Enhancing Learning in Lab and Lecture with *RealTime Physics Labs (RTP)* and *Interactive Lecture Demonstrations (ILDs)* Using Computer-Based Data Acquisition Tools, Personal Response Systems (Clickers) and Interactive Video Analysis

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Abstract

The results of physics education research and the availability of microcomputer-based tools have led to the development over a number of years of the activity-based *Physics Suite*. Most of the *Suite* materials are designed for hands-on learning, for example student-oriented laboratory curricula like *RealTime Physics (RTP)*. One reason for the success of these materials is that they encourage students to take an active role in their learning. More recently, video analysis and personal response systems (clickers) have become available at many schools and universities around the world, and are used by many educators. This paper describes *RealTime Physics* and also materials designed to promote active learning in lecture – *Interactive Lecture Demonstrations (ILDs)* – some of which have been adapted for implementation with clickers or make use of video analysis. Results of studies on the effectiveness of this approach will also be presented.

Introduction

There is considerable evidence that traditional approaches are ineffective in teaching physics concepts [see 1, 2]. A major focus of the work at the University of Oregon and at the Center for Science and Mathematics Teaching (CSMT) at Tufts University has been on the development of active, discovery-based curricula like *RealTime Physics* labs [2, 3, 4] and *Interactive Lecture Demonstrations* [5, 6]. Among the characteristics of these curricula are:

- Use of a learning cycle in which students are challenged to compare predictions – discussed with their peers in small groups – to observations of real experiments.
- Construction of students' knowledge from their own hands-on observations. Rather than the instructor and textbook being the authorities, real observations of the physical world are the authority of knowledge. The instructor's role is as a guide through the learning process.

- Confronting students with the differences between their observations and their beliefs.
- Observation of results from real experiments in understandable ways – often in real time with the support of microcomputer-based tools.
- Encouragement of collaboration and shared learning with peers.
- Laboratory work often used to learn basic concepts.

With the use of the learning cycle and the microcomputer-based tools it has been possible to bring about significant changes in the lecture and laboratory learning environments at a large number of universities, colleges and high schools without changing the lecture/laboratory structure of the introductory physics course. *RealTime Physics* and *Interactive Lecture Demonstrations* are described below.

RealTime Physics: Active Learning Laboratories (RTP)

RealTime Physics is a series of lab modules for the introductory physics course that often use microcomputer-based laboratory tools to help students develop important physics concepts while acquiring vital laboratory skills. Besides data acquisition, computers are used for basic mathematical modeling, data analysis, video analysis and some simulations. *RTP* labs use the learning cycle of prediction, observation and comparison. They have been demonstrated to enhance student learning of physics concepts [1, 2, 4]. There are four *RTP* modules, *Module 1: Mechanics*, *Module 2: Heat and Thermodynamics*, *Module 3: Electricity and Magnetism* and *Module 4: Light and Optics* [3]. Each lab includes a pre-lab preparation sheet to help students prepare, and a homework, designed to reinforce critical concepts and skills. A complete teachers' guide is available online for each module.

Here are some examples of *RealTime Physics* lab activities [3].

(1) Mechanics

Students learn kinematics concepts (the relationships between position, velocity and acceleration) in the first two labs of *Module 1*, Introduction to Motion and Changing Motion. They are introduced to the use of a microcomputer-based motion sensor to explore first the motions of their own bodies walking, and then the motions of a low-friction cart powered by a battery-operated fan. One of the later activities asks them to predict and then observe the velocity-time and acceleration-time graphs when the cart—with the fan blowing in the direction away from the motion sensor – is given a push away from the motion sensor. Figure 1 (a) shows the apparatus, and Figure 1 (b) shows the resulting graphs. Many students predict a v-shaped velocity-time graph, and few predict a constant, negative acceleration, with many believing that the acceleration must be zero at the instant the cart reverses direction. Later, in Lab 6, students observe that the shapes of these graphs are identical to those for the analogous motion of a ball tossed into the air.

