understanding of kinematics.

The results shown are disquieting and do not speak well for traditional instruction. About 60% of the students seem to be learning the simplest velocity concepts and only 25% seem to be learning the simplest acceleration concepts in physics courses. Since everyone knows how hard physics is, some professors have felt that perhaps teaching 25% of the students to understand acceleration may be acceptable. This point of view has two problems. The first problem is that these are student responses to some of the simplest significant questions that indicate understanding. The students do less well on other questions. The second problem is that the large majority of students who demonstrate an understanding of the kinematics concepts, are not learning them in the college physics classes. Most of the students who can answer the questions after traditional instruction know them when they begin the course.

To show that this is the case, we can look at students before and after traditional instruction at the University of Oregon in the environment described in the introduction. Figure 4 shows evidence that most students are not learning the concepts as a result of traditional instruction. This figure shows the result of asking the velocity and acceleration questions shown in Figures 2 and 3 of students in the non-calculus physics class at the University of Oregon. The results are typical of other research we have done where we find less than 10% change in the error rate due to traditional instruction (see also for more information on student learning in colleges and high schools, references 14-19).

Velocity-Time Graphs



An object (such as a toy car) can move in either direction along a horizontal line (the + distance axis). Choose the correct velocity-time graph(s) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer J.

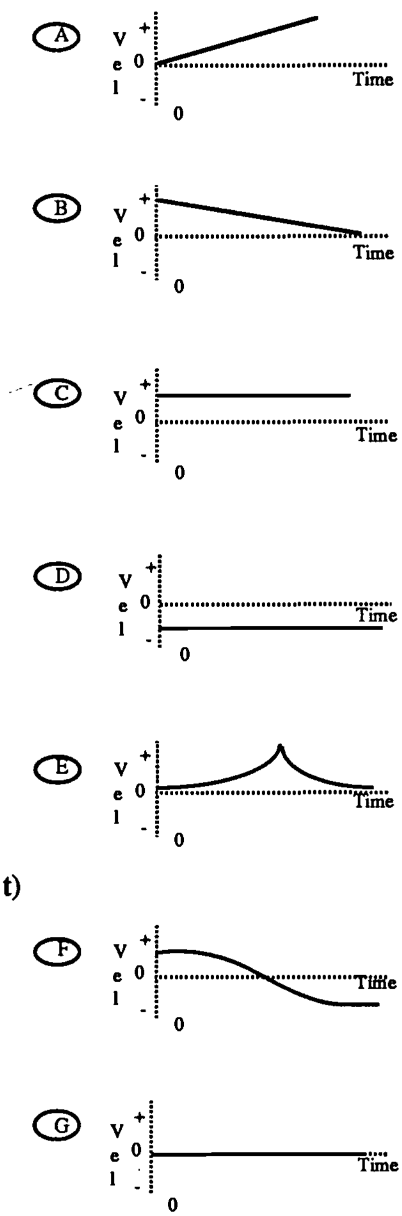
__C__ 1. Which velocity graph shows the object moving away from the origin at a steady (constant) velocity? **(A)**

__G__ 2. Which velocity graph shows the object standing still? **(C)**

__D__ 3. Which velocity graph shows the object moving toward the origin at a steady (constant) velocity? **(B)**

__F__ 4. Which velocity graph shows the object reversing direction? **(E)**

__A__ 5. Which velocity graph shows the object increasing its speed at a steady (constant) rate? **(not significant)**



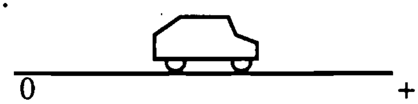
(J) None of these graphs is correct.

Figure 2 Some of the multiple choice velocity questions asked on the kinematics pre- and post-tests. Questions 1 through 5 are the velocity questions referred to in the Figures 1 and 4. The most common "wrong" answer is shown in parentheses.

In this case, the post-test was given to all three sections, but it was only possible to give the pretest to two of the lecture sections. Since the populations of these lecture sections were random (the only selection criterion was time of day) the pretests should have been similar for all three. There were no significant differences between the two sections that were pretested.

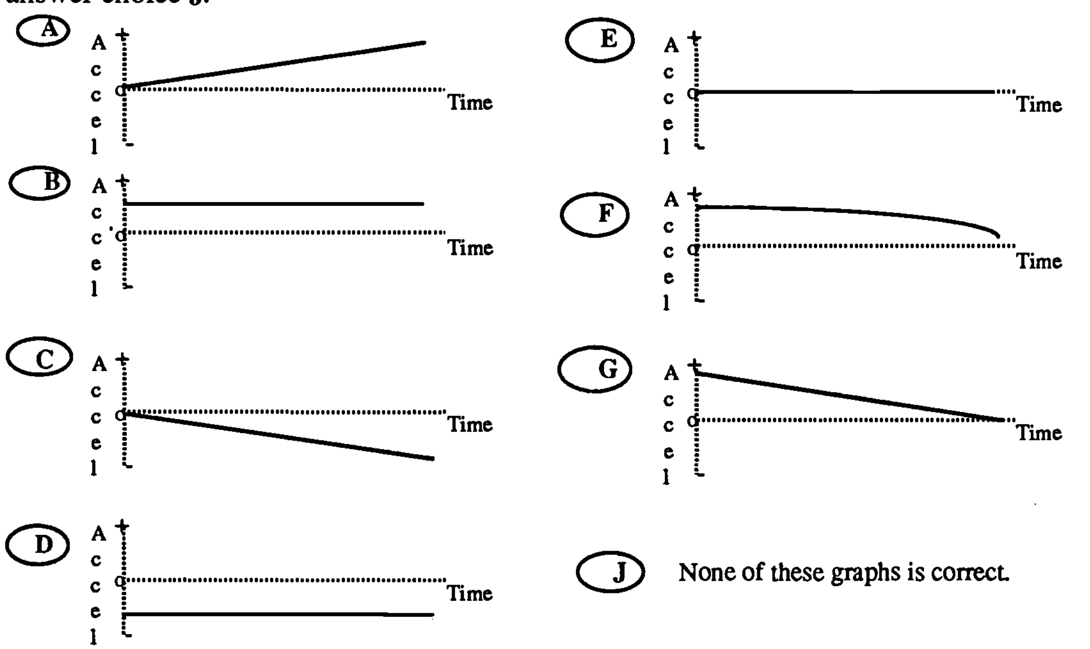
ACCELERATION-TIME GRAPHS

Questions 1-5 refer to a toy car which can move to the right or left along a horizontal line (the + distance axis).



Different motions of the toy car are described below. Choose the letter (A to G) of the acceleration-time graph which could correspond to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice J.



__E__ 1. The car moves toward the right at a constant velocity. (B)

__B__ 2. The car moves toward the right (away from the origin), speeding up at a steady rate. (A)

__D__ 3. The car moves toward the right, slowing down at a steady rate. (C)

__E__ 4. The car moves toward the left (toward the origin) at a constant velocity. (D)

__D__ 5. The car moves toward the left, speedng up at a steady rate. (C)

Figure 3 Some of the multiple choice acceleration questions asked on the kinematics pre and post-tests. Questions 1 through 5 are the acceleration questions referred to in Figures 1 and 4. The most common wrong answers are shown in parentheses.

It was surprising to observe error rates as high as 40%-60% on these simple velocity questions *after kinematics had been covered in lecture* and students had done standard problems. Such results are consistent with the data in Figure 1. As described above, most physics professors had predicted that fewer than 10% of their students would miss these questions. They also felt that students who were unable to answer such simple questions understood very little kinematics. All of the lecturers were aware of the testing, and all made a special effort to teach kinematics graphing and concepts in their lectures. The large error rates

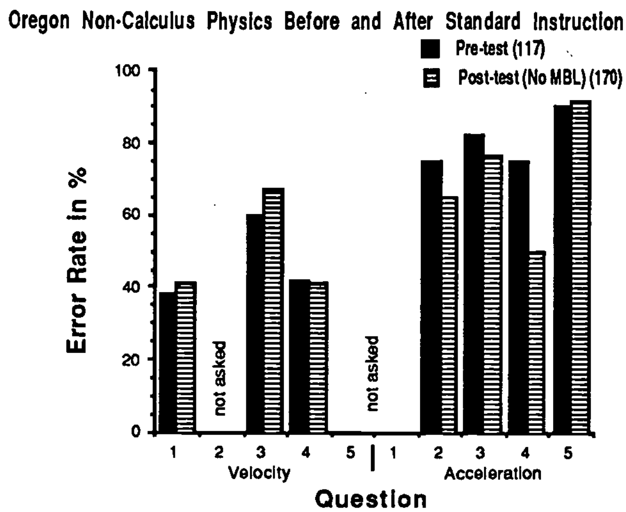


Figure 4 Results for introductory physics lecture students (non-calculus) at the University of Oregon, Fall, 1988--comparison of student error rates on a few velocity and acceleration questions given before and after standard instruction.

on questions 1 and 3 (41% and 67%, respectively after instruction) are not simply the result of the wrong choice of sign. The most common error is the choice of the "distance analogs," graphs A and B. This is consistent with previous studies [11,21], in which students used position models to interpret velocity graphs. The different error rates on these two questions show that students have significantly more difficulty interpreting negative velocities. (This conclusion is borne out by the results of additional testing.) Neither the results of this pretest nor the correct answers were shared with the students.

It should be noted that most students did not miss the questions because they were simply unable to read graphs. More than 95% could answer questions involving distance graphs correctly and students interviewed were intentionally picking graphs consistent with their verbal or written explanations of velocity and acceleration. In 1991 at the University of Oregon we asked more than two hundred students in the non-calculus introductory physics course to explain why they chose particular graphs from the choices. The results confirm that student responses to the short answer questions are consistent with their written explanation of the phenomena. More than 97% of the time, their written explanations were consistent with their answers to the multiple choice questions. As an example, consider question 2 in Figure 3 where students are to pick the appropriate acceleration graph for an object whose velocity is increasing at a steady rate as it moves to the right (positive direction, away from the origin). A typical student explanation given by those few students who think as physicists on the pre-test is:

> A steadily increasing velocity means a constant acceleration and since it is moving to the right the acceleration is positive.

A typical student explanation for a student making the same "correct" choice later in the year is more detailed.

> Steadily increasing velocity toward the right means the velocity vs time graph looks like  Since $a=\Delta v/\Delta t$ equals the slope of the v-t graph, the acceleration is positive and constant.

A typical response by a student (in the majority) who picks graph A:

> Acceleration steadily increases as the velocity does.

Such students are not confusing velocity and acceleration but positing that acceleration behaves like velocity. They are using a velocity "model" for acceleration. The students who continue to view acceleration in this manner do not in general elaborate their responses after instruction in the manner of students choosing the physics explanation.

Why Use This Method of Evaluation?

In spite of the fact that physics professors thought initially that these questions were much too simple for their students and that very few would "miss" them, after seeing the results, some professors suggested that perhaps they are not significant or valid and reliable measures of knowledge. Our research does not support this point of view. The pre- and post-tests that we have used in these studies consist in part of multiple choice questions. From earlier testing of students using free response questions requiring written answers and the drawing of graphs, we have constructed questions that seem to give a reasonable indication of students' basic knowledge of kinematics concepts and of graphical representation. Student answers to these questions correlate well with their written answers on these and earlier tests as the discussion above indicates. We find there are almost no random answers. Almost all students pick choices that we can associate with a small number of student models. This paper presents the results of only a few of more than 50 questions in different formats that are designed to distinguish among student models. Many of the multiple choice questions require students to choose the correct graph from a group of up to 9 graphs. Testing with smaller student samples shows that those who can pick the correct graph under these circumstances are almost equally successful at drawing the graph correctly without being presented with choices. The difficulties in convincing physics professors and high school teachers to give up course time for testing, our desire to make evaluation less subjective, and the effort involved in analyzing large samples moved us to use short answer questions for these studies. Although a more complete understanding of student learning can be gained by an open-ended questioning process, we decided to use short answer questions in order to gather sufficient data at many different institutions to counter the common response that "my students do not have these difficulties you describe." From such questions we are also able to identify students with less common beliefs about motion and follow up with opportunities for open-ended responses to help us understand student thinking.

Student Understanding of Kinematics Concepts after MBL Instruction

A visit to an MBL classroom/laboratory illustrates the contrast with a traditional class. Students are actively involved in their learning. They are sketching predictions and discussing them in groups of two or three. They use MBL tools to collect physical data that are graphed in real time and then can be manipulated and analyzed. The discovery-based curricula take advantage of the fact that MBL tools present data in an immediately understandable graphical form. In the case of a motion laboratory, the students move in front of a motion detector that plots their motion. They appeal to features of the graphs they have just plotted to argue their points of view with their peers. They ask questions and, in many cases, either answer them themselves or find the answers with the help of fellow students. There is a level of student involvement, success, and understanding that is rare in physics and physical science courses. (For descriptions of the software tools, hardware probes, and the Tools for Scientific Thinking discovery-based curricula, see references 15-19. These materials are available from Vernier Software [2]).

Student enthusiasm is wonderful and we feel that such a learning environment would have merit even if it were true that student learning of concepts were about the same as traditional instruction. We are pleased, however, to have made MBL tools and curriculum that are very effective in helping students to learn motion concepts and have worked hard to evaluate such learning. We have been conducting studies of the effectiveness of traditional methods of teaching motion concepts, examples of which were given previously, and of those curricula we have developed that make use MBL tools in the context of active and collaborative learning. As mentioned in the introduction, we have explored student understandings of physics concepts in middle schools and high schools. In colleges and universities we have studied the learning of students in calculus and algebra-based introductory physics courses, including those designed primarily for teacher preparation and enhancement programs. We have used pre- and post-testing and other forms of evaluation to examine the understandings of thousands of college and university physics students who have used the Tools for Scientific Thinking motion curriculum. We have also collected data for a large sample of secondary and middle school students. All of these contexts have provided strong evidence for significantly improved learning and retention by students who used the MBL materials, compared to those taught in lecture. Many examples of these learning results from university calculus and algebra-based physics courses, high schools, and teacher preparation programs have been published [15-19]. The results of this research show that in the case of kinematics, about 95% of university students understand velocity concepts and 80 to 95% understand acceleration concepts after using MBL curricula. Similar or better results have been achieved in high schools. To allow for more discussion of student learning of dynamics, we will not discuss these kinematics results in more detail and refer readers to the papers referenced above .

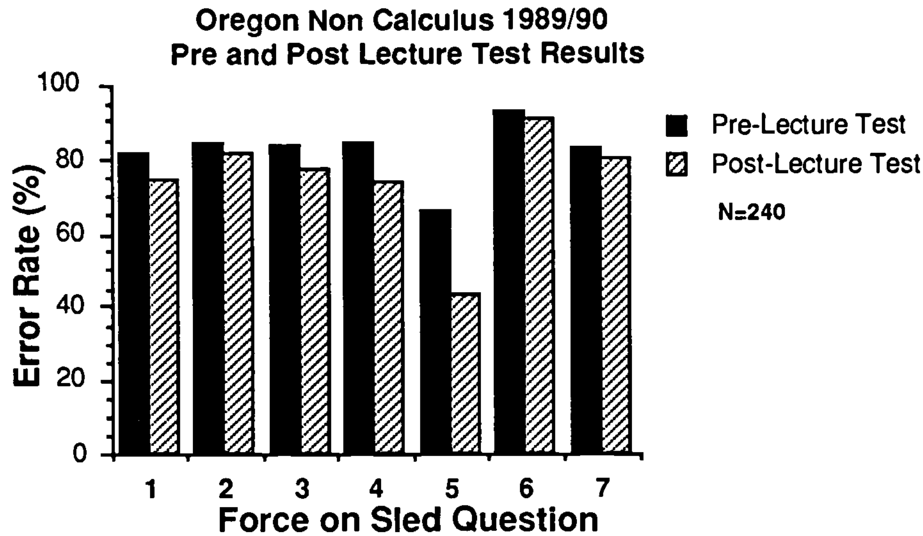
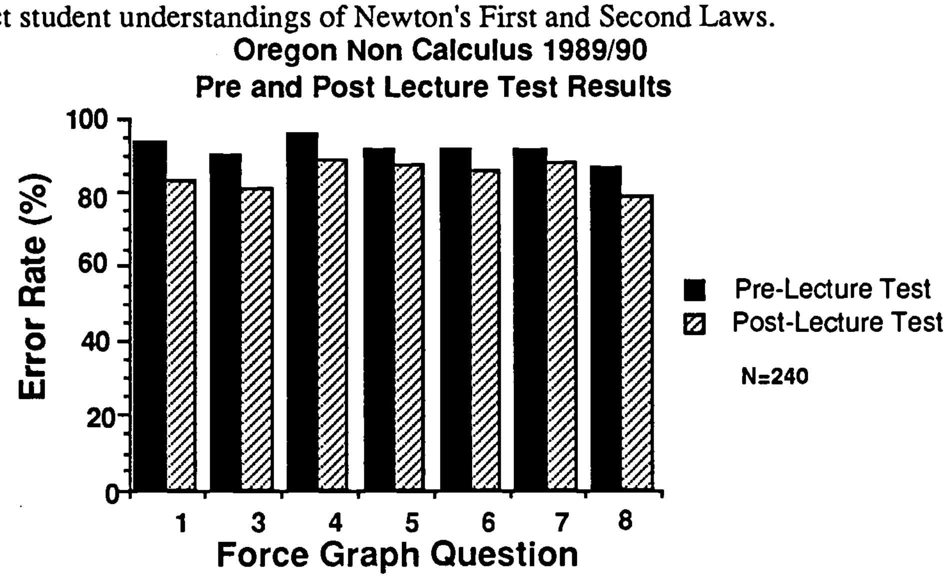


Figure 5 Error rates of 240 University of Oregon students in first year algebra-based physics on the simple dynamics questions shown in Figure 7. The dark bars show results before instruction and the striped bars after traditional instruction.

III. Evaluating Student Learning of Force and Motion (Dynamics) Concepts in Traditional and MBL Environments

Student Understanding of Dynamics Concepts after Traditional Instruction

Very few students entering universities understand force and motion from a Newtonian point a view. Unhappily, only a small additional percentage of students adopt a Newtonian framework after well executed traditional instruction (see Figure 1). The results reported on here reflect student understandings of Newton's First and Second Laws.

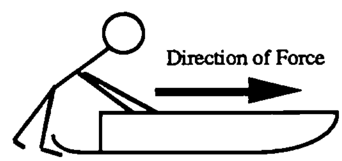


I

Figure 6 Error rates of 240 University of Oregon students in first year algebra-based physics on the simple dynamics questions shown in Figure 8. The dark bars show results before instruction and the striped bars after traditional instruction. Question 2 in this sequence from the Force and Motion Conceptual Evaluation was not asked.

Questions on Force and Motion

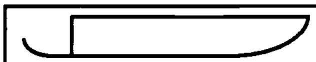
A sled on ice moves in the ways described in questions 1-7 below. Friction is so small that it can be ignored. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would keep the sled moving as described in each statement below. You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice J.



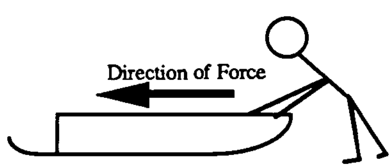
A. The force is toward the right and is increasing in strength (magnitude).

B. The force is toward the right and is of constant strength (magnitude).

C. The force is toward the right and is decreasing in strength (magnitude).



D. No applied force is needed



E. The force is toward the left and is decreasing in strength (magnitude).

F. The force is toward the left and is of constant strength (magnitude).

G. The force is toward the left and is increasing in strength (magnitude).

__B__ 1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)? **A**

__D__ 2. Which force would keep the sled the sled moving toward the right at a steady (constant) velocity? **B**

__F__ 3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)? **C**

__F__ 4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)? **G**

__D__ 5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity? **B**

__B__ 6. The sled is slowing down at a steady rate and has an acceleration in the positve direction. (The positive direction is to the right.) Which force would account for this motion? **C**

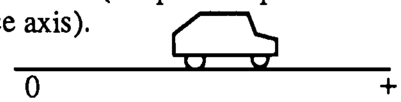
__B__ 7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)? **E**

Figure 7 Force on a sled questions corresponding to the results in Figures 5 and 6. The most common "wrong" answer on the pre-test is given after the questions. These answers are consistent with a velocity implies force hypothesis.

Figures 5 and 6 show that about 90% students in the introductory algebra-based physics course at the University of Oregon were unable to answer dynamics questions in ways that are consistent with a Newtonian view of the world either before or after traditional instruction.

Force Graph Questions

Questions 1-8 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (A through H) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice J.

E 1. The car moves toward the right (away from the origin) with a steady (constant) velocity. **A**

E 2. The car is at rest. **not significant**

A 3. The car moves toward the right and is speeding up at a steady rate (constant acceleration). **C**

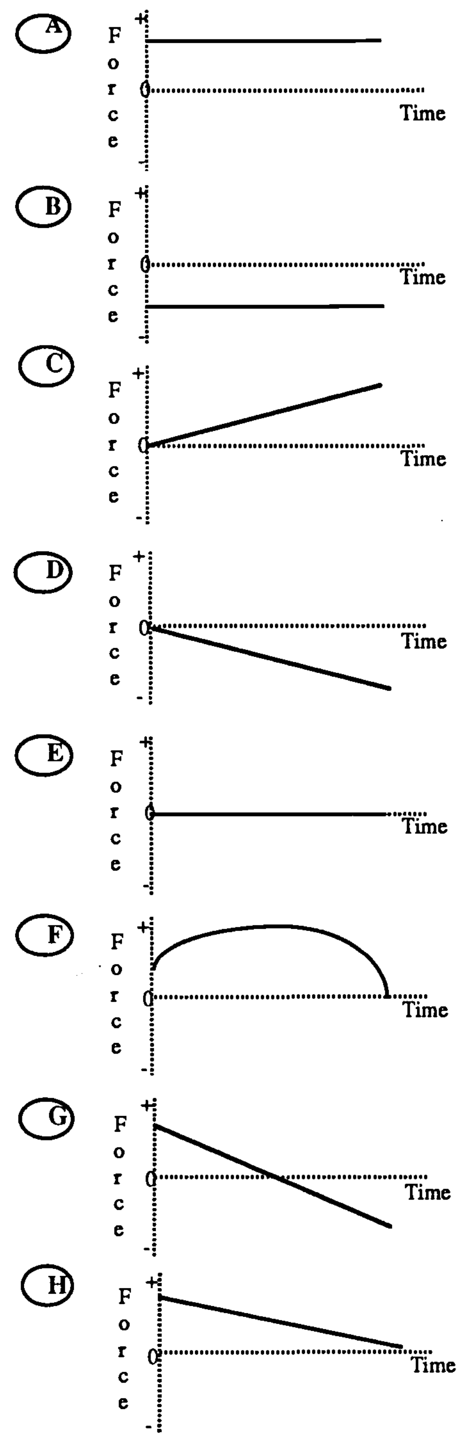
E 4. The car moves toward the left (toward the origin) with a steady (constant) velocity. **B**

B 5. The car moves toward the right and is slowing down at a steady rate (constant acceleration). **H**

B 6. The car moves toward the left and is speeding up at a steady rate (constant acceleration). **D**

G 7. The car moves toward the right, speeds up and then slows down. **F**

E 8. The car was pushed toward the right and then released. Which graph describes the force after the car is released. **H,F,A**



(J) None of these graphs is correct.

Figure 8 Force graph questions corresponding to the results in Figures 5 and 6. The most common "wrong" answer on the pre-test is given after the questions. These answers are consistent with a velocity implies force hypothesis.

These results are typical and not unique to the University of Oregon. The questions asked are shown in Figures 7 and 8. After standard instruction, this large error rate was reduced on average, by an additional 7%. (Note that even if we assign none of the small gain to instruction but assign all 7% to asking the same questions twice, asking the same question twice does not have a large instructional effect. In fact our other research shows that asking the questions two or more times does not produce a measurable gain, certainly not 7%.)

These questions have been selected from the Force and Motion Conceptual Evaluation developed by the Center for Science and Mathematics Teaching at Tufts University. The questions have been asked of thousands of students. The fact that traditional instruction has little effect on student beliefs about force and motion as shown by the results in Figures 5 and 6, is confirmed by considerable additional research. Note that although both sets of questions (force on a sled and force graph sequences) explore the relationship between force and motion, the format is very different. The force on sled questions make no overt reference to a coordinate system, they use "natural" language as much as possible, and they make no reference to graphs. Student responses to questions where there is an exact analog between the force on the sled question and the graphical questions are consistent in spite of these differences.

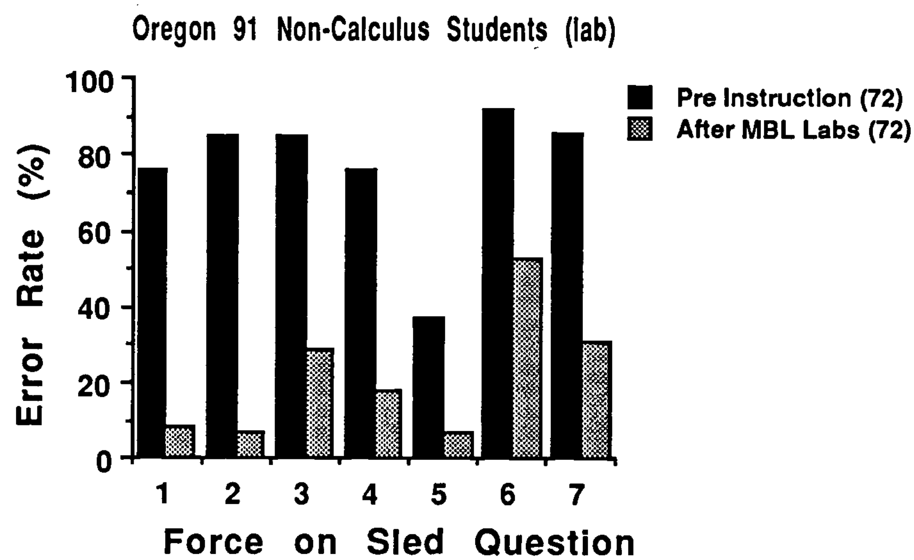


Figure 9 Student performance on the force on a sled questions shown in Figure 7 before instruction (dark bars) and after lectures and MBL laboratories (lighter bars). The same 72 students all took the pre test, listened to lectures, did the MBL laboratories, participated in an interactive MBL lecture demonstration, and took a quiz after instruction.

Student Understanding of Dynamics Concepts after using the MBL curriculum.

The great majority of students at the University of Oregon who completed the kinematics and dynamics laboratory curriculum mentioned above and described in reference 19 answered the questions in Figures 7 and 8 as most physicists would. This point of view is often described as Newtonian. The Newtonian model accurately describes the behavior of objects of everyday sizes moving at ordinary velocities. Objects that are moving at a constant velocity or at rest have no net force acting upon them and objects that are speeding up a constant rate (undergoing constant acceleration) are acted upon by a constant force. Force is proportional to acceleration.

This model held by physicists is in contrast to the almost universal student model that while agreeing that an object at rest is acted upon by a net force of zero, proposes that motion (or more specifically velocity) implies a force. Thus if an object is moving at constant velocity, it experiences a constant force while an object whose velocity is uniformly increasing must be acted upon by an uniformly increasing force. Both views disagree with a Newtonian model. Such a model is sometimes called an "impetus" model and, less accurately, an Aristotelian model.

It may be valuable to discuss a few individual questions. The largest error rate after MBL instruction is question 6 of the force on a sled sequence. About 50% of students missed this question. We know from additional research that 40% of physics professors and high school teachers also miss this question but are then unable to suggest a change in wording. Since some people who very consistently answer questions from a Newtonian viewpoint still miss question six, we must interpret the results cautiously. Such results confirm the value of asking a number of questions to probe understanding of particular concepts and the value of asking them of diverse audiences.

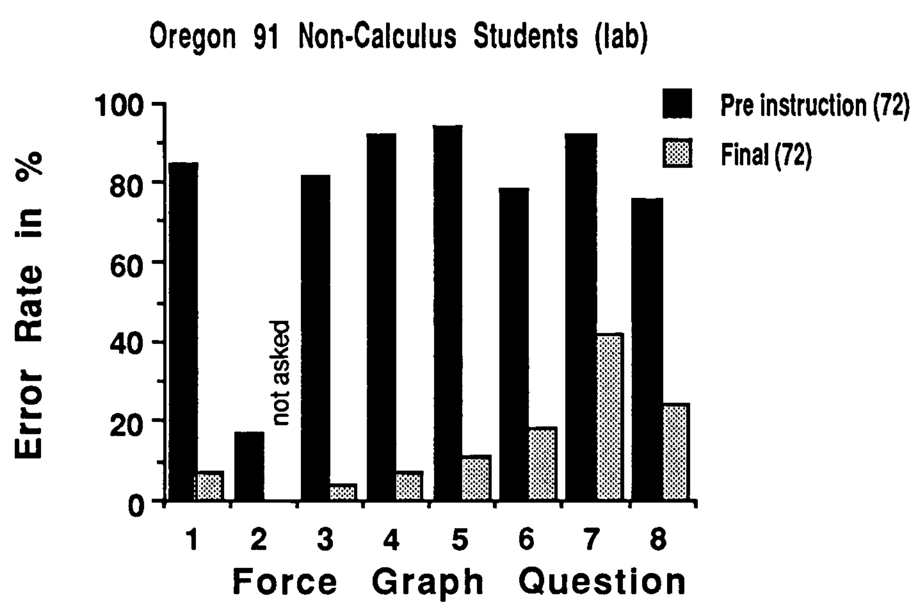


Figure 10 Student performance on the force graph questions shown in Figure 8 before instruction (dark bars) and after lectures and MBL laboratories (lighter bars). The same 72 students all took the pre test, listened to lectures, did the MBL laboratories, participated in an interactive MBL lecture demonstration, and answered these questions on the final exam.

Some questions are asked to make sure that students understand the format and (in some cases) can read English. Question 2 in the force graph sequence is the only question where the most common student views and Newtonian view are the same since the object is at rest (see above). Consequently, it is not "missed" often, even before instruction.

Like the earlier kinematics questions discussed in this paper, students do not answer these questions randomly. The choices were derived from open answer responses of students and from interviews. Most students can find an answer that matches the relationship between force and motion that they have in mind. More than 95% of the responses are either Newtonian or the most common student "model" which is the impetus model. The fact that most students are using "models" (even if they are only applied in very limited circumstances and give results that are in conflict with a more careful examination of physical phenomena) is a good beginning for instruction.

The contrast between 85% of students answering the above questions from a Newtonian perspective after the Tools for Scientific Thinking Curriculum while less than 20% do so after traditional instruction has led some to question the evaluation methods being used. After looking further at the evolution of student understanding of motion and force concepts and after exploring a new teaching technique useful in large lecture sections, we will examine in more detail the correlation between these questions and additional probes of students conceptual knowledge of force and motion.

IV. Hierarchical Understanding of Motion and Force Concepts

The use of the Tools for Scientific Thinking Force and Motion Conceptual Evaluation in actual university and high school classrooms has allowed us to study the learning of mechanics (and the mechanics of learning) by students in many different environments and over an entire course. We have strong statistical evidence that students who do not answer the simple velocity concept questions (Figure 2) as a physicist would will not answer the simple conceptual questions on acceleration or the questions on force and motion as a physicist would. Conversely, students able to answer the acceleration questions as a physicist would will answer the velocity questions "correctly". The same hierarchical relationship exists between acceleration and force. We can illustrate the hierarchy using data from the non-calculus course at Oregon in the fall of 1991. These are the learning data from which we drew many previous conclusions. In the following we will use the term "correct" to indicate the way most physicists would answer the questions.

From the results of the pre-test we find that 65 students miss 2 or more of the velocity questions shown in Figure 2. These same students miss on average 88% of the 5 acceleration questions (Figure 3) and over 90% of the force questions in Figures 7 and 8. To establish a hierarchy, we must also show that students who answer the acceleration questions correctly, answer the velocity questions correctly. In this pre-instruction sample of 230 students only 13 are able to answer all 5 of the acceleration questions correctly. These 13 students also answer all of the velocity questions correctly. To improve the statistics by finding more students able to answer the acceleration questions correctly, we can look later in the semester. After approximately half of the students have taken the Tools for Scientific Thinking motion labs and all students have seen an interactive lecture demonstration on kinematics (see Section IV), there are 102 students who answer all 5 acceleration questions correctly. These same students answer the velocity questions correctly 98% of the time as expected from the smaller sample.

Having established the hierarchical relationship between the learning of velocity and acceleration, we use additional data from the same source to establish the hierarchical relationship between the learning of acceleration and force concepts. On the pre-test, the 142 students who missed at least 4 out of 5 of the acceleration questions, missed 94% of the force graph questions shown in Figure 7. By the final exam, 123 students who missed no more than one force graph question. These same students also answered the acceleration questions correctly 96% of the time. Only 20 students missed substantial number (at least 4 out of 5) of the acceleration questions on the final but they still missed most of the force graph questions (75%).

There is a clear hierarchical learning relationship among simple concepts that indicate understanding of velocity, acceleration, and force. By examining the Oregon and additional learning data, we find that this hierarchy is true for traditional and MBL instruction. There remains a less likely possibility that some unexamined method of mechanics instruction would not result in such an hierarchy. It is also true that some students can answer some simple conceptual questions about acceleration, for example, as a physicist would while missing more sophisticated questions about velocity concepts.

IV. MBL Interactive Lecture Demonstrations: Using non-traditional methods to improve traditional lecture instruction

The data from the Oregon non-calculus course displayed in Figures 5 and 6 from 1989 and 1990 show that standard instruction resulted in an additional 7% of the students in the class answering the conceptual questions on force and motion in a Newtonian manner. The disappointing result becomes somewhat more understandable in light of the hierarchy presented above. At the end of all traditional kinematics and dynamics instruction, a given acceleration question was answered correctly (on average) by 28% of the students. (It is probable that this number was somewhat lower during the time the dynamics lectures were being given.) Since only students who understand acceleration concepts are likely to learn dynamics, the traditional instruction on dynamics could be of benefit to very few and partially accounts for the small number of students who develop a Newtonian view.

In an effort to improve learning of dynamics by students who did not have access to MBL laboratories, David Sokoloff and I developed further the concept of an interactive MBL lecture demonstration that had shown some promise in smaller scale experiments in previous years. In the fall of 1991, students in non-calculus lecture course were given 40 minutes of interactive lecture demonstration on kinematics, based on the learning sequence used in the MBL motion labs. A protocol developed for effective implementation of the interactive lecture demonstrations, is shown in Figure 11. The protocol encourages students to become actively engaged in the learning.

Interactive Lecture Demonstration Protocol

1. Describe the experiment/demonstration and do it for the class without MBL measurements.
2. Ask each student to record an individual prediction on the handout sheet.
3. Ask the class to engage in small group discussions in order to decide on a group prediction.
4. Ask each student to sketch a final prediction on the handout sheet (the group prediction if they came to an agreement). The prediction sheet will be collected at the end of the class.
5. Carry out the experiment/demonstration with MBL measurements displayed.
6. Ask a few students to describe the result and discuss results in the context of the demonstration. Students fill out results sheet which they keep.
7. Discuss analogous physical situations that produce a similar physical result but have different "surface" features.

Figure 11 This is the procedure to follow for each of the lecture demonstration/experiments such as the ones shown in Figure 12. The students are given two sheets, a prediction sheet to hand in so they don't lose credit and a results sheet to fill out for their own use. (Filling out the results should also improve the learning). The students are reminded that there are no wrong predictions.

As a result of this series of interactive demonstrations of kinematics, which were given after kinematics lectures, the acceleration questions were answered correctly by 63% of the students before the traditional lectures on dynamics. This is in contrast to previous years where approximately 25% of the students understood the acceleration concepts. After this preparation, the traditional lectures on dynamics resulted in a 28% (± 6%) average improvement in the force graph questions compared to the 7% (±2 %) from the previous years. We attribute this improvement to the fact that more students understood kinematics since nothing else was changed. The 40 minutes of time invested was well worthwhile since four times as many students benefited from the traditional dynamics instruction. On the other hand, 72%, on average, of the students still answer these question from a non-Newtonian point of view. Even with the enhanced learning of kinematics, attributable in the interactive demonstration, the traditional lectures were not very effective at teaching a Newtonian point of view. The students who used the Tools for Scientific Thinking lab curricula did considerably better and only 15% of the students answer these questions in a non-Newtonian way. (Figure 9).

We employed further interactive lecture demonstrations on force and motion after the traditional lectures. The results were gratifying and approximately 65% of the non-laboratory students answered the force graph questions from a Newtonian point of view in contrast to previous years where only 15 to 20% did so (see Figure 6). We are examining the efficacy of interactive lecture demonstrations at other universities and high schools. (For a more complete description of materials and results, contact the author)

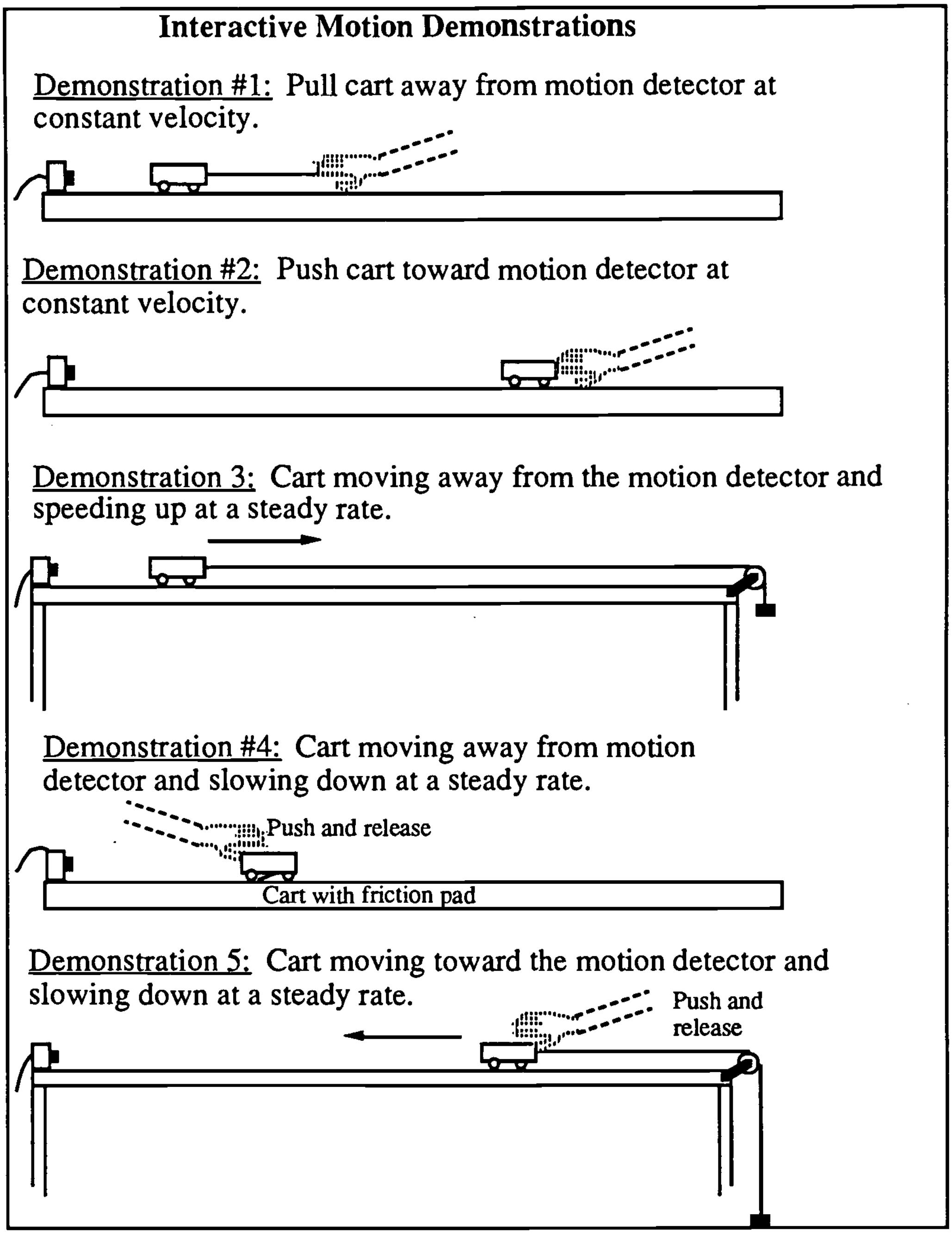


Figure 12 First 5 of 8 demonstration/experiments for Interactive motion demonstrations as examples. Student sheets which are not shown, often ask students to predict both the velocity and acceleration graphs for each demonstration/experiment.

V. Exploring the Significance of the Dynamics Questions on the Force and Motion Conceptual Evaluation.

The success of students in answering the dynamics questions from the Force and Motion Conceptual Evaluation after using the Tools for Scientific Thinking (or Workshop Physics) curricula leads some researchers to ask if the questions are significant indicators of students' understanding of dynamics. To some extent, this paper has already addressed important questions that might be raised. Student answers to the multiple choice graphical format questions of the type shown in Figure 7 correlate with answers to questions probing the same concepts when asked in the very different format of the questions shown in Figure 8 which neither use graphs nor refer explicitly to coordinate systems. The correlation holds both before and after traditional or MBL instruction. We have, however, found the graphical questions easier to formulate and to provide a more explicit indication of student understanding. Also such questions can be asked a number of times without any significant learning taking place from the questions.

New Force Questions On Final

In each of the following examples of motion of an object (1 - 10), choose the one description below (A - J) of the net (resultant) force on the object which could keep the object moving as described. You may use a choice more than once or not at all.

A. The net force is in the direction of the motion and is increasing in strength (magnitude).
B. The net force is in the direction of the motion and is of constant strength (magnitude)
C. The net force is in the direction of the motion and is decreasing in strength (magnitude).
D. The net force is zero.
E. The net force is in the direction opposite the motion and increasing in strength (magnitude).
F. The net force is in the direction opposite the motion and is of constant strength (magnitude)
G. The net force is in the direction opposite the motion and decreasing in strength(magnitude).
J. None of the net force descriptions is correct.

( ) show % of students giving physics answer

B (81) 1. What net force will cause an automobile moving on a highway to speed up at a steady (constant) rate.
D (80) 2. What net force will cause an automobile moving on a highway to maintain a constant speed of 55 miles per hour.
D (99) 3. What is the net force on an ice skater gliding across a frozen lake at a constant speed.
F (95) 4. A ball was thrown upward. What is the net force on the ball right after it is released and is moving upward, slowing down at a steady rate?
B (82) 5. What is the net force on the same ball as it is falling downward after reaching its highest point?
F (93) 6. An automobile moving at 55 miles per hour has the brakes applied suddenly to avoid a deer. What is the net force on the car as it slows down at a quick but steady (constant) rate?
D (54) 7. What is the net force on a bicycle that is being pedaled up a hill at a steady (constant) speed?
B (91) 8. What is the net force on a bicycle that is speeding up at a steady (constant) rate as it rolls down a hill?
F (89) 9. A bicycle after coasting along level ground comes to a hill. What is the net force on the bicycle as it rolls up the hill slowing down at a steady (constant) rate.
F (89) 10. What is the net force on an airplane as it moves down the runway slowing down at a steady (constant) rate after landing.

Figure 13 These questions, which test understanding of Newton's 1st and 2nd Laws in different contexts, were given on the final to students in the University of Oregon introductory non-calculus course. The students had not seen these questions previously. On the final, 123 students answered all or all but one of the force graph questions in Figure 8 in a Newtonian manner. The numbers in parenthesis show the % of these students also answering the questions "correctly." The results show most students consistently apply a Newtonian point of view to unfamiliar questions.

Student Responses to Additional Force and Motion Questions

To explore further the significance of the Newtonian student responses to the above graphical multiple-choice questions, we also asked a set of simple conceptual questions on the final exam that had never been asked of the students at University of Oregon. These questions are of a different format and set in rather different contexts than the questions discussed above. Figure 13 shows ten of these questions. The research question we explored was, if students answered the graphical force questions discussed above (Figure 8) from a Newtonian point of view, what percentage would answer different and unfamiliar questions from the same point of view. The numbers in parenthesis after the Newtonian answer indicate the percentage of students giving this answer. The results are very good with six questions answered correctly by approximately 90% or more of the students. It is interesting that 20% of the students missed question 2 about an automobile moving at constant velocity while only 1% of students missed question 3 where a skater moves at constant velocity. The large number of students who missed question 7, were equally split between choosing a constant force in the direction of and opposite to the motion. It may be the case that the concept of net force is not well understood. We are continuing to explore student responses to questions such as these.

Our expectations for students answering these questions using a Newtonian point of view were somewhat more modest than the actual results. Previous work had shown us that students often do not generalize in ways that seemed obvious to physicists without specific instructional effort to show such generalization is valid. Because of the limited time devoted to the Tools for Scientific Thinking dynamics curriculum (two three-hour laboratories) and the lack of any discussion time to introduce different contexts, we expected higher error rates.

Coin Toss Problems and Analogs

Students most commonly use a motion-implies-force model when they are asked the traditional coin toss problem (e.g. A coin is tossed up into the air. What is the force on the coin on the way up (after release)? At the highest point? and on the way down?). After traditional instruction only 5% of the students in the University of Oregon sample answer the coin toss questions shown in Figure 14 as a physicist would. After the MBL curriculum over 90% of the students answer the coin toss as a physicist would.

The coin toss problem and its analogs provide more evidence that students who answer the graphical force questions in Figure 8 from a Newtonian point of view have made a fundamental belief change. If we look again at the sample of 123 students (see also Figure 14 and discussion) who answered all or all but one of the question in Figure 8 "correctly," we find that 93% of these students answered the cart on the ramp questions shown in Figure 14 "correctly," i.e. from the Newtonian point of view. They had, however, seen this problem previously. Figure 15 shows a coin toss analog they had not seen, a block sliding into a spring. 92% of the students in this sample answered from the Newtonian point of view.

As with the other multiple choice questions on the Force and Motion Conceptual Evaluation, students who answered correctly were also able to describe in words why they picked the answer they did. Students were asked to explain how they determined the force on a cart in Figure 13 just as it reached the highest point (question 2). Typical answers from students who answered these short answer questions about the forces from a Newtonian point of view were:

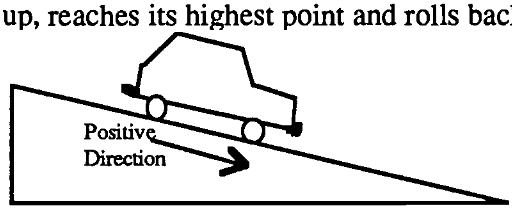
> "After the car is released the only net force acting on it is the x-component of its weight which has a net force down the ramp in the positive direction."

"When the car is at the top of the ramp, its velocity is 0 for just an instant, but in the next instant it is moving down the ramp, v2-v1 = a pos number so it is accel. down. Also, gravity is always pulling down on the car no matter which way it is moving."

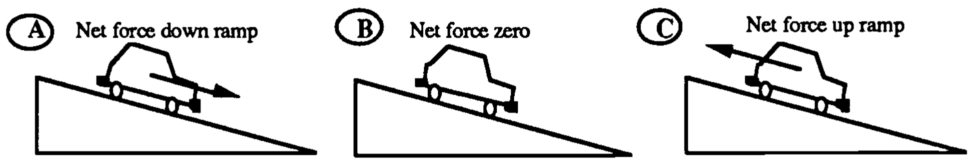
"The only two forces involved were gravity and friction. At the top of the ramp the net force was downward because gravity is higher in magnitude than friction (unless the tires & the ramp were sticky)."

Cart Up and Down Ramp and Coin Toss Questions

Questions 1-3 refer to a toy car which is given a push up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again.



Use one of the following choices (A through C) to indicate the net force acting on the car for each of the cases described below. Answer choice J if you think that none is correct.



_A_1. The car is moving up the ramp after it is released. (C)
_A_2. The car is at its highest point. (B)
_A_3. The car is moving down the ramp. (A)

Questions 4-6 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through C) to indicate the force acting on the coin for each of the cases described below. Answer choice J if you think that none is correct.

A. The force is downward.
B. The force is zero.
C. The force is upward.

_A_4. The coin is moving upward after it is released. (C)
_A_5. The coin is at its highest point. (B)
_A_6. The coin is moving downward. (A)

Figure 14 Coin toss question and an analog from the Force and Motion Conceptual Evaluation. Questions 4 through 6 are one version of the classic coin toss question. The most common pre-test "wrong" answer (shown after question) is consistent with the motion implies force model (given after the questions. Questions 1-3 involve the same knowledge of physics but seem slightly more difficult for students than the coin toss.

Typical student answers for those who answered as if the motion implies force were:

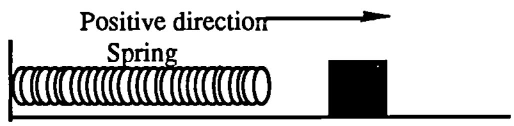
"At the highest point, the toy car's force is switching from one direction to another and there are no net forces acting upon it, so it is zero."