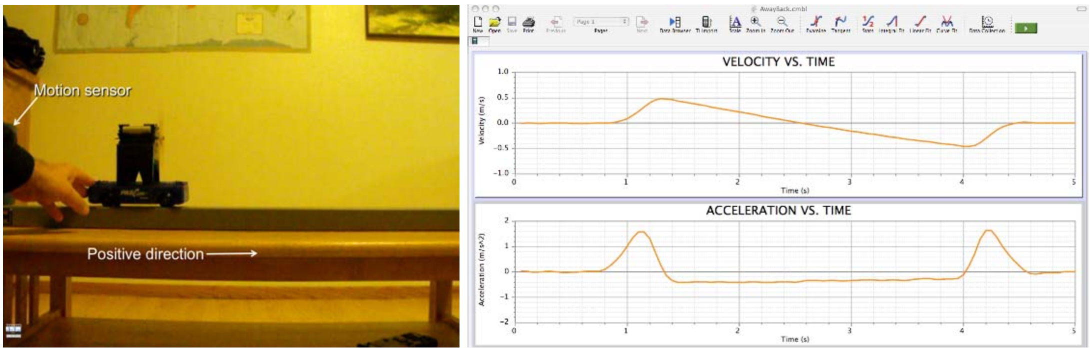


Figure 1. (a) Apparatus for examining the velocity and acceleration of a low-friction cart with a battery-operated fan unit mounted on it, as in *RealTime Physics, Module 1: Mechanics*, Lab 2. (b) The resulting velocity-time and acceleration-time graphs for the motion collected by a motion sensor and displayed in LoggerPro [10].

As another example from *Module 1*, in Lab 9, students explore Newton's Third Law by predicting and measuring the forces between objects colliding with each other. This is done using microcomputer-based force sensors mounted on low-friction carts. In one activity, a massive cart collides with a less massive one that is at rest before the collision. Figure 2 (a) shows the apparatus, and Figure 2 (b) shows the results. Most students predict that the force exerted by cart A on cart B will be larger than the force exerted by cart B on cart A, and are very surprised by the clearly-displayed result.

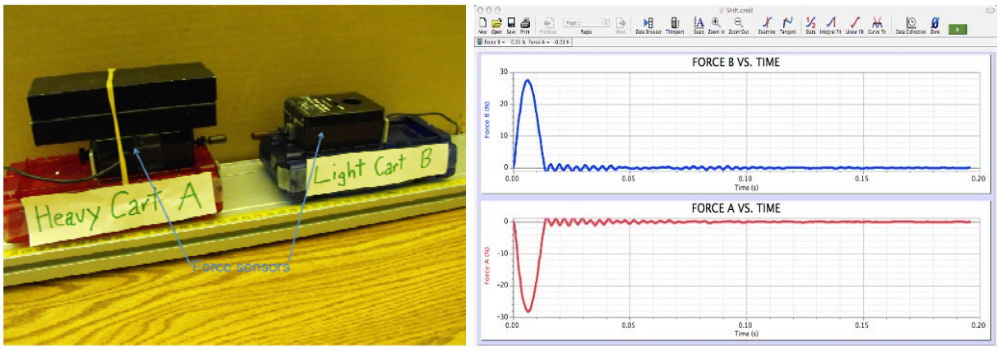


Figure 2. (a) Apparatus for examining the forces between more massive and less massive low-friction carts with the less massive cart initially at rest, as in *RealTime Physics, Module 1: Mechanics*, Lab 9. (b) The resulting force-time graphs during the collision, collected by force sensors and displayed in LoggerPro [10].

(2) Optics

In *Module 4*, Lab 3, Image Formation with Lenses, students explore the function of a lens in forming an image. Research [7] has shown that students don't have a good grasp of what a lens does. This is apparently caused by a failure to realize that each point on an object is a source of an infinite number of rays. For a real image formed by a perfect lens, all of these rays that are incident on the lens (also an infinite number) are focused to a corresponding point on the image. (While drawing ray diagrams with 2-3 special rays is an excellent way to locate the image graphically, the procedure might lead students to think in terms of only 2-3 rays rather than an infinite number!)

In Activity 1-1, students explore this situation using two miniature light bulbs (point sources of light) and a small cylindrical lens. Figure 3 (a) shows the apparatus, and Figure 3 (b) shows the formation of the image. The students are then asked to predict and observe what happens when various changes are made. Figure 4 (a) shows what happens when half the lens is covered with a card, while Figure 4 (b) shows the result when one of the bulbs (half of the object) is covered.