"Because at the one instant the car is at its highest point it is no longer moving so the force is zero for that one instant it is at rest = net force = 0"

The agreement between the multiple choice and open answer responses is almost 100%.

Spring and Block- Coin Toss Analog

Questions 23-25 refer to a block on a table with negligible friction. The block is initially moving toward the left, when it crashes into a spring.



For each of the cases described below, use one of the following choices A - C) to indicate the force acting on the block. Answer choice J if you think that none is correct.

A. The force is positive.

B. The force is zero.

C. The force is negative.

_A_ 23. The block is in contact with the spring, and is moving toward the left and slowing down

_A_ 24. The block is in contact with the spring, and has momentarily come to rest

_A_ 25. The block is in contact with the spring, and is moving toward the right and speeding up

Figure 15 Coin toss analog from the Force and Motion Conceptual Evaluation.

In summary, most students who answer the force graph or force on a sled questions from a Newtonian point of view are able to answer other questions that they have never seen from the same Newtonian point of view and are also able to answer coin toss and coin toss analog questions from the same point of view. In addition, students written explanations agree with their choices on these carefully constructed multiple choice questions. These results support the usefulness of the questions on the Force and Motion Conceptual Evaluation for evaluating student understanding.

VI. Conclusions

We have used large-scale classroom research to study student conceptual learning in mechanics (kinematics and dynamics) and its use in developing new approaches to learning. This paper has combined presentation of actual conceptual learning results as a result of traditional and non-traditional instruction, discussion of the evaluation methods, and evidence for the significance of the evaluation.

Our classroom research on kinematics concepts, based on data from more than 2000 students, has shown that traditional instruction in kinematics is not very effective in US universities. Additional data on kinematics learning shows that most students who understand kinematics concepts are in fact not learning the concepts during their introductory courses but know them when they enter the course. Such data leads to the conclusion that tradition instruction in kinematics has little effect on students' conceptual understanding of this topic. In contrast, the Tools for Scientific Thinking Motion Curricula with MBL laboratories are shown to be effective in teaching kinematics concepts. The questions used to measure conceptual knowledge in kinematics include multiple-choice graphical questions. Results from more than two-hundred students in a introductory physics class at the University of Oregon show that students' written explanations of kinematics concepts correlate with their choices on these short-answer kinematics questions which are part of Tools for Scientific Thinking Force and Motion Conceptual Evaluation.

Large-scale classroom research to study student learning in dynamics, shows that traditional instruction has even less effect on student beliefs. Questions on dynamics from the Force and Motion Conceptual Evaluation that probe the simplest concepts related to Newton's 1st and 2nd laws, show that in many universities, only 10% of students understand such concepts when they enter the class. After high quality traditional instruction at the University of Oregon, only an additional 7% in a sample of more than two hundred students have understood force and motion from the Newtonian point of view. However, more than 85% of students who have used the Tools for Scientific Thinking Motion and Force laboratory curriculum answer the same questions from a Newtonian point of view. Only 5% of students answer the coin toss question and its analogs in a Newtonian manner after traditional instruction, yet more than 85% of the students using the MBL curriculum do so.

Dramatic results might lead one to question the validity of the measurement process. This paper presented evidence that student responses were consistent on different format questions, graphical multiple choice and natural language questions with no overt references to coordinate systems. Students give almost no random answers. 95% of all responses are consistent with the most common student impetus model or with a Newtonian model. Approximately 90% of students who answered the graphical multiple choice questions are able to answer most of additional questions on the final exam with different surface features and format (questions they have not previously been asked). Written answers of more than 200 students were more than 98% consistent with their multiple-choice answers. More than 90% of students who answered the graphical multiple choice in a Newtonian manner also answered the coin toss questions and analog problems from the same point of view. Written answers for the coin toss problems are consistent with their short answer choices.

Further evidence that the questions are probing significant understanding is the strong evidence for a learning hierarchy among velocity, acceleration, and force concepts. Students unable to answer the simple conceptual velocity questions as a physicist would are unable to answer the acceleration questions in the same manner. Statistically students must know the acceleration concepts to answer the force and motion questions from a Newtonian point of view. If students do answer the force and motion questions in a Newtonian manner, then they also answer the acceleration and velocity questions as a physicist would. The evaluation of student conceptual learning in many different contexts has shown that curricula employing microcomputer-based laboratory tools allow students to develop a solid conceptual basis for understanding the world around them. Through the use of these tools, techniques and curricula, students connect their interactions with the physical world to the theories that constitute scientific knowledge.

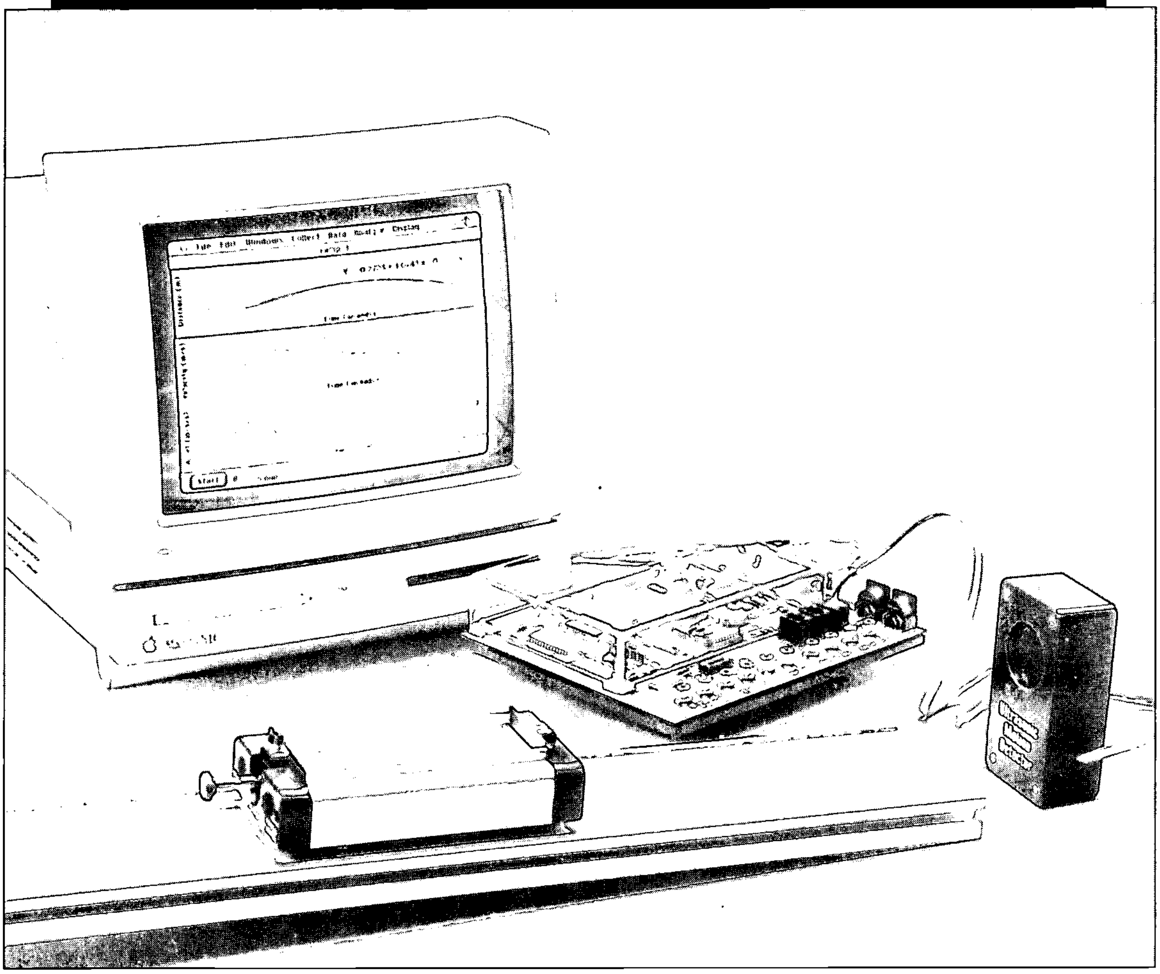
We have used MBL Interactive Lecture Demonstrations to improve traditional instruction in large classrooms with over 200 students. Because of the hierarchical nature of learning in mechanics discussed above, most students are unable to learn force and motion concepts if they do not know kinematics concepts. As a result of a 40 minute series of interactive demonstrations of kinematics (using a protocol to ençourage interactive learning), in which students participated after kinematics lectures, approximately 63% of the students understood acceleration concepts before the traditional lectures on dynamics. In previous years when approximately 25% of the students understood the acceleration concepts, traditional instruction in dynamics resulted in only 7% (±2 %) of students answering force and motion questions from Newtonian point of view. Because more students understood kinematics concepts as a result of the interactive lecture demonstrations, 28% (± 6%) of students adopted a Newtonian point of view after traditional dynamics instruction. When additional MBL Interactive Lecture Demonstrations in dynamics (another 50 minutes) were given after the lectures, approximately 65% of the non-laboratory students answered the force graph questions from a Newtonian point of view in strong contrast to previous years where only 15 to 20% did so after all instruction.

The evaluation of student conceptual learning in many different contexts has shown that, while traditional instruction has little effect, curricula based on classroom research and employing MBL tools allow students to develop a solid conceptual basis for understanding the world around them. There is evidence that the Force and Motion Conceptual Evaluation is a useful measure of conceptual understanding on the part of the students.

Footnotes and References

1. This work was supported in part by the National Science Foundation under the Student Oriented Science Project and the MBL for Teaching Teachers project, by the Fund for Improvement of Post-secondary Education (FIPSE) of the U.S. Department of Education under the "Tools for Scientific Thinking" project and "Interactive Physics" at Tufts University, the US Department of Education, the Board of Regents of Massachusetts, and Apple Computer, Inc.
2. These materials are available through Vernier Software, 2920 S.W. 89th Street, Portland, OR 97225.
3. The original participating colleges and universities are Tufts University, University of Oregon, California Polytechnic State University, San Luis Obispo, Dickinson College, Massachusetts Institute of Technology, Muskingum College and Xavier University. Additional schools have been involved in developmental work including Arizona State University, Lee College, Ohio State, Joliet CC, U. of Texas,Austin.
4. Arons, A.: Achieving wider scientific literacy, Daedalus **112**, 91-117 (1983)
5. Brassell, H.: The Effect of real-time laboratory graphing on learning graphic representations of distance and velocity, J. Res. Sci. Teaching **24**, 385-395 (1987)
6. diSessa, A.A.: The third revolution in computers and education, J. Res. Sci. Teaching **24**, 343-367 (1987)
7. Halloun, I.A. and Hestenes, D.: The initial knowledge state of college physics students, Am. J. Phys. **53**, 1043-1055 (1985) and Common sense concepts about motion, Am. J. Phys. **53**, 1056-1065 (1985)
8. Laws, P.: Workshop physics: replacing lectures with real experience, *Proc. Conf. Computers in Phys. Instruction*, Redish, E. and Risley, J. eds. (Addison Wesley, Reading, MA, 1989), 22-32
9. Laws, P.: Calculus-based physics without lectures, Phys. Today **44**, 24-31 (Dec., 1991)
10. McDermott, L.C.: Research on conceptual understanding in mechanics, Phys. Today **37**, 24-32 (July, 1984)
11. McDermott, L.C., Rosenquist, M.L. and van Zee, E.H.: Student difficulties in connecting graphs and physics: Examples from kinematics, Am. J. Phys. **55**, 503-513 (1987)
12. Peters, P.C.: Even honors students have conceptual difficulties with physics, Am. J. Phys. **50**, 501-508 (1982)
13. Rosenquist, M.L. and McDermott, L.C.: A conceptual approach to teaching kinematics," Am. J. Phys. **55**, 407-415 (1987)
14. Thornton, R.K.: Access to college science: Microcomputer-based laboratories for the naive science learner, Collegiate Microcomputer V (1), 100-106 (1987)
15. Thornton, R.K.: Tools for scientific thinking: Learning physical concepts with real-time laboratory measurement tools, *Proc. Conf. Computers in Sci. Teaching*, Redish, E. and Risley, J. eds. (Addison Wesley, Reading, MA, 1989), pp. 177-189
16. Thornton, R.K.: Tools for scientific thinking--microcomputer-based laboratories for teaching physics, Phys. Ed. **22**, 230-238 (1987)
17. Thornton, R.K.: Enhancing and evaluating students' learning of motion concepts. Chapter in *Intelligent Learning Environments and Knowledge Acquisition in Physics*, A. Tiberghien and H. Mandl, eds. (Berlin-Heidelberg-New York, Springer Verlag, NATO Science Series, 1992)
18. Thornton, R.K. and Sokoloff, D.: Learning motion concepts using real-time microcomputer-based laboratory tools. Am. J. Phys. **58** (9), 858-66, (Sept. 1990)
19. Thornton, R.K.: Changing the physics teaching laboratory: Using technology and new approaches to learning to create an experiential environment for learning physics concepts, *Proc. of the Europhysics Conference on The Role of Experiment in Physics Education*, University of Ljubljana Slovenia (in press)
20. Tinker, R.K. and Thornton, R.K.: Constructing student knowledge in science, in *New Directions in Educational Technology*, Scanlon, E. and O'Shea, T., eds. (Springer Verlag, NATO Science Series, to be published)
21. Trowbridge, D.E. and McDermott, L.C.: Investigation of student understanding of the concept of velocity in one dimension, Am. J. Phys. **48**, 1020-1028 (1980) and Investigation of student understanding of the concept of acceleration in one dimension," Am. J. Phys. **49**, 242-253 (1981)

Universal Lab Interface



Use Your Macintosh® in the Science Lab!

Vernier
SOFTWARE

The Universal Lab Interface (ULI) allows a wide variety of sensors to be interfaced to the Macintosh. Sensors available include ultrasonic motion detectors, force sensors, radiation monitors, photogates, pH probes, temperature probes, pressure sensors, light sensors, and microphones. The ULI is really a computer that controls and reads values from the sensors and communicates with the Macintosh using the modem port. Programs can then analyze and display data and graphs as the experiment takes place. Software is available for motion/force studies, photogate timing, nuclear radiation counting, temperature measurement, general analog data acquisition, and sound.

Macintosh software and curricular materials for the ULI have been developed as part of the Tools for Scientific Thinking Project at Tufts University under the direction of Ronald Thornton. Additional software and curricular materials have been developed as part of the Workshop Physics Project at Dickinson College under the direction of Priscilla Laws. These materials have received awards from NCRIPTAL, the Merck Foundation, *Media & Methods*, and *Computers in Physics*. System requirements are any Mac Plus or newer Macintosh computer with either System 6 or System 7.

Universal Lab Interface (ULI) Package: Includes ULI, User's Manual, cable to Macintosh, 9-volt power supply, Event Timer Software (for use with photogates), Data Logger Software, ULI HyperCard Starter Stack, and Test Leads $350

Software for the Universal Lab Interface

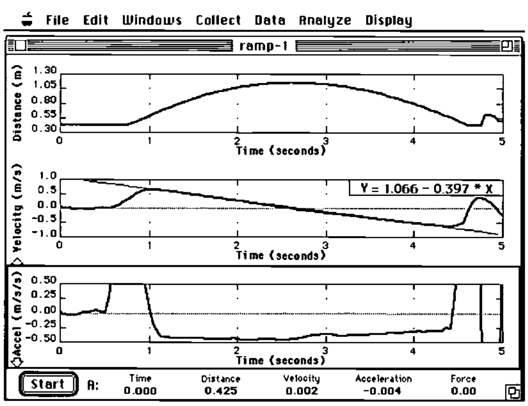
Two programs come with the ULI (Data Logger and Event Timer). Four additional programs are available. A site license is included with each purchase.

- MacMotion $25
  (requires Motion Detector; force sensor recommended)
- Event Counter $25
  (requires Radiation Monitor)
- MacTemp $25
  (requires one or two temperature probes)
- Sound $25
  (requires Microphone/Amplifier)

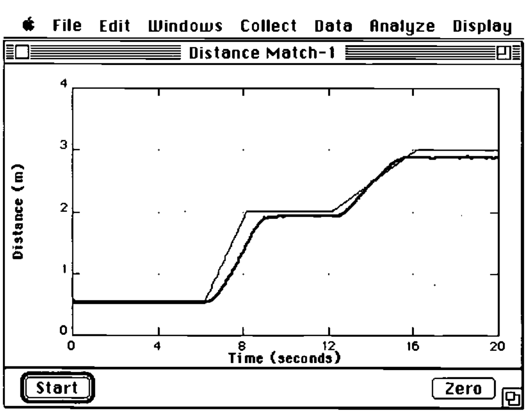
New 4.0 Versions!

New versions of MacMotion, MacTemp, Data Logger, and Sound are now available. New versions include curve fitting, statistics, a text screen, and spreadsheet-like columns. Upgrades are available for previous purchasers for $15 each. Send in your original program disk(s) with order.

MacMotion



The motion of a cart up and down a ramp.

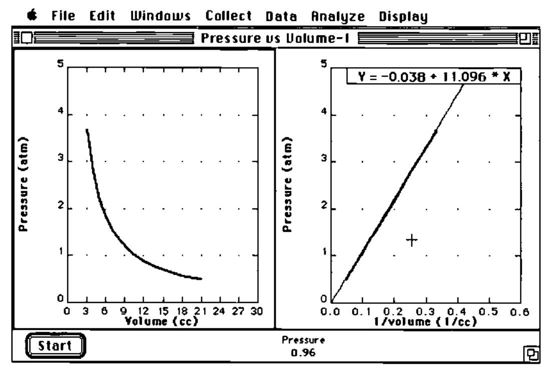


A student attempts to match a motion graph.

Awards Honoree 1992 *Media & Methods*

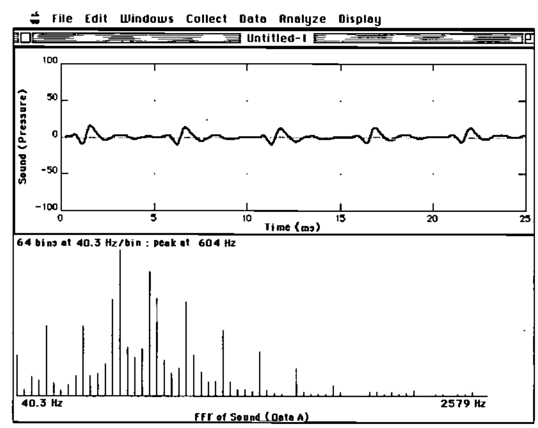
1991 winner of award for *"Innovative Software in Physics Education"* from *Computers in Physics.*

Data Logger



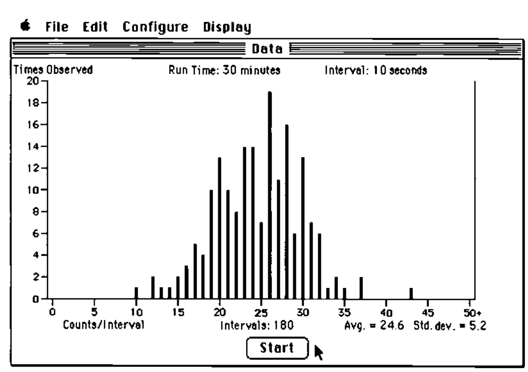
A Boyle's law experiment with a second graph of Pressure vs. 1/Volume.

Sound



A sound displayed with its FFT.

Event Counter



A histogram showing counts/interval.

Sensor/Probe	Assembled	Parts Kit	Use with...
Ultrasonic Motion Detector	$95 (U-MD)		MacMotion
Force Probe	$125 (U-FP)		MacMotion
Student Force Sensor	$99 (SFS-DIN)		MacMotion or Data Logger
Strain Gage Force Sensor Kit		$30 (SGK-DIN)	MacMotion or Data Logger
Standard Temperature Probe	$43 (TPA-DIN)	$28 (TPK-DIN)	MacTemp or Data Logger
Quick-Response Temperature Probe	$49 (TPAQ-DIN)		MacTemp or Data Logger
Budget Temperature Probe	$17 (TPB-DIN)		MacTemp or Data Logger
pH Amplifier pH Electrode	$40 (PHA-DIN) $32 (7120B)	$25 (PHK-DIN) $32 (7120B)	Data Logger
Thermocouple	$35 (TCA-DIN)	$20 (TCK-DIN)	Data Logger
Light Sensor	$39 (LS-DIN)		Data Logger
Magnetic Field Sensor	$44 (MG-DIN)		Data Logger
Pressure Sensor	$60 (PS-DIN)		Data Logger
Barometer	$56 (BAR-DIN)		Data Logger
Heart Rate Monitor	$47 (HRM-DIN)		Data Logger
ULI Microphone / Amplifier	$30 (MCA-U)	$15 (MIC-U)	Sound
Radiation Monitor	$190 (U-RM)		Event Counter
Photogate System	PASCO scientific	$38 (2PUL)	Event Timer
Adapter for PASCO Photogates or Smart Pulley	$5 (ADP)		Event Timer
Voltage Measurement Leads	1 included with ULI; additional $7 (TL)		Data Logger

See pp. 4-5 for descriptions of the ULI probes.

Ordering Information

Mail: **Vernier Software**
2920 S.W. 89th Street
Portland, OR 97225-3513
Phone: (503) 297-5317
FAX: (503) 297-1760

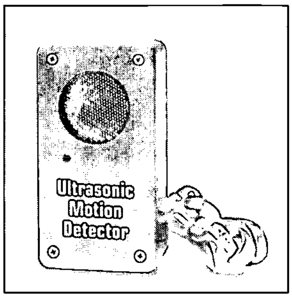
Prices are in U.S. dollars and are F.O.B. shipping point.
Prices are subject to change without notice.

Estimated Shipping and Handling:
U.S. orders: 3% ($4.00 minimum)
Canadian orders: 5% ($6.00 minimum)
Foreign orders: 12% ($15.00 minimum)

Vernier
SOFTWARE

Ultrasonic Motion Detector

The Ultrasonic Motion Detector is like the automatic range finder on a Polaroid camera. This sonar device emits ultrasonic pulses at a rate adjustable between 10 and 50 times per second. The time it takes for the reflected pulses to return is used to calculate distance, velocity, and acceleration. The range is 0.5 to 6 meters.



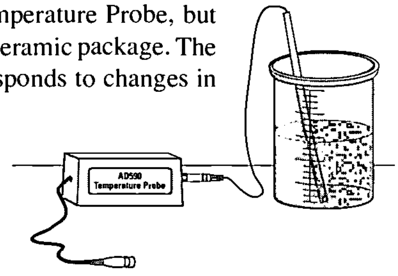
Temperature Probes

Standard Temperature Probe

The Standard Temperature Probe is designed to be a rugged, general-purpose laboratory temperature probe. The probe consists of a brass tube with an AD590 sensor at the end. The tube is covered with Teflon heat-shrink tubing to allow it to stand up to chemicals. Range: -8°C to +150°C (±0.5°C).

Quick-Response Temperature Probe

The Quick-Response Temperature Probe is electronically the same as our standard Temperature Probe, but the sensor is in a smaller, ceramic package. The result is that the probe responds to changes in temperature much faster, but is less protected, both chemically and physically. Recommended for use in air and water only. Range: -8°C to +150°C (±0.5°C).



Budget Temperature Probe

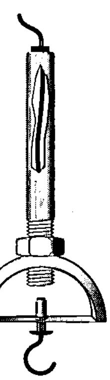
The Budget Temperature Probe can be used in many situations where quick response is not important. The probe has a brass tube with an LM34 temperature sensor at the end. It is somewhat less durable than our Standard Temperature Probe. Range is -15°C to +150°C (±0.5°C).

Force Sensors for Use with the ULI

We have two assembled force sensors and a strain gage kit that can be used with the ULI to measure force.

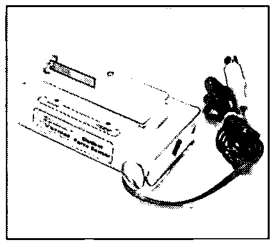
Force Probe

The Force Probe developed at Tufts University contains a Hall effect sensor that measures magnetic field strength. It is an easy-to-use replacement for a spring scale. The moveable portion of the probe, which has a small permanent magnet attached to it, flexes when it is pushed or pulled by an external force. The corresponding changes in magnetic field strength are directly related to the force applied. This probe is used extensively in the *Tools for Scientific Thinking* curriculum.



Student Force Sensor

Our new strain gage force measurement device can be mounted on a ring stand or used as a replacement for a hand-held spring scale. Heavy steel construction. Produces stable, linear, reproducible results.