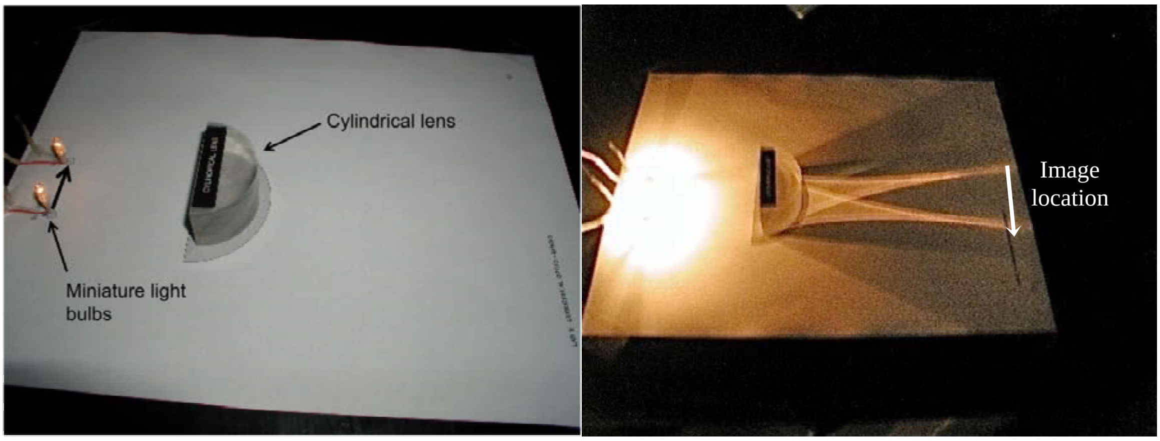


Figure 3. (a) Apparatus for examining real image formation by a lens, as in *RealTime Physics, Module 3: Light and Optics*, Lab 3. (b) The observations when the two point source light bulbs are lighted.

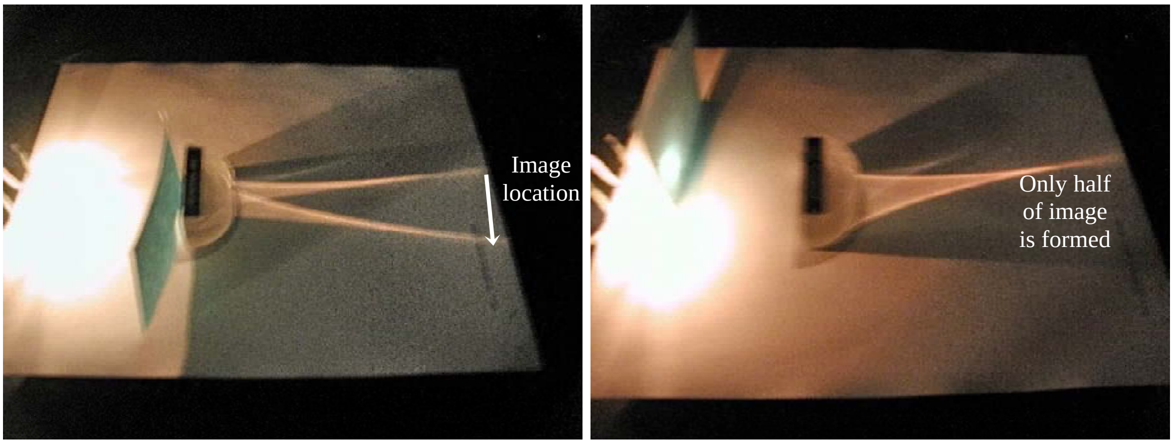


Figure 4. (a) The observation when half the lens in Figure 3 (b) is covered by a card. (b) The observation when one of the two bulbs (half of the object) is blocked.

(3) Electricity and Magnetism

Here's one more *RealTime Physics* example, this one from *Module 3*, *Electricity and Magnetism*. This activity from Lab 1, Electric Charges, Forces and Fields, also demonstrates the use of video analysis to examine the physical world. Electrostatics experiments are difficult to do, especially in humid environments. Carrying out a quantitative electrostatics experiment on Coulomb's law in the introductory physics laboratory is virtually impossible. After students do some qualitative activities with Scotch Magic© tape, Investigation 2 makes use of a video produced under controlled conditions to examine the force between two charged objects *quantitatively*.