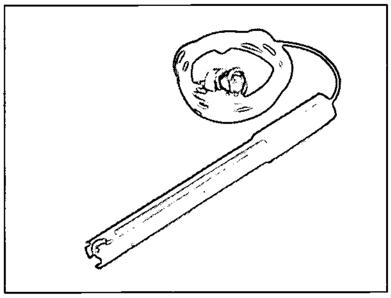


Strain Gage Force Sensor Kit

The Strain Gage Parts Kit provides the parts to build a strain gage force measurement system. This project is fairly complex and should be assembled only by those with experience in electronics. It can be a great way to learn about strain gages.

	Force Probe	Student Force Sensor	Strain Gage Kit
Price/Order Code:	$125	$99	$30
Assembled and Tested?	Yes	Yes	No
Can be used with:	MacMotion	MacMotion or Data Logger	MacMotion or Data Logger
Principle of Operation:	Hall effect	Strain gages	Strain gages
Range/Sensitivity:	0.05 to 20 N. Adjustable sensitivity.	0.05 to 20 N. Offset and sensitivity potentiometers provided.	The range and sensitivity depends completely on the beam on which you choose to mount the strain gages. The range can be from a fraction of a newton to thousands of newtons.

pH Electrode and pH Amplifier

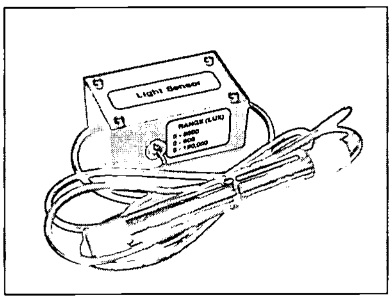


These two devices together allow your computer to be used as a pH meter. The pH Electrode is a student grade, Ag-AgCl combination electrode with a range of 0 to 13 pH. The pH Amplifier contains the signal conditioning circuitry.

Magnetic Field Sensor

This sensor, which uses a Hall effect transducer, is sensitive enough to measure the earth's magnetic field. It can also be used to study the field around permanent magnets, coils, and electrical devices.

Light Sensor



Our Light Sensor approximates the human eye in spectral response and can be used over three different illumination ranges, selected with a switch. It can be used for inverse square law experiments or for studying solar energy.

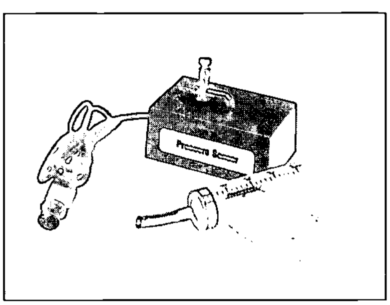
Thermocouple

This probe uses type K thermocouple wire to measure the difference in temperature between its two junctions. It can be used over the range 0 to 1400°C (±10°C). One popular use is for studying flame temperatures.

Barometer

The Barometer can be used for either weather studies or for lab experiments involving pressures close to normal air pressure. The pressure range is 24 to 32 inches of Hg (0.8 to 1.05 atm) absolute pressure.

Pressure Sensor



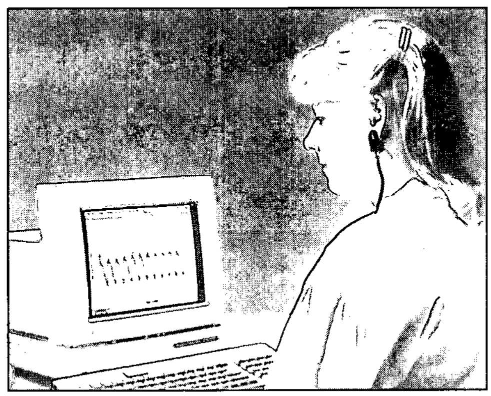
Our Pressure Sensor has a range of 0 to 100 psi (0 to 6.8 atm) absolute pressure. It is designed for gas law experiments. A plastic syringe and tubing is included for use with Boyle's law experiments.

Radiation Monitor

The Radiation Monitor was adapted for the Workshop Physics courses at Dickinson College. It consists of a Geiger tube and ratemeter mounted in a small, rugged, plastic case. The unit is battery operated and can be used without a computer for measurement of alpha, beta, and gamma radiation from background sources. It can be used with a ULI and the Event Counter software to explore radiation statistics, measure the rate of nuclear decay, and monitor radon daughters.

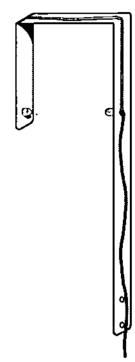
Heart Rate Monitor

This is our first biological sensor. A small ear clip is provided. Clip it on your ear and the Data Logger software will display a pattern representing your heart rhythm. Plot the pattern, measure the time between peaks, and you can determine your pulse rate. A simple program is included with the sensor which displays the heart rate in beats/minute.



Using the Heart Rate Monitor

Photogates



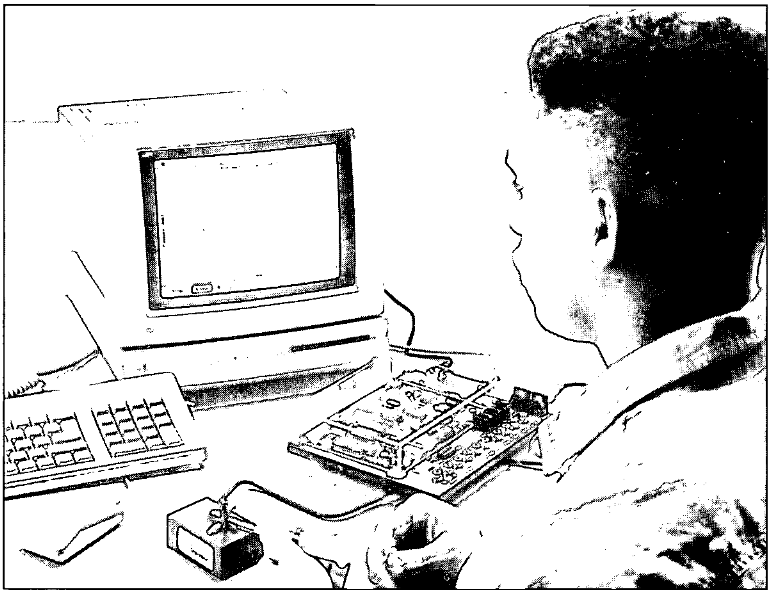
Photogates to use with the ULI can be purchased either as a 2-Photogate Parts Kit from Vernier Software or assembled from PASCO scientific. An adapter (our order code ADP) is required for PASCO photogates with stereo phone plugs. The photogates can be used with the Event Timer program to study free fall, rolling objects, air track collisions, pendula, camera shutters, etc.

Microphone/Amplifier

The ULI Microphone/Amplifier is used with the Sound program for displaying sound wave patterns. It includes an electret microphone and an amplifier circuit.

Curricular Materials for Use with the ULI

Workshop Physics Curricular Materials



Workshop Physics is an award-winning approach to the teaching of introductory physics in which the traditional separation of lecture and laboratory is abandoned. The curricular materials utilize recent developments in physics education research and make extensive use of the Macintosh-based ULI hardware and software, as well as other standard microcomputer software for the rapid collection, graphical display and analysis of data. Materials include calculus-based and non-calculus-based Activity Guides, which can be used either as the basis for a computer-augmented guided inquiry laboratory program or as the basis for a full workshop style of course without formal lectures. Each Activity Guide serves as a student workbook consisting of units that stress direct experience with physical phenomena. Students store the Activity Guide units in 3-ring binders, write observations, record data and perform analyses directly in the guide pages.

The Calculus-Based Activity Guide

Includes 28 units on Mechanics, Waves, Heat and Temperature, Electricity and Magnetism, and Radioactivity, as well as an introduction to course procedures and Appendices. Available in printed loose leaf form for local reproduction or as a series of three compressed Microsoft Word 4.0 Macintosh disks suitable for local revision and reproduction. The principal author is Priscilla Laws, Professor of Physics at Dickinson College.

Printed Version, unbound (900 pages)...........(CG-P) $40
Three 800K Disks with Word 4.0 Files ....(CG-D) $20

The Non-Calculus-Based Activity Guide

The 19 units in this version cover topics in Mechanics, Heat and Temperature, Waves, Fluids, Geometric Optics, Electricity and Magnetism, and Radioactivity, as well as an introduction to course procedures and Appendices. Available in printed loose leaf form for local reproduction or as a series of three Macintosh MacWrite disks suitable for local revision and reproduction. The principal author is John Luetzelschwab, Physics Professor at Dickinson College.

Printed Version, unbound (400 pages) ....(NCG-P) $30
Three 800K Disks with MacWrite Files ......(NCG-D) $15

ULI Software Developer's Guide

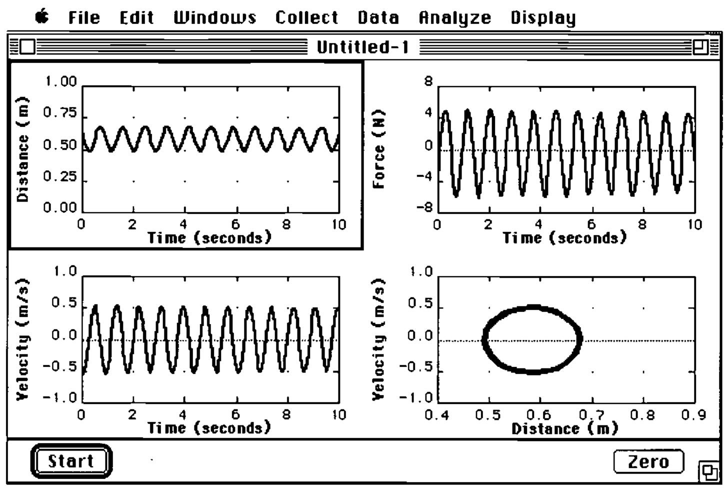
The Universal Lab Interface can be used with any computer that has a serial port, not just Macintoshes. This manual explains how to use simple commands to operate the ULI. The EPROM of the ULI contains about a dozen machine-coded routines for the on-board preprocessing of signals from sensors and for serial communication with host computers. Most of the programming necessary for data acquisition is already done for you. The Developer's Guide explains how to use ASCII based communications protocols to take advantage of this built-in program code. Software can then be developed to send signals from a large range of sensors to any microcomputer with an RS-232 or RS-422 serial port. Information in the Software Developer's Guide can also be used to control the ULI from within a telecommunications program. For example, some teachers are using the ULI to bring data directly into spreadsheets on both Macintosh and IBM-compatible computers.

Developer's Guide ....(U-SDG) $8

Curricular Materials for Use with the ULI

Tools for Scientific Thinking Curricula and Teachers' Guide

The Tools for Scientific Thinking curricula make use of Microcomputer-Based Laboratory materials for student development of concepts and intuition in the laboratory. The Motion and Force units are designed for use with the Ultrasonic Motion Detector and Force Probe. The Heat and Temperature units are designed for use with two ULI temperature probes and a heat pulser with the ULI and the MacTemp software.



Simple Harmonic Motion Studied with MacMotion

The curriculum encourages instructors to use a traditional laboratory setting for conceptual development on the part of their students. Only readily available or easily constructed laboratory equipment is used. Each curriculum piece consists of a series of guided investigations suitable for either the high school or introductory college laboratory, in either calculus or non-calculus-based courses. The curriculum makes extensive use of predictions and peer learning, and pays careful attention to student alternative understandings which have been documented in the literature. The materials have been subjected to extensive classroom testing, and have resulted in dramatic improvement in conceptual understanding. The units are accompanied by a detailed Teachers' Guide, and come in printed loose leaf format, suitable for local reproduction.

The Tools for Scientific Thinking Project at Tufts University has been supported by major grants from FIPSE (U.S. Department of Education) and the National Science Foundation. The principal authors are David Sokoloff of the University of Oregon and Ronald Thornton of Tufts University.

Motion and Force

There are five curriculum pieces. Each requires about three hours of laboratory work. *Introduction to Motion* covers concepts of position and velocity for constant velocity kinematics. *Introduction to Motion–Changing Motion* covers changing velocities and acceleration. Use is made of simple apparatus such as dynamics carts and ramps, and students' own body motions are used extensively in the introductory parts. A Force Probe is not required for these two units.

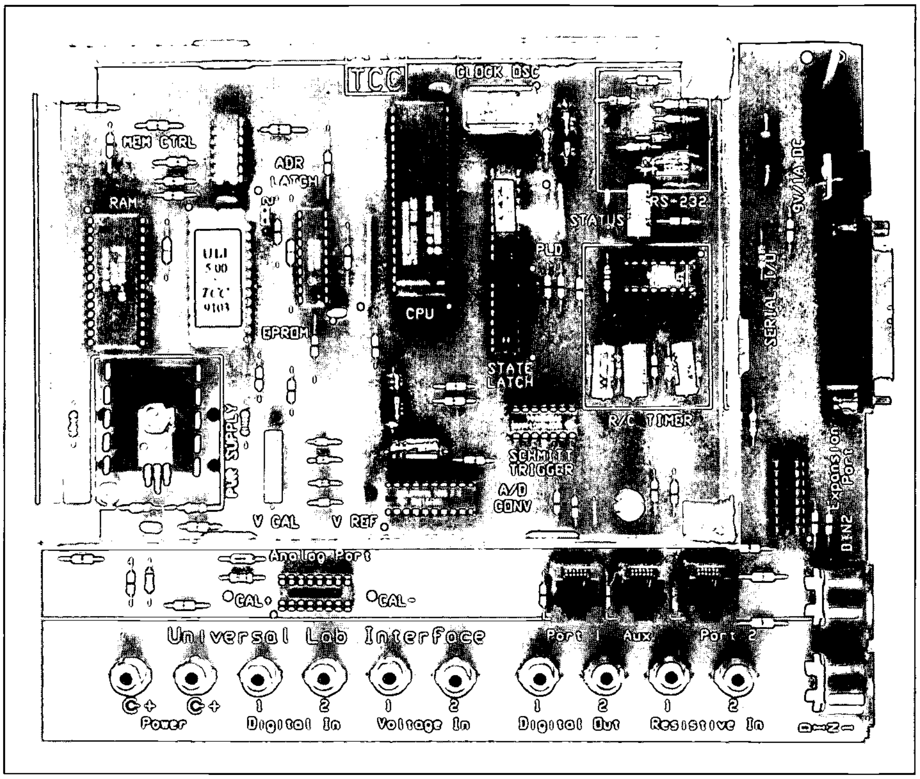
Passive Forces covers concepts of tension, normal force and frictional forces. *Force and Motion* covers dynamics and Newton's laws of motion. Use is made of simple apparatus such as dynamics carts and ramps. *Periodic Motion: Simple Harmonic Oscillations* covers the simple harmonic motion of a mass hanging from a spring, graphs of position, velocity, acceleration, dependence of period on amplitude, mass and spring constant, and energy concepts. Both a Motion Detector and Force Probe are required for these units.

Unbound with Teachers' Guide, 226 pages ..... (TST-M) $20

Heat and Temperature

There are four curriculum pieces. Each requires about three hours of laboratory work. *Introduction to Heat and Temperature* explores the concepts of temperature and heat, and the difference between them. *Energy Transfer and Temperature Changes* explores changes in temperature when heat or other forms of energy are transferred between systems, introduces specific heat capacity both conceptually and quantitatively, and explores the mechanical equivalent of heat. *Changing Phase: Ice to Water and Water to Steam* explores temperature graphs during phase changes, and looks quantitatively at the latent heats of fusion and vaporization. *Heat Energy Transfer* explores the dependence of heat transfer on temperature difference, and examines various means of reducing heat flow. Two temperature probes and a heat-pulser (which must be constructed) are required for all of these units.

Unbound with Teachers' Guide, 180 pages .... (HT) $20



Technical Information on the ULI Hardware

Microprocessor: SAB A-P, 8032 running at 12 MHz – includes an internal 256 byte RAM, four 8-bit ports, and three 16-bit timers.

EPROM: 16k bytes programmed with routines to control data collection.

RAM: 8k bytes, can be used for temporary data storage.

Power Supply: 9-volt, 1 amp, wall-mount transformer

Analog-to-Digital Converter: TLC1541IN - 10-bit A/D converter with 11 inputs, an on-chip multiplexer, and sample-and-hold circuitry. Voltage input range: 0 to 5.12 volts. Maximum sampling rate: 13,300 samples/sec. Two analog inputs are brought in from the most frequently used connectors.

Resistive Inputs: Four inputs similar to the resistive inputs on either Apple II or IBM game ports.

Digital Inputs: Two 74HC Schmitt trigger logic inputs.

Digital Output: Two totem pole CMOS 74HC outputs.

Serial Communication: Maximum baud rate: 38.4k - The ULI automatically matches the baud rate being used by the computer.
Word Length: 8 bits; Parity: none; Stop Bits: 1
Handshake: X-on/X-off (<control><s>, <control><q>)

ULI Design: The ULI was designed and is manufactured by Transpacific Computer Company. It was developed for projects at Dickinson College, Tufts University, and Technical Education Research Center.

Connectors:

RCA type:	(2) 5-volt power	(2) Digital output
	(2) Digital input	(2) Resistive input
	(2) Voltage input	

(3) 6-pin modular telephone connectors including voltage in, digital output, digital input, and power leads.

(2) 5-pin DIN sockets including voltage in and power leads.

16-pin DIP socket "analog port" including all 11 voltage input lines and the analog reference voltage (5.12 V)

16-pin DIP socket "expansion port" including 4 resistive inputs, 4 voltage inputs, 2 digital inputs, 2 digital outputs, and power supply lines.

APPENDIX III

ENGAGING STUDENTS WITH INTERACTIVE, MICROCOMPUTER-BASED DEMONSTRATIONS

Ronald K. Thornton,
Tufts University and University of Rome

and

David R. Sokoloff
University of Oregon

A Tools for Scientific Thinking Project
Center for Science and Math Teaching, Tufts University

With support from:

U.S. Department of Education, F.I.P.S.E.
National Science Foundation

ENGAGING STUDENTS WITH INTERACTIVE, MICROCOMPUTER-BASED DEMONSTRATIONS

Previous studies:
Significant and persistent learning gains in force and motion concepts in the laboratory through the use of microcomputer-based tools (motion detector and force probe) and the Tools for Scientific Thinking inquiry-based curriculum. (Microcomputer-Based Laboratories--MBL.)

Present study:
Significant and persistent learning gains in force and motion concepts through brief exposures to interactive lecture demonstrations using microcomputer-based tools (motion detector and force probe).

INTERACTIVE LECTURE DEMONSTRATION PROCEDURE

1. Describe the demonstration and do it for the class without MBL measurements.
2. Students record individual prediction.
3. Class engages in small group discussions.
4. Each student records final prediction on handout sheet (which will be collected).
5. Carry out the demonstration with MBL measurements displayed.
6. Ask a few students to describe the result and discuss results in the context of the demonstration. Students fill out results sheet which they keep.
7. Discuss analogous physical situations with different "surface" features. (That is a different physical situation that is based on the same concept.)

This is the procedure to follow to follow for each of the lecture demonstrations. The students get two sheets, a prediction sheet to hand in so they don't lose credit and a results sheet to fill out for their own use. (Filling out the results should improve the learning). Remind students there are no wrong predictions.

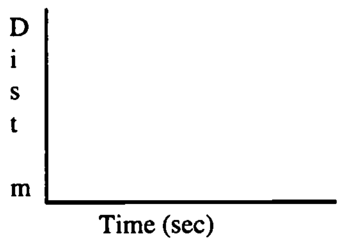
Name__________________________

HUMAN MOTION PREDICTION SHEET

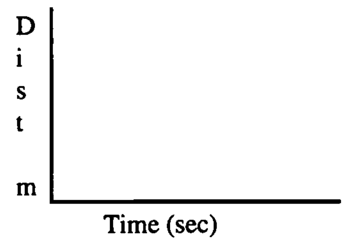
FOR INTERACTIVE LECTURE DEMONSTRATIONS

(HAND THIS SHEET IN)

Demonstration 1: Sketch below your prediction of the distance (position)-time graph for a person moving away from the motion detector at a steady (constant) velocity. On the other axis sketch your prediction for a person moving toward the motion detector (the orgin) at a steady (constant) velocity.

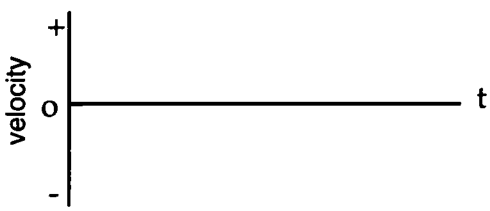


moving away

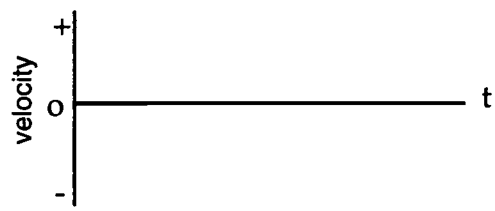


moving toward

Demonstration 2: Sketch below your prediction of the **velocity-time** graph for a person moving away from the motion detector at a steady (constant) velocity. On the other axis sketch your prediction for a person moving toward the motion detector (the orgin) at a steady (constant) velocity.

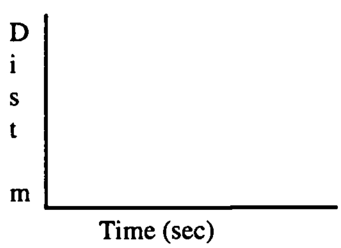


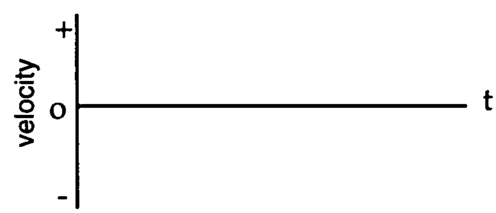
moving away



moving toward

Demonstration 3: Sketch below your predictions for the distance-time and velocity-time graphs of a person moving away from the motion detector at approximately twice the speed of demo's 1 and 2.





moving away at twice the speed

Describe in words how the **distance-time** graph changes when the speed is twice as fast.

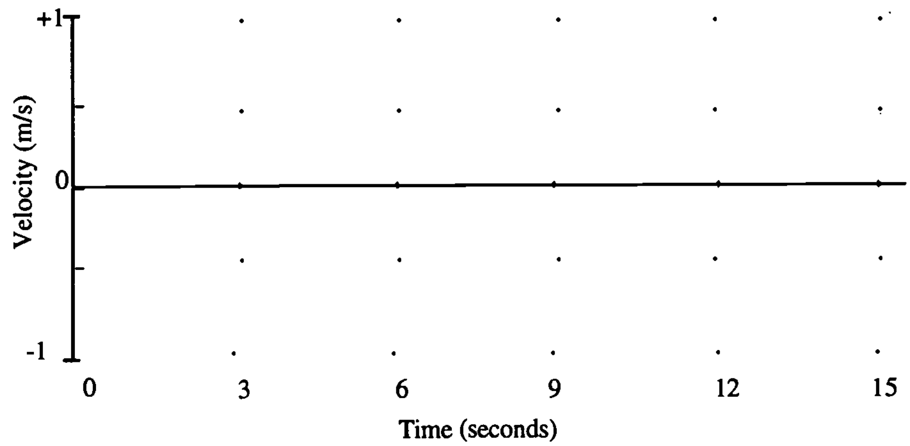
Describe in words how the **velocity-time** graph changes when the speed is twice as fast.

Name________________________

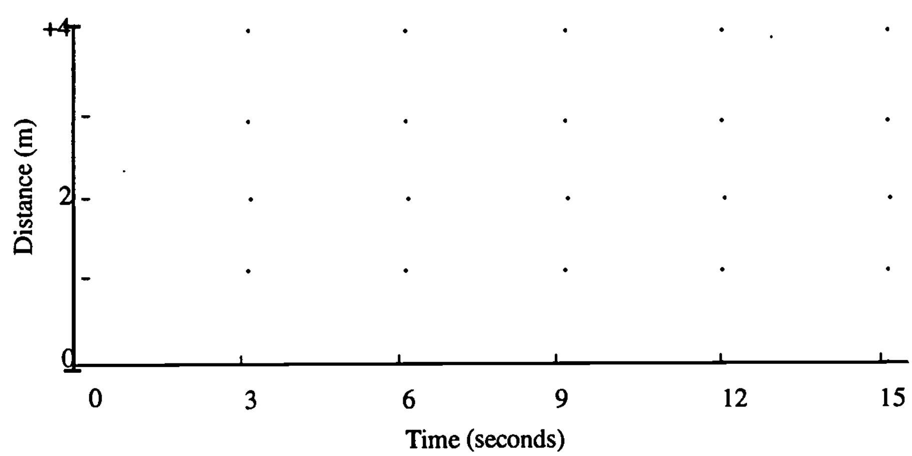
Demonstration 4: Predict a velocity-time graph for a more complicated motion. Using a *dashed line* draw your *prediction* of the velocity graph produced when a person—

- walks away from the detector slowly and steadily for 6 seconds
- stands still for 6 seconds
- and walks toward the detector steadily about twice as fast as before

Compare predictions with the people around you and see if you can all agree. Use a solid line to draw in your group prediction.



Predict the distance (position)-time graph for the motion described above. Follow the same procedure described above.



INTERACTIVE HUMAN MOTION DEMONSTRATIONS

Demonstrations are obvious from the sheet the students fill out. Follow procedure above.

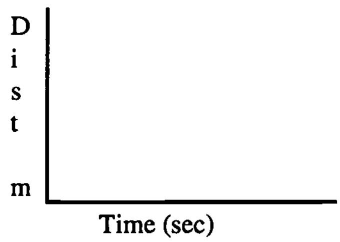
You may use this sheet to record actual results

HUMAN MOTION RESULTS SHEET

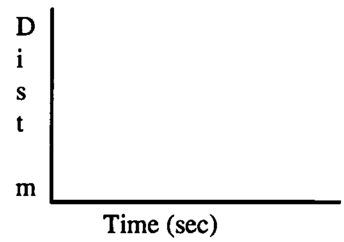
FOR INTERACTIVE LECTURE DEMONSTRATIONS

(SAVE THIS SHEET FOR YOUR OWN USE)

Demonstration 1: Sketch below the results of the distance (position)-time graph for a person moving away from the motion detector at a steady (constant) velocity. On the other axis sketch the result for a person moving toward the motion detector (the orgin) at a steady (constant) velocity.

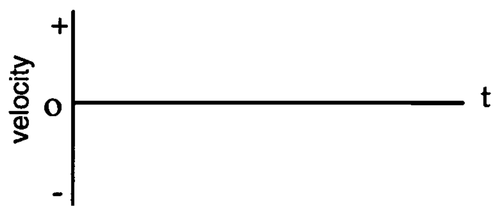


moving away result

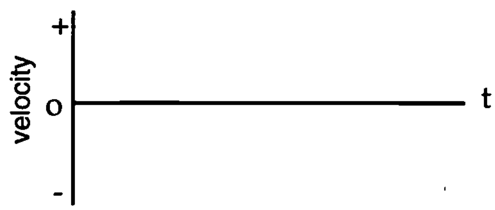


moving toward result

Demonstration 2: Sketch below the **velocity-time** graph that results when a person moves away from the motion detector at a steady (constant) velocity. On the other axis sketch the result for a person moving toward the motion detector (the orgin) at a steady (constant) velocity.

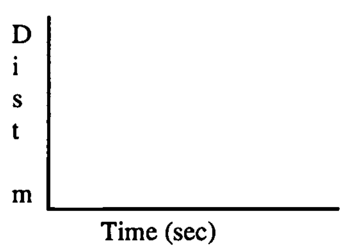


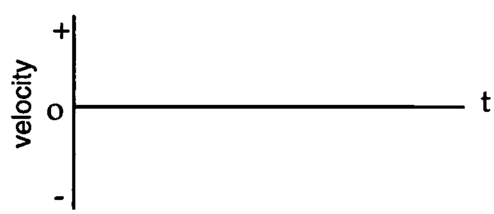
moving away



moving toward

Demonstration 3: Sketch below the distance-time and velocity-time graphs of a person moving away from the motion detector at approximately twice the speed of demo's 1 and 2.





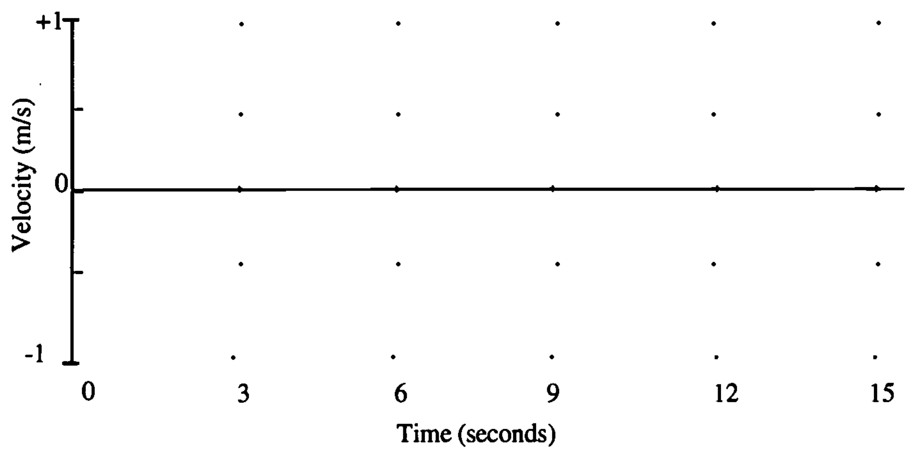
moving away at twice the speed

Describe in words how the **distance-time** graph changes when the speed is twice as fast.

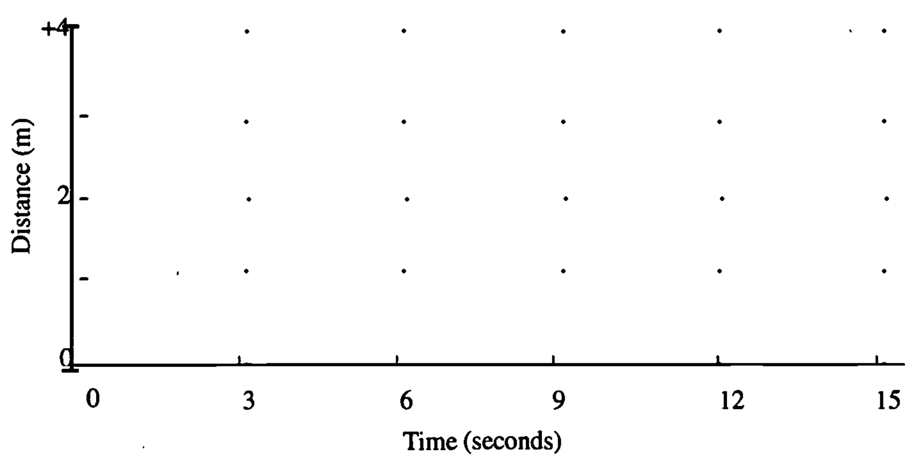
Describe in words how the **velocity-time** graph changes when the speed is twice as fast.

Demonstration 4: A velocity-time graph for a more complicated motion. Using a *dashed line* draw the velocity graph produced when a person—

- walks away from the detector slowly and steadily for 6 seconds
- stands still for 6 seconds
- and walks toward the detector steadily about twice as fast as before



Draw the distance (position)-time graph for the motion described above.



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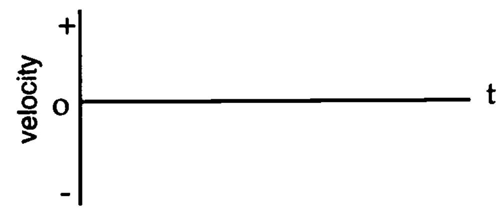
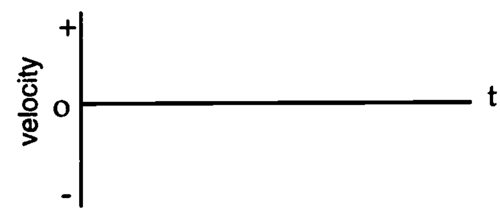
Name________________________________

MOTION PREDICTION SHEET
FOR INTERACTIVE LECTURE DEMONSTRATIONS
(HAND THIS SHEET IN)

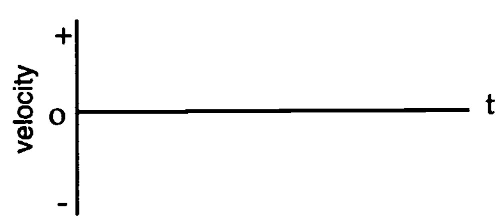
Demonstration 1: Sketch below your prediction of the velocity-time graph for the cart moving away from the motion detector at a steady (constant) velocity.

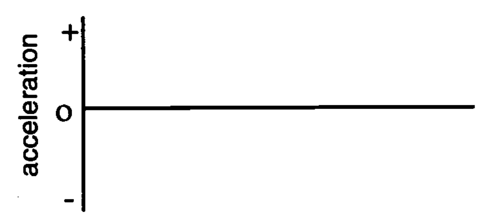


Demonstration 2: Sketch below your prediction of the velocity-time graph for the cart moving toward the motion detector at a steady (constant) velocity.

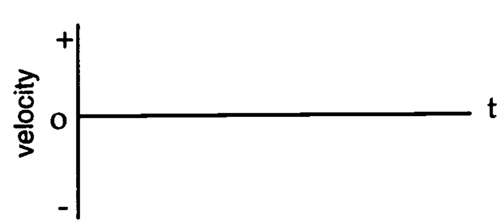


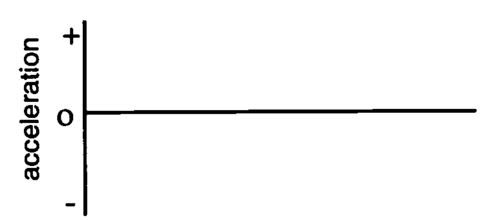
Demonstration 3: Sketch below your predictions for the velocity-time and acceleration-time graphs of the cart moving away from the motion detector and speeding up at a steady rate.





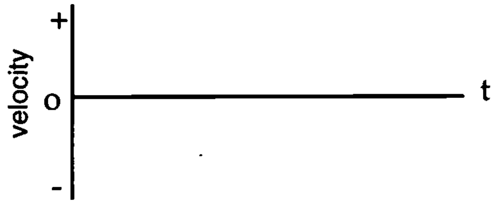
Demonstration 4: Sketch below your predictions for the velocity-time and acceleration-time graphs of the cart moving away from the motion detector and slowing down at a steady rate.

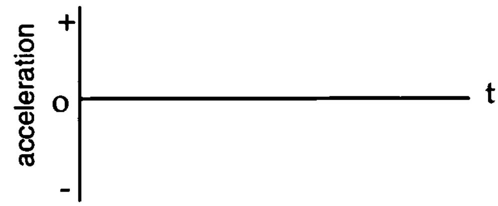




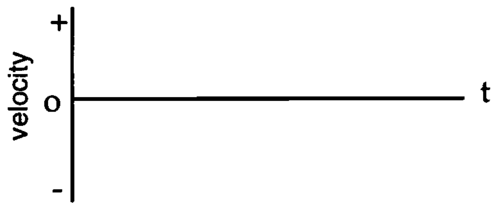
Name______________________________

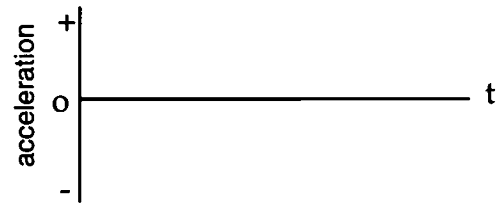
Demonstration 5: Sketch below your predictions for the velocity-time and acceleration-time graphs of the cart moving toward the motion detector and slowing down at a steady rate.



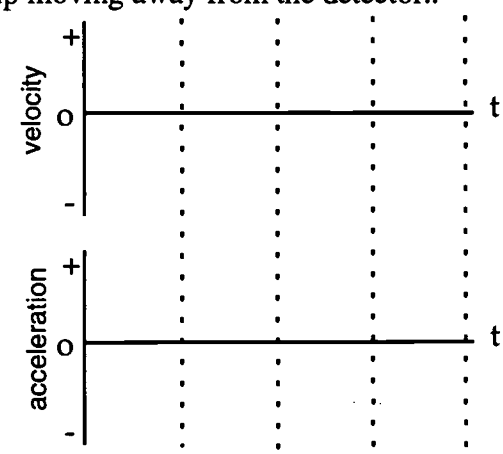


Demonstration 6: Sketch below your predictions for the velocity-time and acceleration-time graphs of the cart moving toward the motion detector and speeding up at a steady rate.





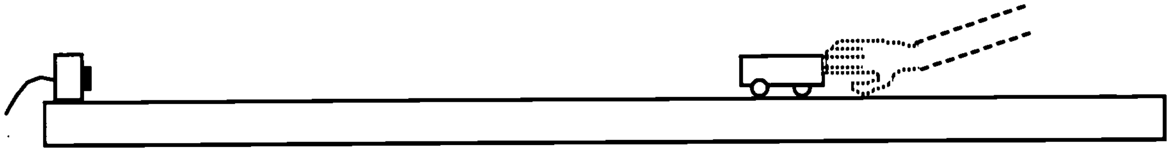
Demonstration 7: Sketch below your predictions for the velocity-time and acceleration-time graphs for the cart (with a constant force away from the motion detector) which is given a short push toward the motion detector (and is released) Sketch the graph as the cart slows down moving toward the detector, comes to rest and then speeds up moving away from the detector..



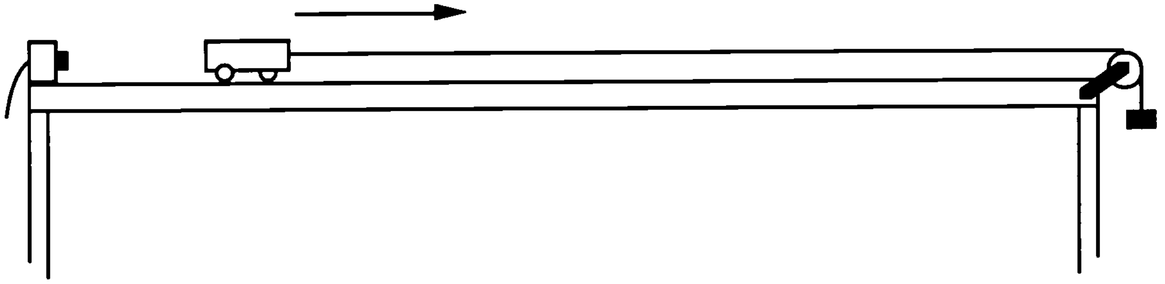
INTERACTIVE MOTION DEMONSTRATIONS

Demonstration #1: Pull cart away from motion detector at constant velocity.

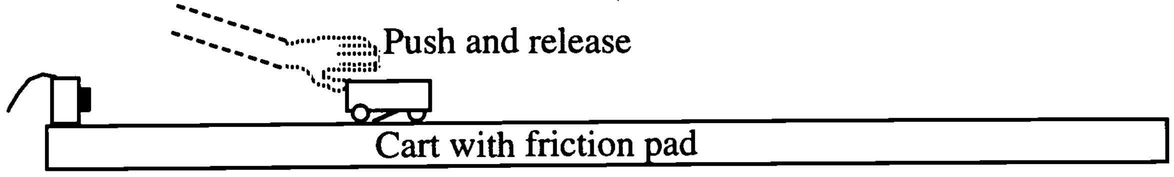
Demonstration #2: Push cart toward motion detector at constant velocity.



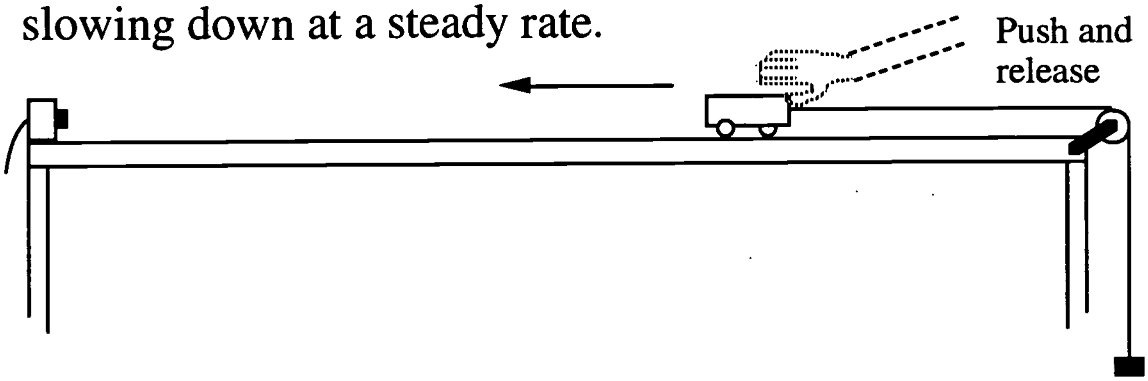
Demonstration 3: Cart moving away from the motion detector and speeding up at a steady rate.



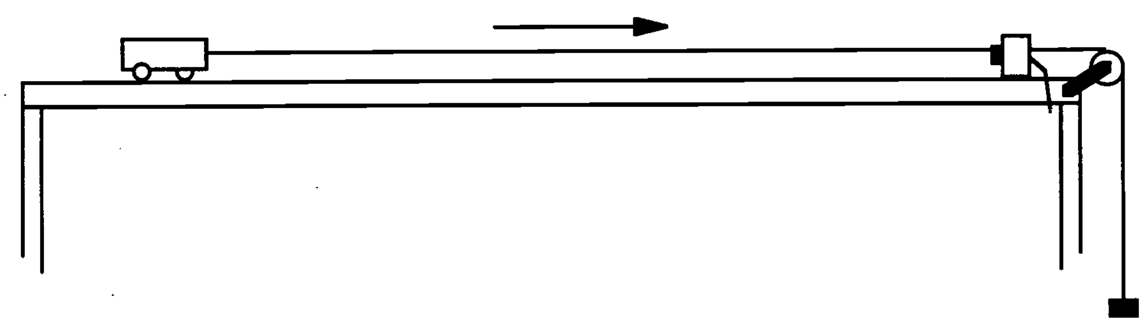
Demonstration #4: Cart moving away from motion detector and slowing down at a steady rate.



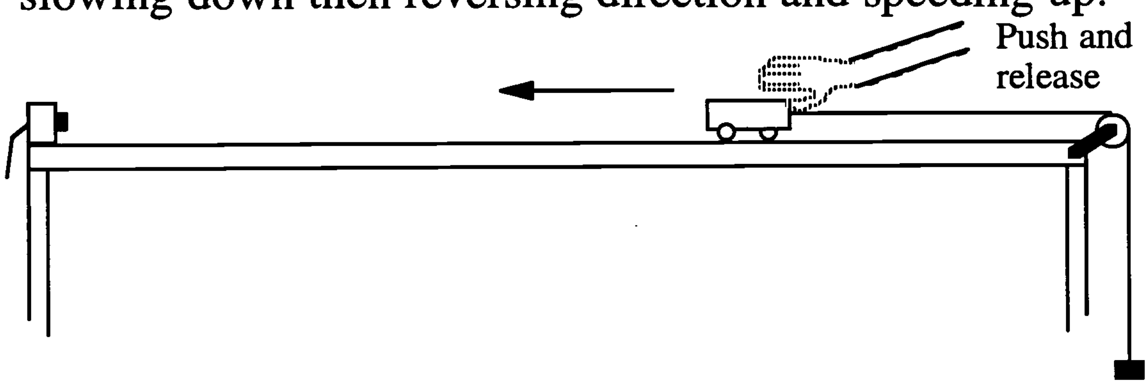
Demonstration 5: Cart moving toward the motion detector and slowing down at a steady rate.



Demonstration #6: Cart moving toward the motion detector and speeding up at a steady rate.

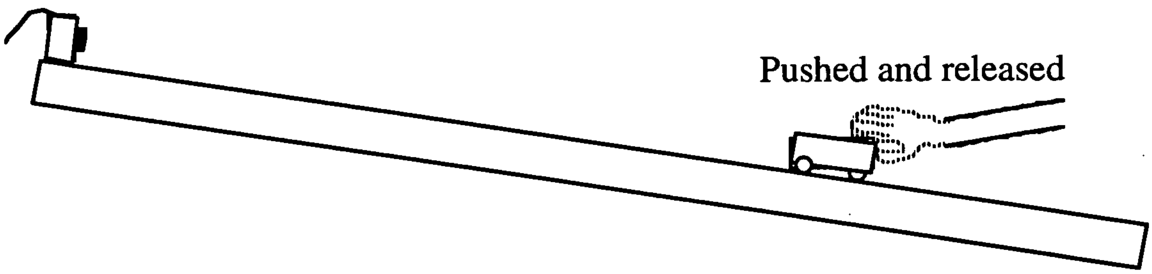


Demonstration 7: Cart moving toward the motion detector and slowing down then reversing direction and speeding up.



Optional Demonstration: Compare to last demo and to coin toss

Demonstration #8: Cart moving up the inclined ramp, coming to rest and then moving down the ramp.

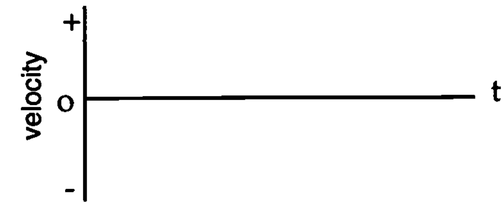


MOTION RESULTS SHEET

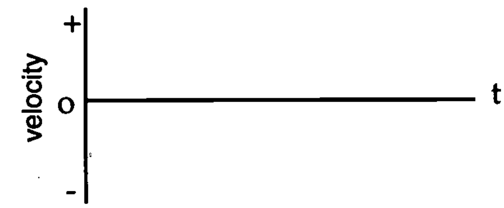
FOR INTERACTIVE LECTURE DEMONSTRATIONS

(SAVE THIS SHEET FOR YOUR OWN USE)

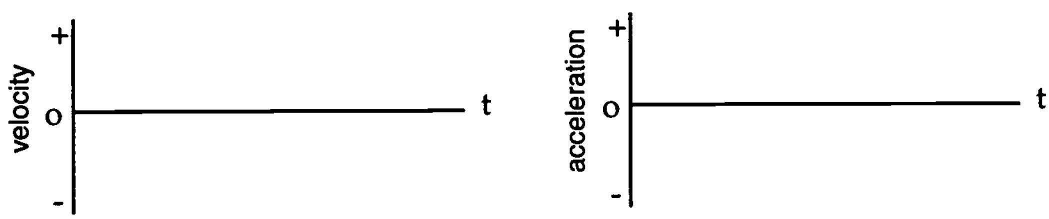
Demonstration 1: Sketch the actual velocity-time graph for the cart moving away from the motion detector at a steady (constant) velocity.



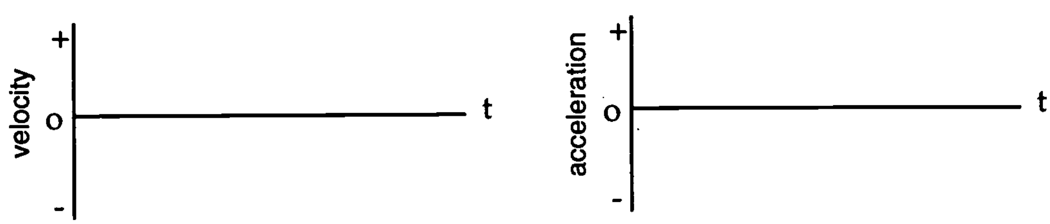
Demonstration 2: Sketch the velocity-time graph for the cart moving toward the motion detector at a steady (constant) velocity.



Demonstration 3: Sketch below the velocity-time and acceleration-time graphs of the cart moving away from the motion detector and speeding up at a steady rate.

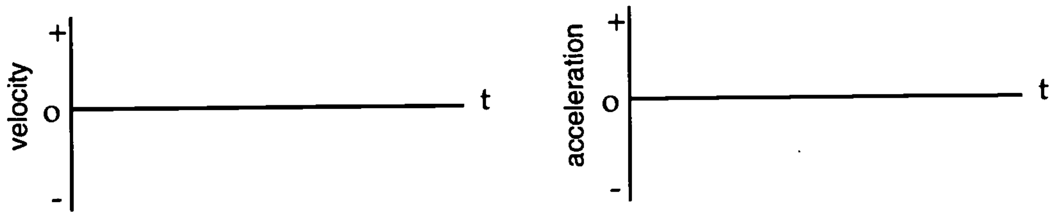


Demonstration 4: Sketch below the velocity-time and acceleration-time graphs of the cart moving away from the motion detector and slowing down at a steady rate.

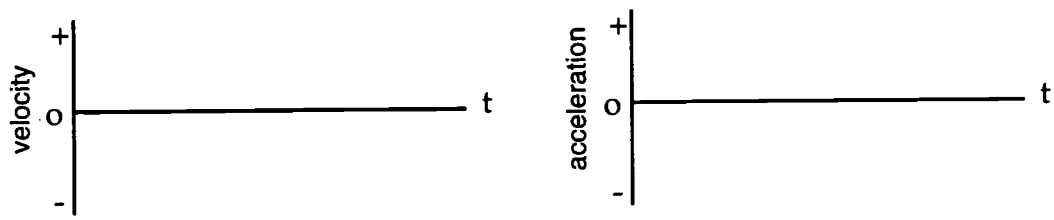


You may use this sheet to record actual results

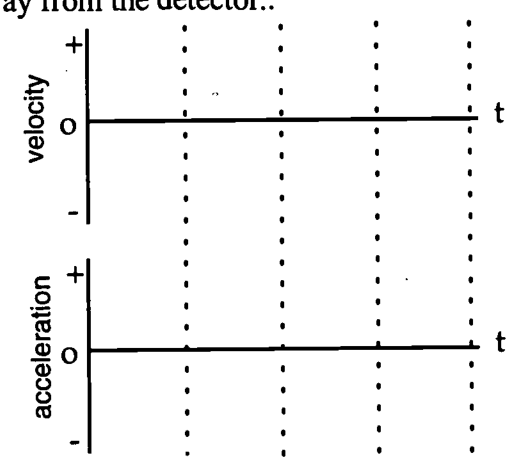
<u>Demonstration 5:</u> Sketch below the velocity-time and acceleration-time graphs of the cart moving <u>toward</u> the motion detector and <u>slowing down</u> at a steady rate.



<u>Demonstration 6:</u> Sketch below the velocity-time and acceleration-time graphs of the cart moving <u>toward</u> the motion detector and <u>speeding up</u> at a steady rate.



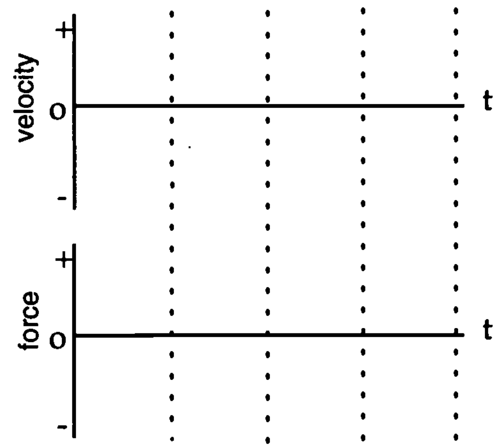
<u>Demonstration 7:</u> Sketch below the velocity-time and acceleration-time graphs for the cart (with a constant force away from the motion detector) which is given a short push toward the motion detector (and is released) Sketch the graph as the cart slows down moving toward the detector, comes to rest and then speeds up moving away from the detector..



Name____________________________

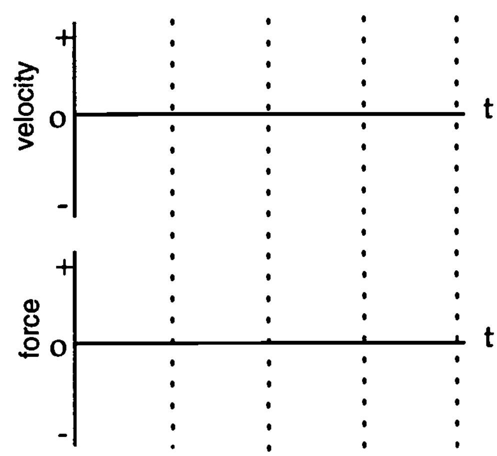
FORCE AND MOTION PREDICTION SHEET
FOR INTERACTIVE LECTURE DEMONSTRATIONS
(HAND THIS SHEET IN)

Demonstration 1: A cart with friction is pulled along the table away from the motion detector at a steady (constant) velocity. Sketch below your predictions of the velocity-time and force-time graphs for this motion.



Demonstration 2: The frictional force acting on the cart is reduced by adjusting the friction pad on the bottom. The cart is then pulled along the table at the same steady (constant) velocity. Sketch on the same axes above using dashed lines your predictions of the velocity-time and force-time graphs for this motion.

Demonstration 3: The frictional force acting on the cart is made very small (almost no friction). The cart is then pulled along the table at the same steady (constant) velocity. Sketch on the axes below your predictions of the velocity-time and force-time graphs for motion at a steady (constant) velocity *without friction.*



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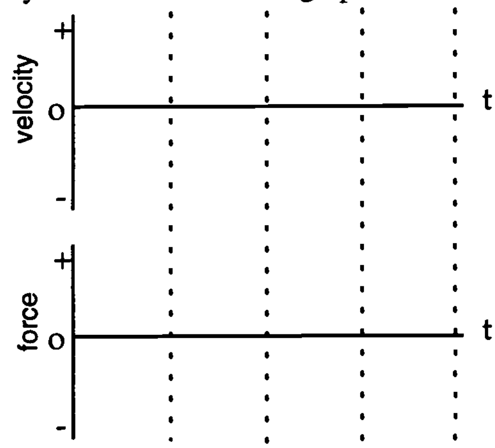
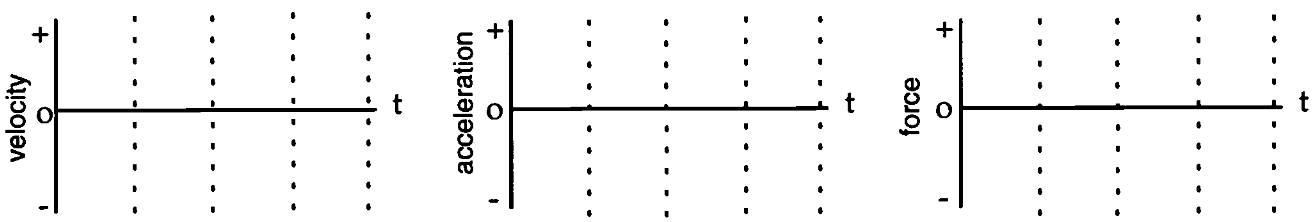
Name______________________________

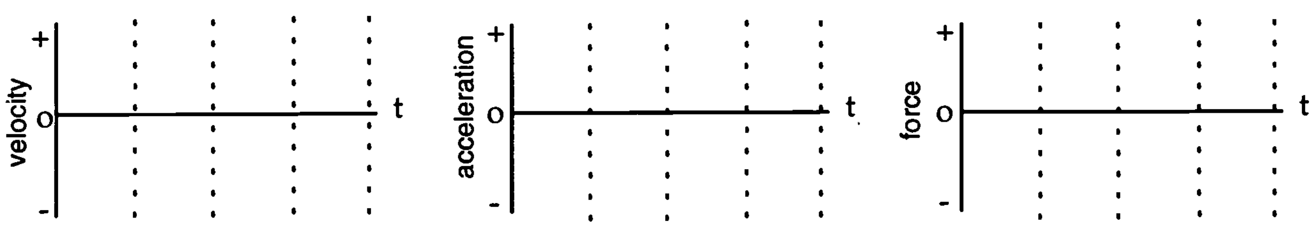
Demonstration 4: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push away from the motion detector and then released. Sketch on the axes below your predictions of the velocity-time and force-time graphs for the motion *after the cart is released.*



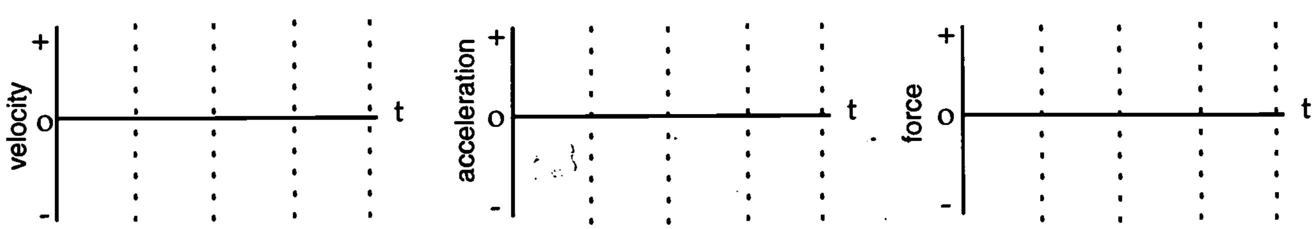
Demonstration 5: The frictional force acting on the cart remains very small (almost no friction). The cart is pulled so that it moves away from the motion detector speeding up at a steady rate (constant acceleration). Sketch on the axes below your predictions of the velocity-time, acceleration-time and force-time graphs for this motion.



Demonstration 6: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push toward the motion detector and released. A force pulls it in the direction away from the motion detector. It moves toward the motion detector slowing down at a steady rate (constant acceleration). Sketch on the axes below your predictions of the velocity-time, acceleration-time and force-time graphs for this motion *after the cart is released.*

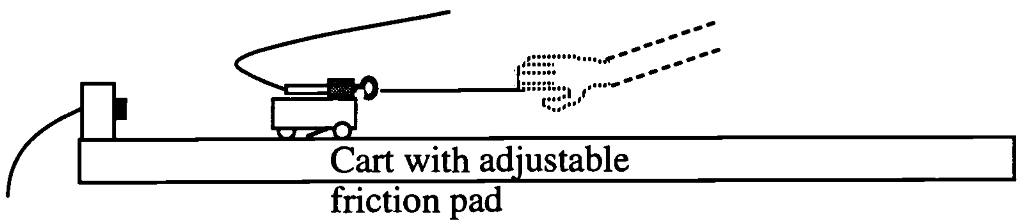


Demonstration 7: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push toward the motion detector and released It moves toward the motion detector slowing down at a steady rate (constant acceleration), comes to rest momentarily and then moves away from the motion detector speeding up at a steady rate. Sketch on the axes below your predictions of the velocity-time, acceleration-time and force-time graphs for this motion *after the cart is released.*

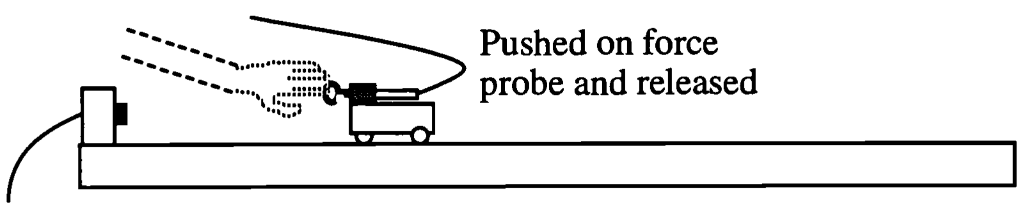


INTERACTIVE FORCE AND MOTION DEMONSTRATIONS

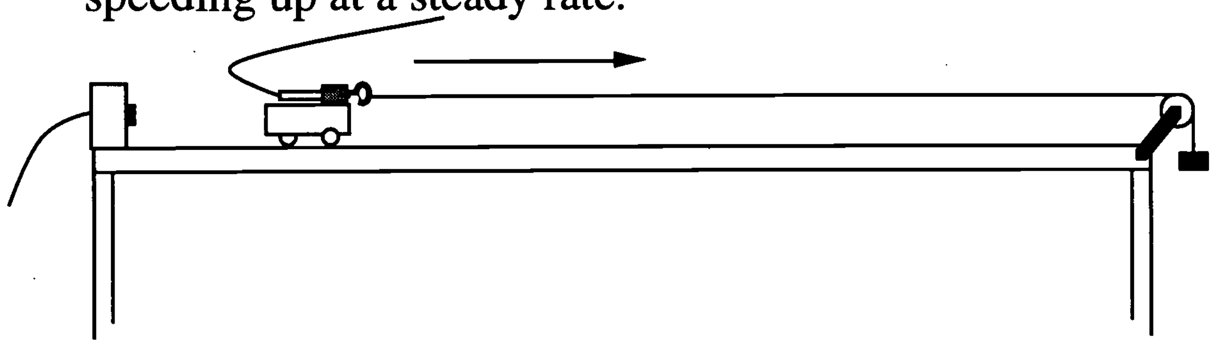
<u>Demonstrations # 1, 2, 3:</u> Cart pulled away from the motion detector at a constant velocity with smaller and smaller frictional force.



<u>Demonstrations # 4:</u> Cart with very small frictional force given a push away from the motion detector and released.



<u>Demonstration #5:</u> The cart (with very small friction) is pulled so that it moves away from the motion detector, speeding up at a steady rate.



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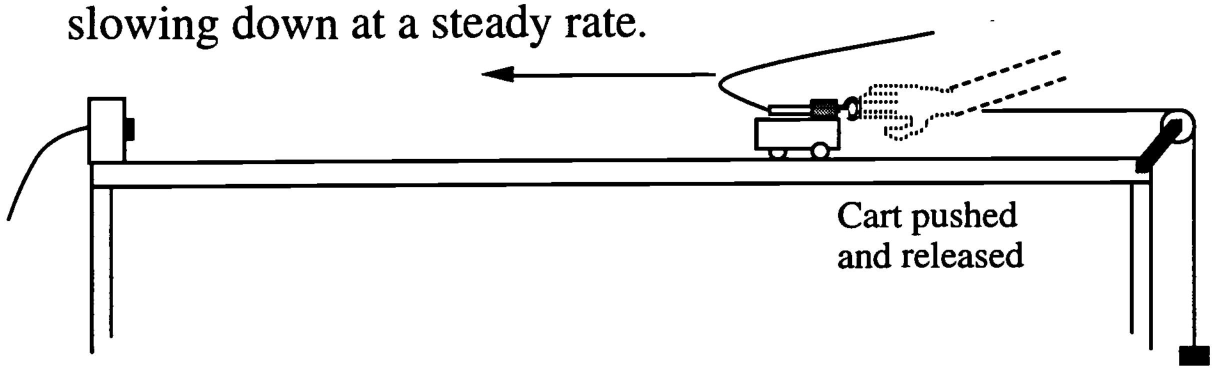
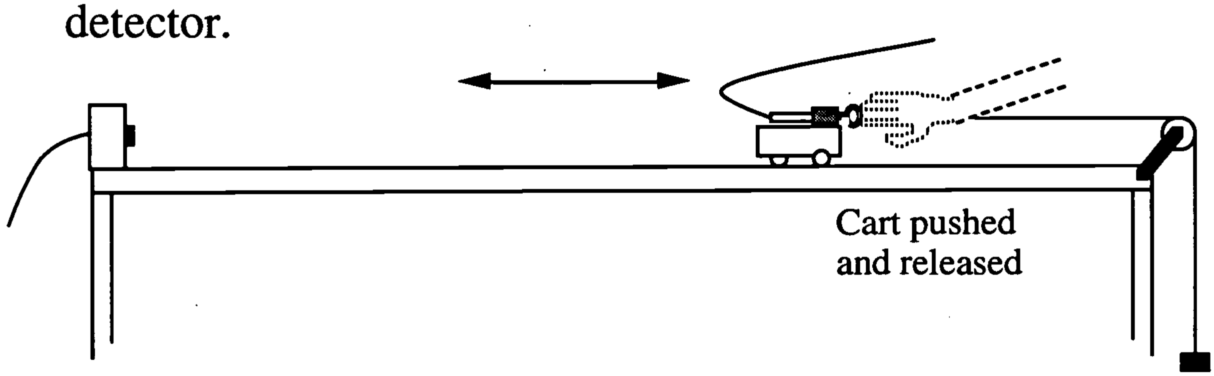
Demonstration #6: The cart (with very small friction) is given a push toward the motion detector and released. A force acts in the direction away from the motion detector. The cart moves toward the motion detector, slowing down at a steady rate.



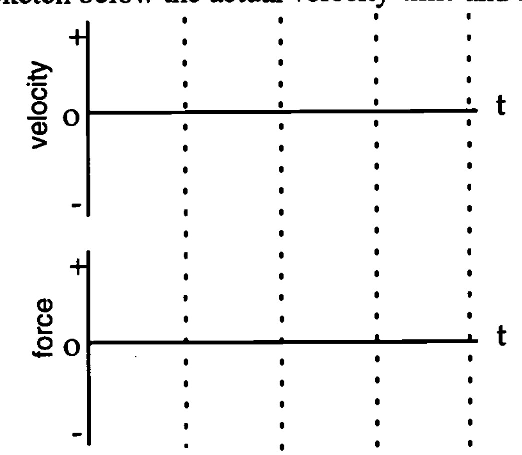
Demonstration #7: The cart (with very small friction) is given a push toward the motion detector and released. A force acts in the direction away from the motion detector. The cart moves toward the motion detector, slowing down at a steady rate, comes to rest momentarily and then moves away from the motion detector.



You may use this sheet to record actual results

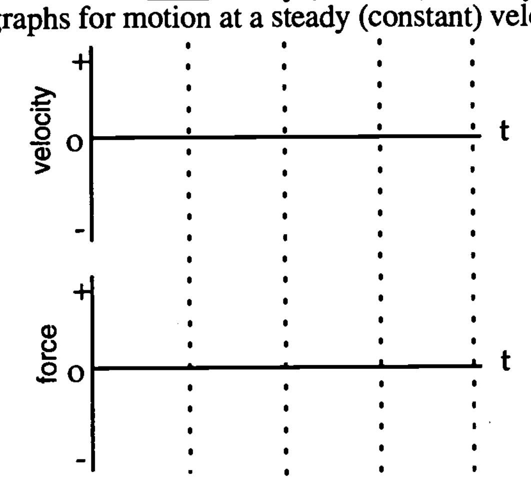
FORCE AND MOTION RESULTS SHEET
FOR INTERACTIVE LECTURE DEMONSTRATIONS
(SAVE THIS SHEET FOR YOUR OWN USE)

Demonstration 1: A cart with friction is pulled along the table away from the motion detector at a steady (constant) velocity. Sketch below the actual velocity-time and force-time graphs for this motion.

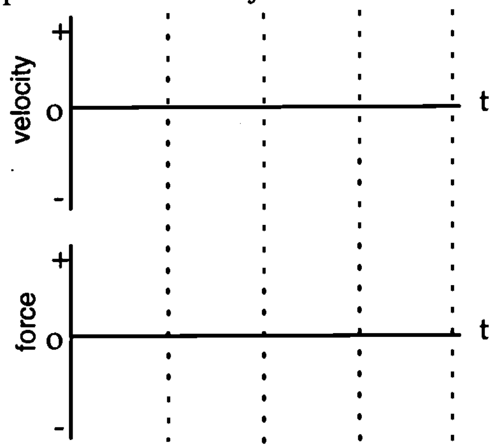


Demonstration 2: The frictional force acting on the cart is reduced by adjusting the friction pad on the bottom. The cart is then pulled along the table at the same steady (constant) velocity. Sketch on the same axes above using dashed lines the velocity-time and force-time graphs for this motion.

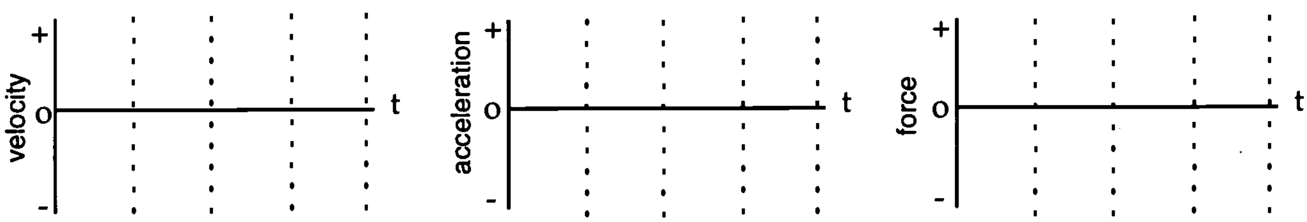
Demonstration 3: The frictional force acting on the cart is made very small (almost no friction). The cart is then pulled along the table at the same steady (constant) velocity. Sketch on the axes below the velocity-time and force-time graphs for motion at a steady (constant) velocity *without friction.*



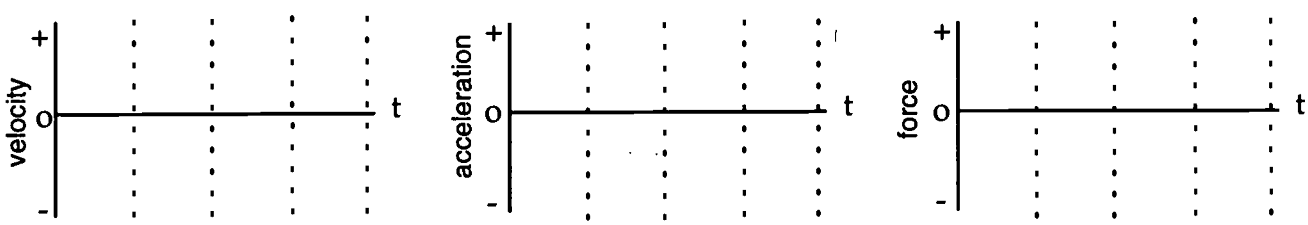
Demonstration 4: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push away from the motion detector and then released. Sketch on the axes below the velocity-time and force-time graphs for the motion *after the cart is released.*



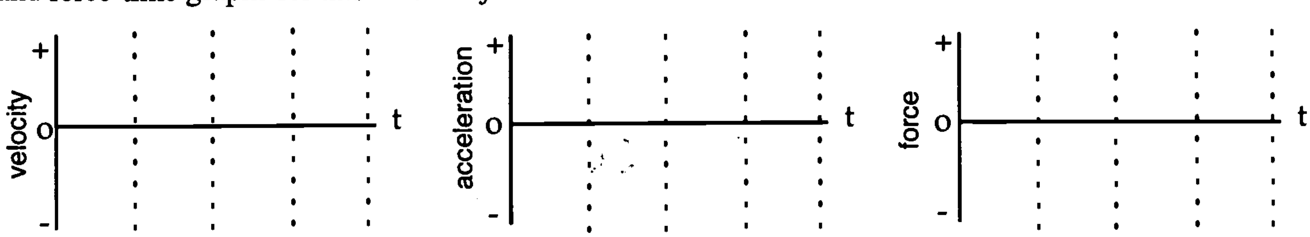
Demonstration 5: The frictional force acting on the cart remains very small (almost no friction). The cart is pulled so that it moves away from the motion detector speeding up at a steady rate (constant acceleration). Sketch on the axes below the velocity-time, acceleration-time and force-time graphs for this motion.



Demonstration 6: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push toward the motion detector and released. A force pulls it in the direction away from the motion detector. It moves toward the motion detector slowing down at a steady rate (constant acceleration). Sketch on the axes below the velocity-time, acceleration-time and force-time graphs for this motion *after the cart is released.*



Demonstration 7: The frictional force acting on the cart remains very small (almost no friction). The cart is given a push toward the motion detector and released It moves toward the motion detector slowing down at a steady rate (constant acceleration), comes to rest momentarily and then moves away from the motion detector speeding up at a steady rate. Sketch on the axes below the velocity-time, acceleration-time and force-time graphs for this motion *after the cart is released.*



APPENDIX IV

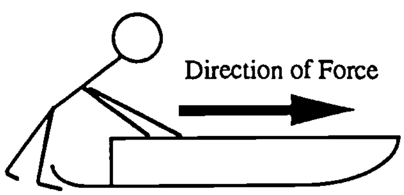
Directions: Answer questions 1-43 in spaces on the answer sheet by filling in the circle corresponding to the correct answer with a #2 or softer pencil.

Also fill in only the following information on your answer sheet:

1. Write in your last name, a space and then your first name in the **NAME** boxes and fill in the corresponding circles with your pencil. Do not fill in your student number.
2. Fill in the circle corresponding to **M** or **F** in the **SEX** space.

A sled on ice moves in the ways described in questions 1-7 below. Friction is so small that it can be ignored. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would keep the sled moving as described in each statement below.

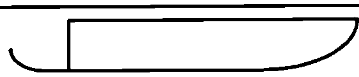
You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice J.



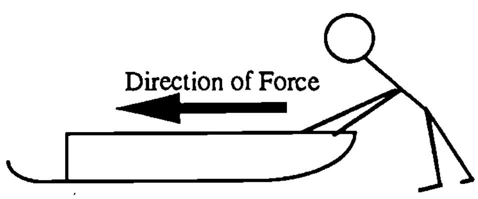
A. The force is toward the right and is increasing in strength (magnitude).

B. The force is toward the right and is of constant strength (magnitude).

C. The force is toward the right and is decreasing in strength (magnitude).



D. No applied force is needed



E. The force is toward the left and is decreasing in strength (magnitude).

F. The force is toward the left and is of constant strength (magnitude).

G. The force is toward the left and is increasing in strength (magnitude).

______1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?

______2. Which force would keep the sled the sled moving toward the right at a steady (constant) velocity?

______3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?

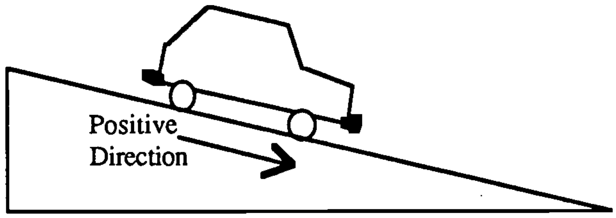
______4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?

______5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?

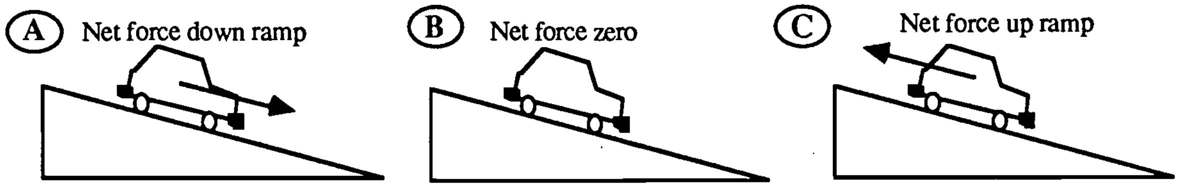
______6. The sled is slowing down at a steady rate and has an acceleration in the positve direction. (The positive direction is to the right.) Which force would account for this motion?

______7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

Questions 8-10 refer to a toy car which is given a push up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again.



Use one of the following choices (A through C) to indicate the net force acting on the car for each of the cases described below. Answer choice J if you think that none is correct.



______8. The car is moving up the ramp after it is released.
______9. The car is at its highest point.
______10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through C) to indicate the force acting on the coin for each of the cases described below. Answer choice J if you think that none is correct.

- **A.** The force is downward.
- **B.** The force is zero.
- **C** The force is upward.

______11. The coin is moving upward after it is released.
______12. The coin is at its highest point.
______13. The coin is moving downward.

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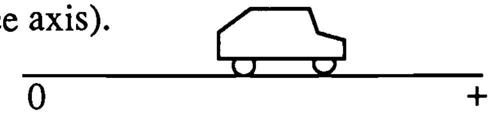
Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



<u>Assume that friction is so small that it can be ignored.</u>

A force is applied to the car. Choose the <u>one</u> force graph (**A** through **H**) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

__14. The car moves toward the right (away from the origin) with a steady (constant) velocity.

__15. The car is at rest.

__16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).

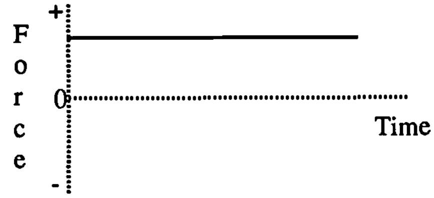
__17. The car moves toward the left (toward the origin) with a steady (constant) velocity.

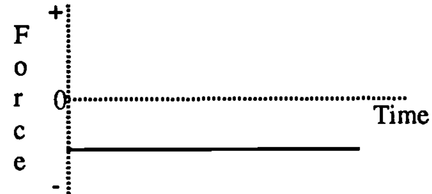
__18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).

__19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).

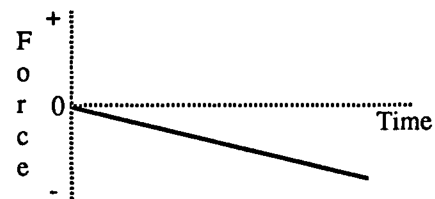
__20. The car moves toward the right, speeds up and then slows down.

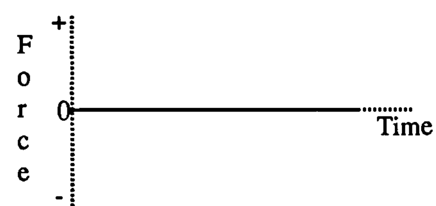
__21. The car was pushed toward the right and then released. Which graph describes the force <u>after</u> the car is released.

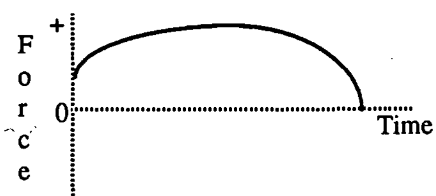
(A)


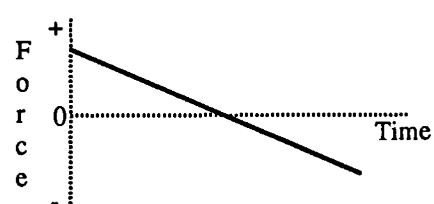
(B)


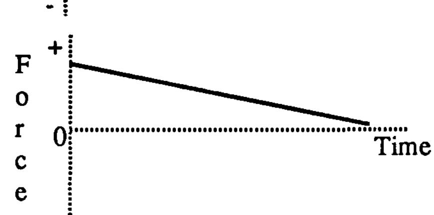
(C)


(D)


(E)


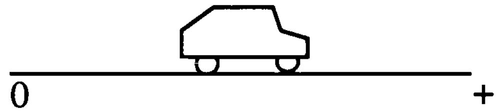
(F)


(G)


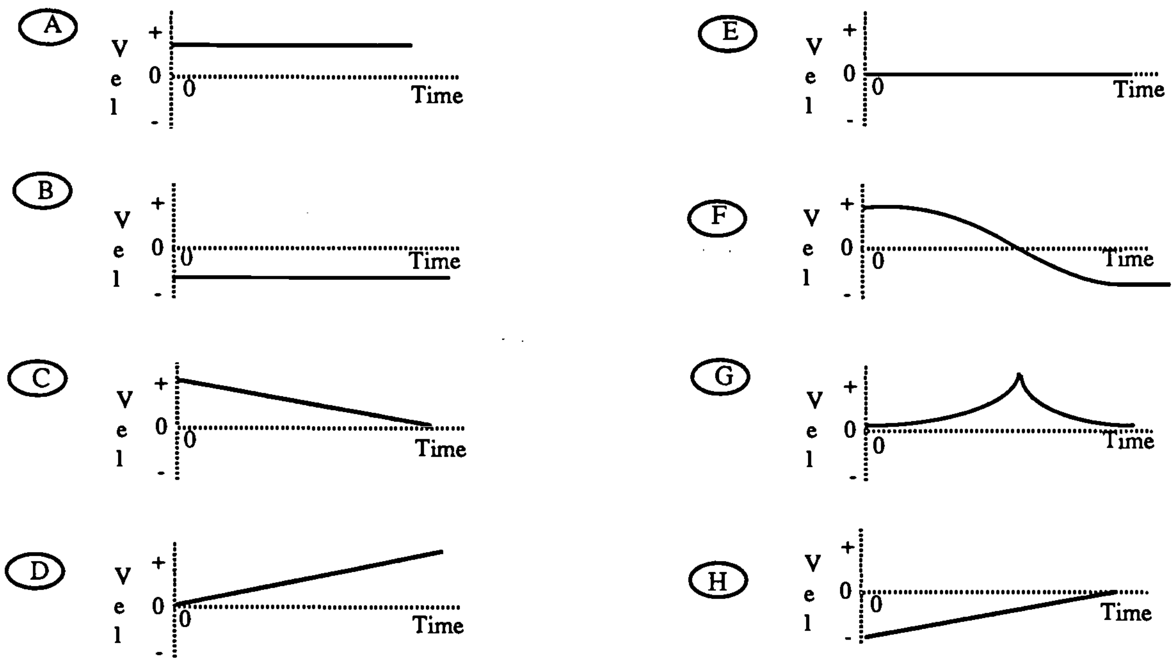
(H)


(J) None of these graphs is correct.

Questions 22-25 refer to a toy car which can move to the right or left along a horizontal line (the positive portion of the distance axis).



Choose the correct velocity-time graph (**A - G**) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer choice **J**.



(J) None of these graphs is correct.

___22. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?

___23. Which velocity graph shows the car reversing direction?

___24. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?

___25. Which velocity graph shows the car increasing its speed at a steady (constant) rate?

Questions 26-28 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **C**) to indicate the sign of the acceleration of the coin for each of the cases described below. Take **up** to be the **positive** direction. Answer choice **J** if you think that none is correct.

A. The acceleration is negative.

B. The acceleration is zero.

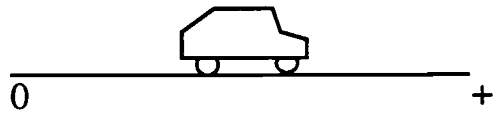
C. The acceleration is positive.

___26. The coin is moving upward after it is released.

___27. The coin is at its highest point.

___28. The coin is moving downward.

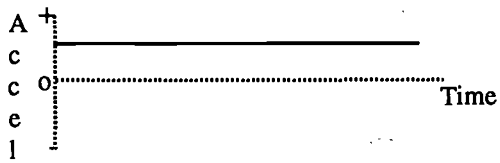
Questions 29-35 refer to a toy car which can move to the right or left along a horizontal line (the + distance axis.



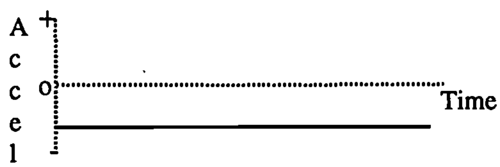
Different motions of the car are described below. Choose the letter (**A** to **G**) of the acceleration-time graph which could correspond to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

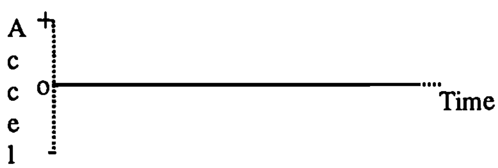
(A)



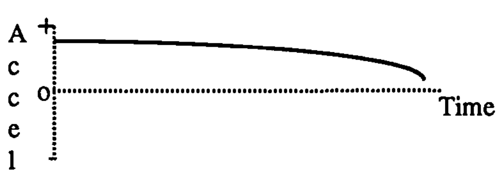
(B)



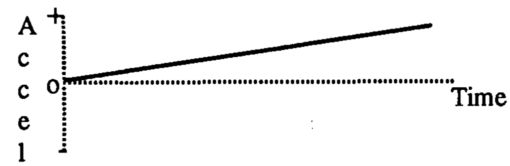
(C)



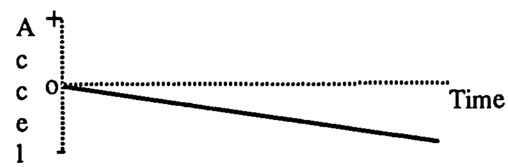
(D)



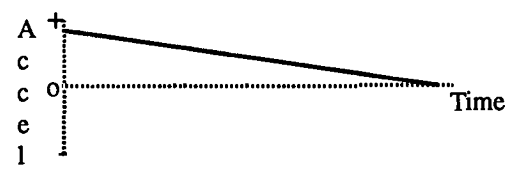
(E)



(F)



(G)



(J) None of these graphs is correct.

______29. The car moves toward the right (away from the origin), speeding up at a steady rate.
______30. The car moves toward the right, slowing down at a steady rate.
______31. The car moves toward the left (toward the origin) at a constant velocity.
______32. The car moves toward the left, speeding up at a steady rate.
______33. The car moves toward the right at a constant velocity.

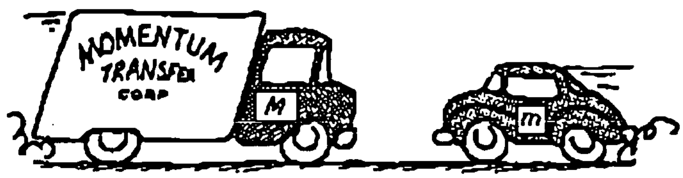
34. Describe your reasoning in reaching your answer to question 29. (Answer on the answer sheet and use as much space as you need)

35. Describe your reasoning in reaching your answer to question 33. (Answer on the answer sheet and use as much space as you need)

Questions 36-40 refer to collisions between a car and a truck. For each description of a collision (36-40) below, choose the one answer from the possibilities **A** though **J** that best describes the forces between the car and the truck.

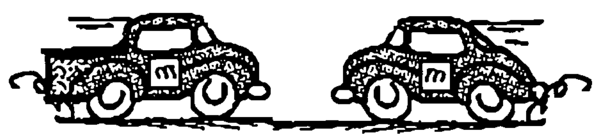
A. The truck exerts a greater amount of force on the car than the car exerts on the truck.
B. The car exerts a greater amount of force on the truck than the truck exerts on the car.
C. Neither exerts a force on the other; the car gets smashed simply because it is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't exert a force on the truck.
E. The truck exerts the same amount of force on the car as the car exerts on the truck.
F. Not enough information is given to pick one of the answers above.
J. None of the answers above describes the situation correctly.

In questions 36 through 38 the truck is much heavier than the car .



_____36. They are both moving at the same speed when they collide. Which choice describes the forces?
_____37. The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?
_____38. The heavier truck is standing still when the car hits it. Which choice describes the forces?

In questions 39 and 40 the truck is a small pickup and is the same weight as the car.



_____39. Both the truck and the car are moving at the same speed when they collide. Which choice describes the forces?
_____40. The truck is standing still when the car hits it. Which choice describes the forces?

Questions 41-43 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

Pick one of the choices **A** through **J** below which correctly describes the forces between the car and the truck for each of the descriptions (41-43).

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.
B. The force of the car pushing against the truck is less then that of the truck pushing back against the car.
C. The force of the car pushing against the truck is greater then that of the truck pushing back against the car.
D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.
E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.
J. None of these descriptions is correct.

_____41. The car is pushing on the truck, but not hard enough to make the truck move.
_____42. The car, still pushing the truck, is **speeding up** to get to cruising speed.
_____43. The car, still pushing the truck, is at cruising speed and continues to travel at the same speed.

_____44. A book is at rest on a table top. Which of the following acurrately descibe the significant force(s) which is (are) acting on the book?

A. Only a downward force due to gravity.

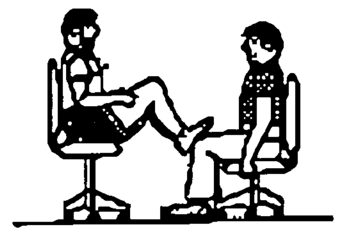
B. Only the upward force by the table.

C. Since the book is at rest, there are no forces acting on it.

D. An upward force by the table is equal to the downward force due to gravity

J. None of the above

_____45. Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,



A. Neither student exerts a force on the other.

B. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.

C. Each student exerts a force on the other, but Jim exerts the larger force.

D. Each student exerts a force on the other, but Bob exerts the larger force.

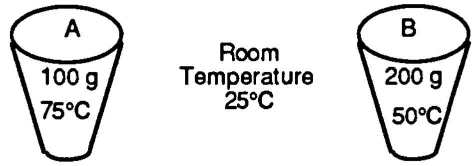
E. Each student exerts the same amount of force on the other.

J. None of these answers is correct.

QUESTIONS ON HEAT AND TEMPERATURE

Directions: Put your name on the answer sheet provided. Answer all questions on the answer sheet.

Questions 1 through 3 refer to two cups of water, A and B. The cups are placed in a room where the temperature is 25 °C.



_______1. Cup A contains 100 grams of water and cup B contains twice as much water. The water in both cups was initially at room temperature. Cup A was heated to 75°C and cup B was heated to 50°C. Which cup had more heat energy transferred to it?

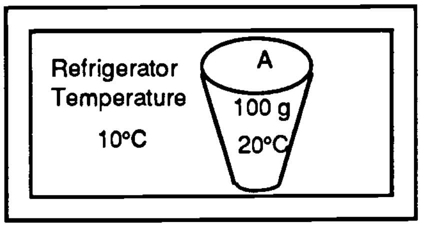
A) Cup A had more heat energy transferred
B) Cup B had more heat energy transferred
C) Both cups had the same amount of heat energy transferred
D) not enough information is given to determine the answer

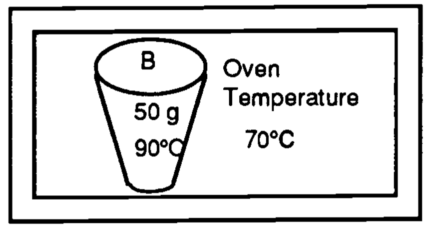
_______2. Cup A contains 100 grams of water and cup B contains 50 grams of water. The water in both cups was initially at room temperature. Cup A was then heated to 45°C and cup B was heated to 90°C. Which cup had more heat energy transferred to it?

A) Cup A had more heat energy transferred
B) Cup B had more heat energy transferred
C) Both cups had the same amount of heat energy transferred
D) not enough information is given to determine the answer

_______3. Cup A contains 100 grams of water and cup B contains 80 grams of water. The water in both cups was initially at room temperature. Cup A was then heated to 45°C and cup B was heated to 50°C. Which cup had more heat energy transferred to it?

A) Cup A had more heat energy transferred
B) Cup B had more heat energy transferred
C) Both cups had the same amount of heat energy transferred
D) not enough information is given to determine the answer

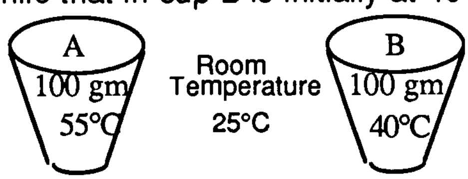




_______4. Cup A contains 100 grams of water and is initially at 10°C in a refrigerator. Cup A is heated until its temperature is 20°C. Cup B contains 50 grams of water initially at 70°C in an oven. Cup B is heated until its temperature is 90°C. Which cup had more heat energy transferred to it?

A) Cup A had more heat energy transferred
B) Cup B had more heat energy transferred
C) Both cups had the same amount of heat energy transferred
D) not enough information is given to determine the answer

Questions 5 -7 refer to two cups, A and B. Each cup contains the same amount of water (100 gms). The cups are placed in a room where the temperature is 25 °C. The water in cup A is initially at 55°C, while that in cup B is initially at 40°C.



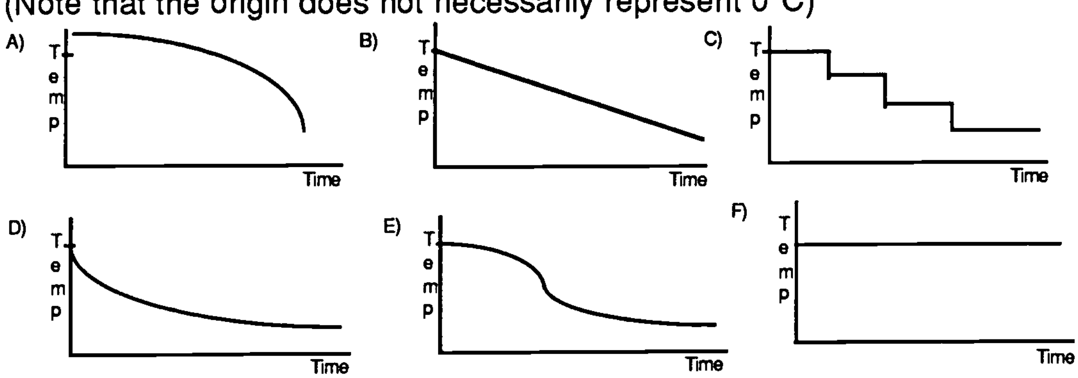
_______5. Initially, which cup will cool down at a faster rate?

A) A will cool faster **B)** B will cool faster **C)** they both will cool at the same rate
D) not enough information is given to determine the answer

_______6. Which cup will reach its final temperature most quickly?

A) Cup A **B)** Cup B **C)** Both take the same time
D) not enough information is given to determine the answer

_______7. Which of the following graphs best represents the shape of the graph of the temperature of cup A over time? Answer **H** if you think that none is correct. (Note that the origin does not necessarily represent 0°C)



_______8. Small coffee cup heaters are placed in cups A and B and heat is transferred to keep the cups at the temperatures shown. The cups contain the same amount of water. Which answer best describes the rate that heat must be transferred to maintain the temperatures shown?

Cup A will require heat at
- **A)** about five times the rate of B
- **B)** about twice the rate of B
- **C)** a slightly faster rate than B

Both cups will require heat at
- **D)** the same rate

Cup B will require heat at
- **E)** about five times the rate of A
- **F)** about twice the rate of A
- **G)** a slightly faster rate than A

H) None of the above answers is correct

_______9. Cup A in question 6 is placed outside where the temperature is 5°C. Compare the rate at which heat must be transferred to keep the water at 45°C outdoors to the rate required to keep the water at 45°C inside the room.

When the cup is outside, more heat must be transferred
- **A)** at about five times the rate as inside
- **B)** at about twice the rate as inside
- **C)** at a slightly faster rate than inside

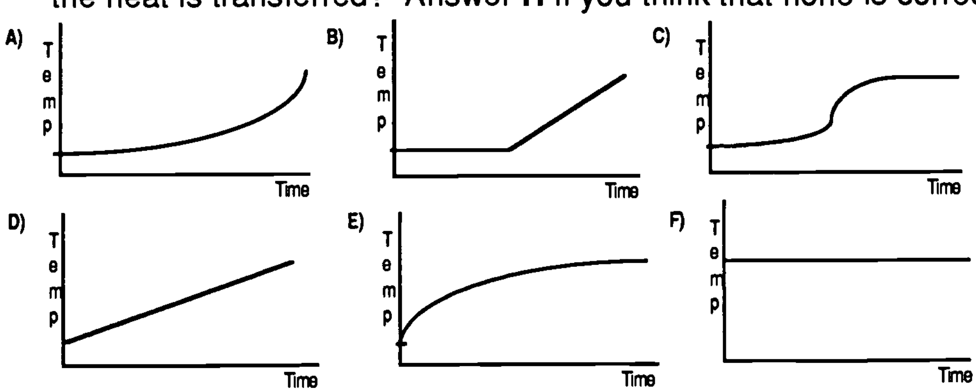
D) Heat must be transferred at the same rate outside and inside

When the cup is inside, more heat must be transferred
- **E)** at about five times the rate as outside
- **F)** at about twice the rate as outside
- **G)** at a slightly faster rate than outside

H) None of the above answers is correct

Questions 10 -13 refer to a cup which contains water at room temperature. The cup is **perfectly insulated** *so that no heat can transfer into or out* of the cup. A small coffee cup heater inside the cup is used to transfer heat to the water.

_______10. If heat is transferred to the cup at a steady rate, which of the graphs below best represents the shape of the graph of the temperature of the water over time as the heat is transferred? Answer **H** if you think that none is correct.



Each of the questions 11 -13 describes a change in the situation described in question 10 (a heater in water in a perfectly insulated cup). For each question, choose the answer that best describes the temperature rise due to the change described.

The temperature rise would be **A)** four times as large.
B) two times as large.
C) the same.
D) half as large.
E) one quarter as large.
H) None of the above answers is correct.

______11. There is the same amount of water and twice the amount of heat is transferred.

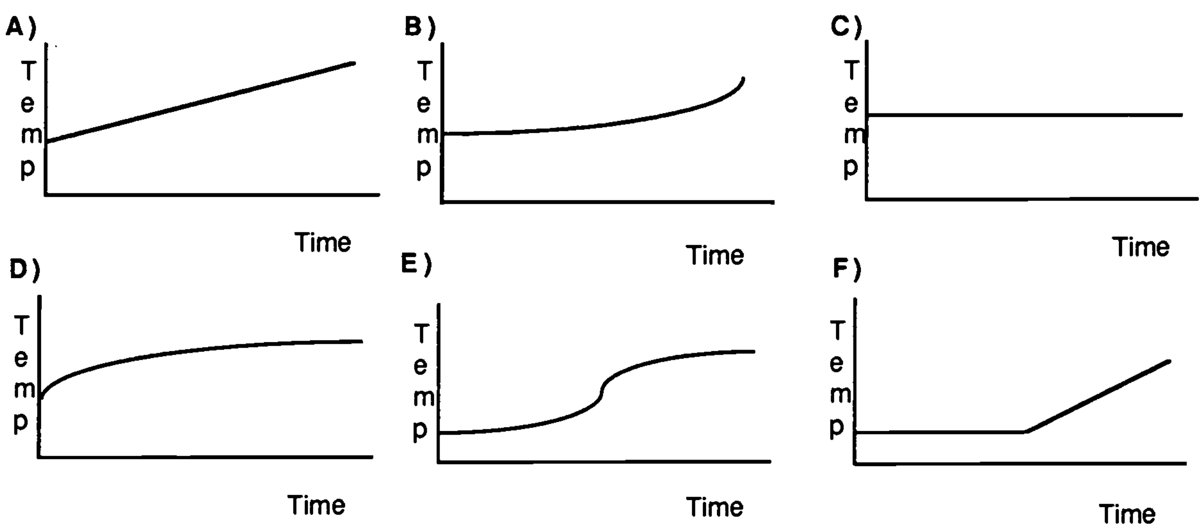
______12. There is half as much water and the same amount of heat is transferred.

______13. The water is replaced by an equal mass of a liquid with half the specific heat capacity of water. The same amount of heat is transferred.

Questions 14-17 refer to a cup which contains a mixture of 50 grams of ice and 50 grams of water at 0°C. The cup is **perfectly insulated** so that no heat can transfer in or out. Room temperature is 25°C.

A small coffee cup heater inside the cup allows heat to be transferred to the ice and water mixture. Heat is transferred at a steady rate and the mixture is stirred continuously so that the temperature is always uniform throughout the mixture. For each question below, choose the **shape** of the temperature-time graph that best corresponds to the temperature of the mixture during the time interval described.

If you think no graph is appropriate, write **H.** (You may choose a graph more than once. The origin of the graphs does not necessarily represent 0°C.)



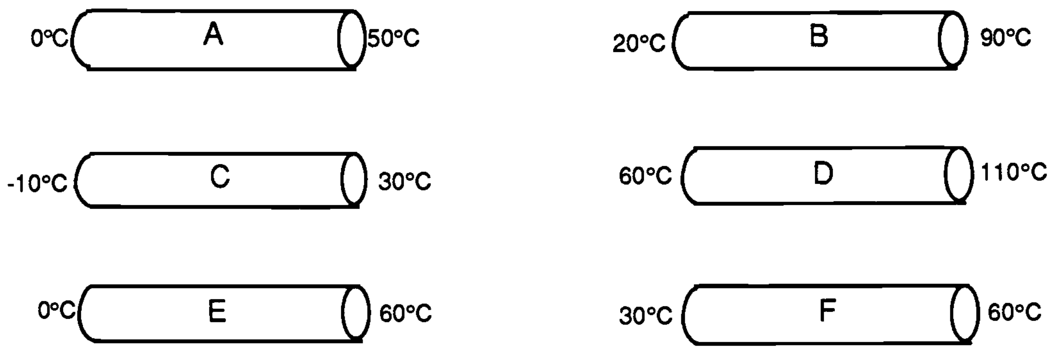
______14. The graph shows a time interval when the ice is melting but there is still some ice in the water.

______15. The graph shows a time interval when there is still some ice at the beginning of the time interval, but all the ice disappears before the end of the interval.

______16. There is only water (the ice is completely melted before the time interval begins), but no boiling occurs during the interval.

______17. The water is boiling during the entire time interval shown by the graph.

Questions 18 to 20 refer to the six identical rods below (All are made of the same metal and the rods have the same shape). The temperatures at each end of the rods are indicated. The sides of the rods are insulated so that no heat can flow in or out .



______18. Along which rod does heat flow at the slowest rate? Answer **G** if you think that heat flows at the same rate along all of the rods.

______19. Along which rod does heat flow at the fastest rate? Answer **G** if you think that heat flows at the same rate along all of the rods.

______20. Along which rod is the rate of heat flow the same as along rod A? Answer **G** if you think that heat flows at the same rate along all of the rods. Answer **H** if you think that no rod has the same rate of heat flow as A.

Questions 21-22 refer to a pan of water on a stove. The water is initially at room temperature (20°C). When the burner is turned on, it takes 3 minutes for the water to begin boiling.

______21. Which time in minutes is a possible time for the water to completely boil away?

A) 1
B) 3
C) 8
D) 22
E) 68
F) None of these is possible
G) Not enough information is given to answer the question

______22. On the same burner, the same pan now starts with more room temperature water. It takes 6 minutes for the water to begin boiling. How long will it take for the water to completely boil away compared to the water in question (21)?

A) Less time
B) About the same time
C) About twice as long
D) Much longer
E) None of these is correct
F) Not enough information is given to answer the question

_____23. Cup A contains 100 grams of water at 0°C and cup B contains 100 grams of water at 50°C. The contents of the two cups are mixed together in an insulated container (no heat can transfer in or out). The final temperature of the water in the container is

A) Lower than 0°C
B) 0°C
C) between 0°C and 25°C
D) 25°C
E) Between 25°C and 50°C
F) 50°C
G) Higher than 50°C

_____24. Cup A again contains 100 grams of water at 0°C but cup B now contains 200 grams of water at 50°C. The contents of the two cups are mixed together in an insulated container (no heat can transfer in or out). The final temperature of the water in the container is

A) Lower than 0°C
B) 0°C
C) between 0°C and 25°C
D) 25°C
E) Between 25°C and 50°C
F) 50°C
G) Higher than 50°C

_____25. Three objects are kept outside for a long time on a cold day: a piece of cotton, a piece of wood and a piece of metal. Which object feels the coldest when you touch it?

A) The cotton
B) The wood
C) The metal
D) They all feel the same

_____26. Which of the objects above would have the lowest temperature?

A) The cotton
B) The wood
C) The metal
D) They are all the same temperature

_____27. The objects in questions 25 and 26 are placed in an oven heated to 90°C and left for a long time. Which object will feel warmest when you touch it?

A) The cotton
B) The wood
C) The metal
D) They all feel the same

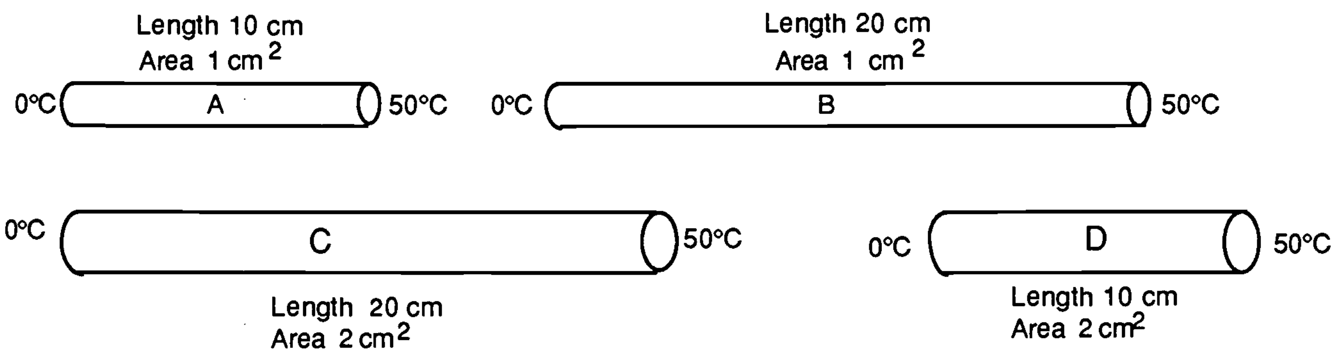
_____28 Which of the objects above would have the highest temperature?

A) The cotton
B) The wood
C) The metal
D) They all have the same temperature

_____29. There are three pots of boiling water on the stove. Which one has the lowest temperature?

A) The one that is boiling vigorously
B) The one that has been boiling for the longest time
C) The one that is just barely boiling
D) They all have the same temperature

Question 30 refers to the four rods made of the same metal which are shown below. Each rod has one end kept at 50°C and the other end kept at 0°C. The rods have the lengths and cross-sectional areas shown. The sides of the rods are insulated so that no heat can flow in or out of the sides .



______30. Along which rod does heat flow at the fastest rate? Answer **E** if you think that heat flows at the same rate along all of the rods.

APPENDIX V

TALKS AND COLLOQUIA GIVEN TO UNIVERSITY PROFESSORS

"Black Boxes and Automatic Data Collection: Exploring the Intelligent Use of Technology in the Teaching Laboratory," invited talk at Lab Focus '93 AAPT Conference, Boise State University, Boise, ID, Aug., 1993.R.K. Thornton

"RealTime Physics: Active Learning in the Introductory Laboratory," Lab Focus '93, August, 1993. D. Sokoloff.

Invited Talk, "Workshop Physics: Reflections on Six Years of Laboratory-Based Introductory Physics Teaching," Lab Focus '93 Meeting, Boise State University, Boise, ID, Aug. 5-7, 1993. P. Laws.

"Teaching About Dynamics: A New Approach to Understanding Newton's Laws," AAPT/PTRA, Boise, August, 1993. D. Sokoloff.

"Practical Aspects of Instituting Active Learning in a University Setting ," Invited lecture and workshop, Department of Physics, Dickinson College, June 11, 1993. D. Sokoloff.

"Active Physics Learning: Microcomputer-based Labs and Interactive Demonstrations," Conference on the Introductory Physics Course,on the occasion of the retirement of Robert Resnick, Rensselaer Polytechnic Institute, Troy, NY, May, 1993, R.K. Thornton.

"RealTime Physics: A New Interactive Introductory Laboratory Program," invited workshop at the Conference on the Introductory Physics Course, Rensselaer Polytechnic Institute, May 23, 1993. D. Sokoloff and R. Thornton.

Invited Talk, "Teaching Introductory Physics Without Lectures," Sloan Workshop, Cornell University, Ithaca, NY, May 8-9, 1993. P. Laws.

Invited Talk , "New Approaches to Undergraduate Teaching: Introductory Courses," Conference for Department Chairs, APS & AAPT, Washington, DC, May 1-2, 1993. P. Laws.

"Learning Physics Concepts Using New Technologies and New Approaches to Learning" invited talk for 52 physics professors at the New Waves in Teaching Physics for the Student of Tomorrow,City University of New York, NYC, April, 1993, R.K. Thornton.

Colloquium, "Alternatives to Lectures in Introductory Science Courses," University of Delaware, Newark, DE, April 28, 1993. P. Laws.

"RealTime Physics: A New Interactive Introductory Laboratory Program," invited talk at Pacific Northwest Association for College Physics meeting, April 16, 1993. D. Sokoloff.

"Microcomputer-based Labs and Interactive Demonstrations" invited talk at the Conference on Undergraduate Laboratories, Pacific Northwest Association for College Physics, Oregon City, Oregon, April, 1993 R.K. Thornton.

Colloquium, "Teaching Introductory Physics Without Lectures," Pennsylvania State University, State College, March 29-30, 1993. P. Laws.

Colloquium, West Virginia University Physics Department, Morgantown, March 4, 1993. P. Laws.

Invited Talk, "How Women View Activity-Based Physics Courses," Women and Minorities in Physics Conference, Southern California Area Modern Physics Institute (SCAMPI), California State Polytechnic University, Pomona, CA, Feb. 26-27, 1993. P. Laws.

Colloquium, "Teaching Introductory Physics Without Lectures," North Carolina State University, Feb. 22, 1993. P. Laws.

Colloquium, "Alternatives to Lectures in Introductory Science Courses," Rensselaer Polytechnic Institute, Troy, NY, Feb. 17, 1993. P. Laws.

"Active Learning in Introductory Physics" and "No More Lectures," invited exhibit and workshop at National Science Foundation Invitational Conference, "Beyond National Standards and Goals: Excellence in Mathematics and Science Education K-16," Washington, D.C., February 9-11, 1993. P. Laws, D. Sokoloff and R. Thornton.

Colloquium, "Teaching Introductory Physics Without Lectures," University of New Mexico, Albuquerque, Jan. 29, 1993. P. Laws.

Colloquium, "Teaching Introductory Physics Without Lectures," University of Utah, Salt Lake City, Jan. 28, 1993. P. Laws.

Full-day workshop, "RealTime Physics: A New Introductory Laboratory Program," American Association of Physics Teachers, August 8, 1993 (Boise) and January 3, 1993 (New Orleans). P. Laws, D. Sokoloff, and R. Thornton.

"Does Physics Instruction Put Female Students at a Disadvantage? Research Data on Gender Differences in Traditional & Non-traditional Settings"and "Combining Real-Time Data Collection with Analysis and Modeling", invited talks at the national meeting of the American Association for Physics Teachers (AAPT), New Orleans, January, 1993. R.K. Thornton

"Computer-Based Video Analysis of Physical Phenomena," American Association of Physics Teachers, New Orleans, LA, Jan. 5, 1993. P. Laws.

"RealTime Mechanics: Using MBL Tools in a New Mechanics Laboratory Sequence," American Association of Physics Teachers Winter Meeting, New Orleans, January 4, 1993, AAPT Announcer **22**, 38 (1992). D. Sokoloff.

"Workshop Physics: Using New Computer Tools for Video Analysis of 2D Motion and Modeling," American Association of Physics Teachers, New Orleans, LA, Jan. 4, 1993. P. Laws.

"Workshop Physics: Learning Through Inquiry," Association of American Colleges, Jan. 13-16, 1993. P. Laws.

"Engaging Students with Microcomputer-Based Laboratories and Interactive Lecture Demonstrations," Instructional Innovations panel, National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Science and Mathematics Teachers, November 4-6, 1992. (To be published in proceedings.) D. Sokoloff.

Invited Talk, "The Science of Teaching Physics," University of Florida, Oct. 14, 1992. P. Laws.

Invited Talk, "Teaching Science Without Lecturing," James Madison University, Sept. 23, 1992. P. Laws.

"Using Microcomputer-Based Laboratories to Enhance Student Understanding of Relative Motion and Reference Frames," invited talk at the national meeting of the American Association for Physics Teachers (AAPT), Orono, Maine, August, 1992. R.K. Thornton

"Changing the Physics Teaching Laboratory", opening address Europhysics Conference, Univ. of Ljubljana, Slovenia, July, 1992 R.K. Thornton

"Mastering Physics Concepts Using Microcomputer-Based Laboratories," and "Teaching Physics as a Workshop Course--Using Pedagogy, Apparatus and Computer Tools," Invited American Association of Physics Teachers full-day workshops at AAPT Summer Meeting, Orono, Maine, August 10-15, 1992, AAPT Summer Meeting, Vancouver, B.C., June 23-29, 1991, AAPT Winter Meeting, San Antonio, January 19-24, 1991, AAPT Summer Meeting, Minneapolis, June 25-30, 1990, and AAPT Winter Meeting, Atlanta, January 20 - 26, 1990. P. Laws, D. Sokoloff, and R. Thornton.

Colloquium on Workshop Physics Program, University of Oregon, June 4, 1992. P. Laws.

"Improving Physics Courses for Engineers," invited talk at the national meeting of the ASEE, Toledo, OH June 1992.R.K. Thornton

Workshop for Italian University and Secondary Physics Professors and Pre-service teachers, University of Rome, Italy, April, 1992, R. Thornton.

Invited Talk on Workshop Physics Program, Buffalo State College, Buffalo, NY, April 4, 1992. P. Laws.

Speaker through the American Institute of Physics Visiting Scientist Program, South Dakota State University, Brookings, SD, March 28, 1992. P. Laws.

Invited Talk, "Teaching Introductory Sciences Without Lectures," Michigan State University, East Lansing, MI, March 27, 1992. P. Laws.

Speaker through the American Institute of Physics Visiting Scientist Program, Moorhead State University, Moorhead, MN, March 25-26, 1992. P. Laws.

Invited Talk on Workshop Physics Program, University of North Carolina, Greensboro, NC, March 22-24, 1992. P. Laws.

Invited Talk, Texas Section of the American Association of Physics Teachers, Southwest Texas University, March 5-7, 1992. P. Laws.

Speaker through the American Institute of Physics Visiting Scientist Program, Frostburg State University, Frostburg, MD, March 2-3, 1992. P. Laws.

Invited Talk on Workshop Physics Program, University of North Carolina, Greensboro, NC, March 22-24, 1992. P. Laws.

Invited Talk, Texas Section of the American Association of Physics Teachers, Southwest Texas University, San Marcos, TX, March 5-7, 1992. P. Laws.

Speaker through the American Institute of Physics Visiting Scientist Program, Frostburg State University, Frostburg, MD, March 2-3, 1992. P. Laws.

Invited Talk, "Teaching Introductory Sciences Without Lectures," Michigan State University, East Lansing, MI, March 27, 1992. P. Laws.

Invited Talk with Ronald K. Thornton, "Real Experience, Numerical Integration, and Computer Simulations," at the Annual Meeting of the Association for the Advancement of Science, Chicago, IL, Feb. 10, 1992.

Invited lecture, "Teaching Introductory Science Without Lectures," Shippensburg University, Shippensburg, PA, Feb. 26, 1992. P. Laws.

Colloquium, "Teaching Introductory Physics Without Lectures," Drexel University, Philadelphia, PA, Jan. 30, 1992. P. Laws.

"Using Classroom Research to Develop New Approaches and New Technologies for Learning Physics Concepts", invited talk at the national meeting of the American Association for Physics Teachers (AAPT), Orlando, Fl, January, 1992. R.K. Thornton

Colloquium, "Teaching Introductory Physics Without Lectures," Drexel University, Philadelphia, PA, Jan. 30, 1992.

"Reform of Physics Education in the University and Secondary Schools" invited seminars in the phyiscs departments at the Universities of Roma, Pavia, Bologna, Padova, and Napoli in Italy, April, May 1992. R.K. Thornton

Physics Colloquium, "Active Learning of Physics Concepts Using Microcomputer-Based Tools," Ohio State University, April 20, 1992. D. Sokoloff.

"Using Large-Scale Classroom Research to Study Student Conceptual Learning in Mechanics and to Develop New Approaches to Learning," opening talk, NATO Advanced Study Conference on Science Education, Amsterdam, November, 1992. R.K. Thornton

Invited Talk, "The Science of Teaching Physics," University of Florida, Gainesville, FL, Oct. 14, 1992. P. Laws.

Invited Talk, "Teaching Science Without Lecturing," James Madison University, Harrisonburg, VA, Sept. 23, 1992. P. Laws.

"Integrating Computer Simulations with Real Experiments," American Association of Physics Teachers, Orono, ME, Aug. 14, 1992. P. Laws.

"Using Microcomputer-based Laboratories to Enhance Student Understanding of Relative Motion and Reference Frames", invited talk at the International GIRIP conference "Teaching about Reference Frames: From Copernicus to Einstein," Nicolaus Copernicus Unversity, Torun, Poland, August 1991. R.K. Thornton

Colloquium on Workshop Physics Program, University of Oregon, Portland, OR, June 4, 1992."Workshop Physics--Learning from Doing Real Physics,"

invited presentation as part of the panel "Physics--The Development of a Lean, Lively, Lab-Rich Curriculum," at the Project Kaleidoscope National Colloquium, Washington, DC, February 4-5, 1991. D. Sokoloff.

"Investigacion Cognoscitiva y Educatcion en Fisica," Two week short course for 25 South and Middle American physics professors on student learning and physics education research. Sponsored by UNESCO at the Advanced Study Institute (IDEA), Caracas, Venezuela, November, 1991, R.K. Thornton

Physics Colloquium, "Workshop Physics: Replacing Lectures in Introductory Courses With Real Experience," Lowell University, Lowell, MA, April 18, 1991. Laws and Thornton

Invited Talk, "Workshop Physics: Learning Introductory Physics Without Lectures," University of Washington, Seattle, WA, April 1, 1991.

"Teaching Fundamental Physics concepts Using New Technologies and New Approaches to Learning", invited talk at the National Meeting of the American Physical Society, Washington, DC, April, 1991. R.K. Thornton

Physics Colloquium on Workshop Physics Program, Wayne State University, Detroit, MI, March 21, 1991.

Colloquium Speaker on Workshop Physics Program, Department of Physics, Millersville University, Lancaster, PA, March 6, 1991.

Plenary Address Speaker on Workshop Physics Program at the National Colloquium sponsored by the NSF-Funded Project Kaleidoscope on *What Works: Strengthening Undergraduate Science and Mathematics* held at the National Academy of Sciences, Washington, DC, Feb. 4, 1991.

"Active Learning of Science Concepts Using Educational Technology" invited presentation at faculty seminar "Assessing the Impact of Technology on Learning," Harvard University, Cambridge, MA February, 1991 R.K. Thornton

"Using Microcomputer-Based Laboratory Materials in a Comprehensive Learning Environment," Invited Session of the Comprehensive Unified Learning Environment at the Winter Meeting of the American Association of Physics Teachers, San Antonio, TX, Jan. 22, 1991.

"Learning Introductory Science by Doing It: Replacing Lectures with Macintosh Tools," Macademia Conference at the University of California at Berkeley, Sept. 21, 1990.

"Active Learning of Physics Concepts," invited talk NATO Advanced Study Workshop "Physics and Learning Environments" Lyon, France, July, 1990. R.K. Thornton

"Workshop Physics: Teaching the Introductory Course without Lectures," Physics Colloquium at Michigan State University, East Lansing, MI, Feb. 20, 1990.

Physics Colloquium on Workshop Physics, Arizona State University (Oct. 1989).

"Learning Physical Concepts with Real-Time Laboratory Measurement Tools," invited talk physics department University of Rome, Italy, October 1989 R.K. Thornton

"Using Microcomputer-based Laboratory Tools to Enhance Experiential Learning of Physics Concepts," NATO Advanced Study Workshop "Student Development of Physics Concepts: The Role of Educational Technology," University of Pavia, Italy, October, 1989 R.K. Thornton

"Active Learning of Physics Concepts Using MBL," plenary talk at international conference "Microcomputers in Physics Education," Cukurova University, Adana, Turkey, September 1989 R.K. Thornton

ADDITIONAL GRANTS FOR CONTINUATION OF INTERACTIVE PHYSICS

Institutions Involved	Source of Support	Act Type	Grant #	Project Title	Description of the Project
TU & DC	NSF	C	USE 9150589	Student Oriented Science (SOS)	This project aims to improve introductory science courses by 1) developing MBL tools for use in a number of disciplines; and 2) developing, supporting, disseminating and evaluating interactive introductory physics curricular materials. Special attention is being paid to adaptation of these materials for use at large universities. The project will involve the testing of MBL tools and curricular materials at a number of other institutions. Evaluation of materials will include a study of student attitudes toward science, level of scientific literacy, and conceptual learning gains.
DC & TU	NSF	W/D	DUE 9255402 USE 9054224	Summer Seminar on tTeaching Intro Physics with Interactive Methods and Computers	This project helps introductory physics teachers develop instructional, computing, and laboratory interfacing skills needed to help students leam physics by using computers in the exploration of real world phenomena. Thirty teachers attend a two-week seminar offered in June of '91, '92, '93, and '94.
DC	NSF	W/D	DUE 9054224-01	Supplemental Grant	This supplemental grant provides funds to help teachers who have attended a two-week seminar during the summer of '91 or '92 acquire equipment, software, or travel funds to help with the implementation of new interactive teaching methods enhanced by the use of computer tools. Funding for travel allows teachers to visit institutions that are actively using the techniques and tools being promoted in the program.
DC, TU, UO	NSF	C	USE 9153725	Workshop Physics Lab. Leadership (Real Time Physics)	This project involves the development of introductory physics laboratory materials centered around the use of MBL tools. The lab activities will be adapted from curricular materials developed and classroom tested from the WP and TFST projects. Student activity guides will be created for three sets of topics: Mechanics, Thermodynamics, and Circuits. The laboratory sequences that have been developed are being called Real Time Physics Laboratories.
DC	NSF	E	USE 9251262	Inst. & Lab. Improvement	This grant allows the Dickinson Dept. of Physics & Astronomy to replace the Macintosh SE computers in two introductory physics laboratories with Macintosh IIsi computers and color monitors. This also included funding for new laser printers, a new file server, and current spreadsheet, word-processing, and other software appropriate for use with the Workshop Physics program.

KEY

C	Curriculum Development
W/D	Workshops/Dissemination
E	Equipment Grant
DC	Dickinson College
TU	Tufts University
UO	University of Oregon

ADDITIONAL GRANTS FOR CONTINUATION OF INTERACTIVE PHYSICS

Institutions Involved	Source of Support	Act Type	Grant #	Project Title	Description of the Project
TU, DC	Dept. of Ed.	W/D C	R215D-30295	High School Workshops	In this project six MBL science units will be developed for use in a series of teacher workshops intended to help high school teachers improve teaching not only in their own classrooms but develop the capabilities to train fellow teachers in their own regions. Three sites will be established for teacher training including Dickinson College, The University of Oregon, and Tufts University. The workshops will extend over a three-year period at each of the sites. Funds have been allocated to do follow up consultation with teachers who attend workshops.
TU	NSF	R C	USE 9251262	Foundations for Computer-based Physics Instruction	Research, curriculum and tool development grant in cooperation with David Hestenes of Arizona State U. that is studying and experimenting with learning environments and computer tools which allow students to learn the fundamental basis of physics, modeling.

NOTICE

REPRODUCTION BASIS