Figure 5 shows the last frame from the movie with a charged prod as close to a charged hanging ball as it will be. The positions of the prod and hanging ball in the successive frames of the movie have been marked. Students are asked to analyze the movie to plot a graph of the force (F) between the prod and the ball as a function of the distance (r) between their centers. Figure 5 also shows the graph and the mathematical relationship that is established between F and r.

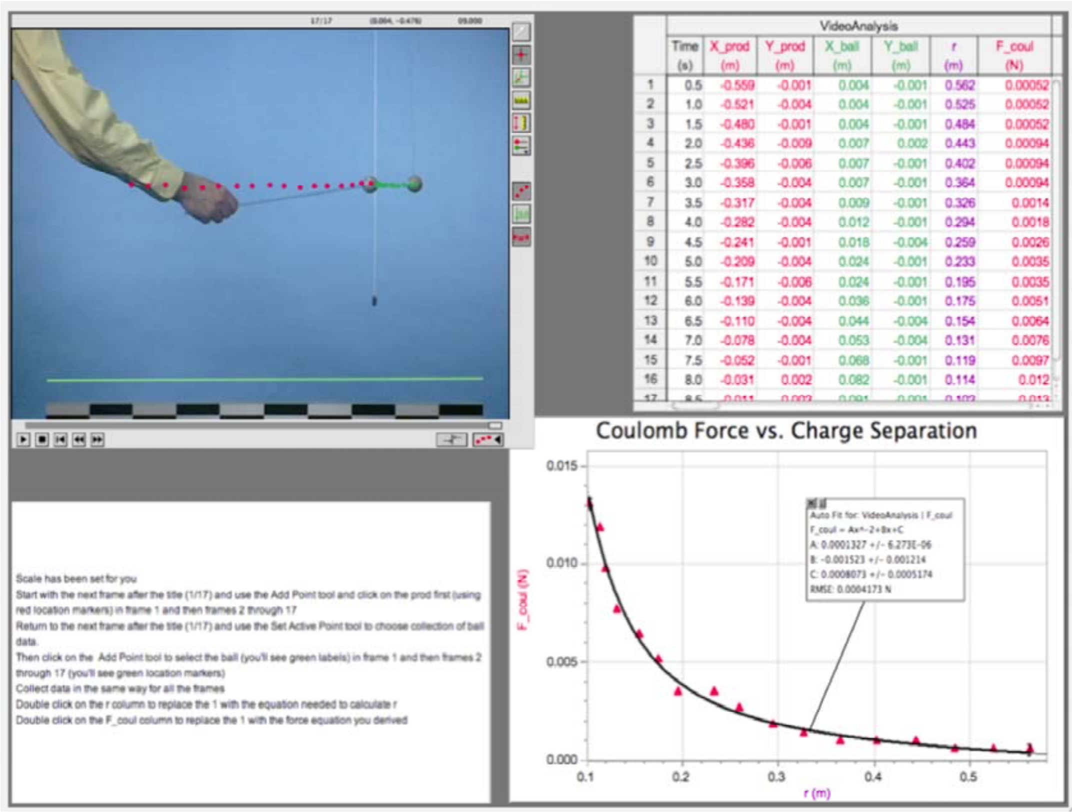


Figure 5. Composite screen from LoggerPro [10] showing (a) last frame from a video of a charged prod and hanging, charged ball, (b) data for the positions of the centers of the prod and ball and calculated values for the force between them (F) and the distance between their centers (r), (c) instructions for data collection and (d) graph of F vs. r, and mathematical analysis of the relationship between them.

Do students learn from *RealTime Physics labs*? As an example, here are results of the assessment of learning gains for the image formation with lenses activities. Students in the algebra-trigonometry-based general physics course at the University of Oregon had only a 20 % normalized learning gain on the physics education research-based Light and Optics Conceptual Evaluation (LOCE) [8] after all traditional instruction on image formation. After doing the *RTP* activities, their learning gain from the pre-test was 90 %. In addition, the last question on the test shows the real image of an arrow formed by a lens, with two (non-principal) rays from the bottom of the arrow and two (non-principal) rays from the top of the arrow drawn incident on the lens. (See Figure 6). Students were asked to continue these four rays through the lens to illustrate how the image was formed. This task is easy if one understands the function of a perfect lens. While after traditional instruction, only 33 % were able to continue these rays correctly, after the *RTP* activities, 76 % could do so.

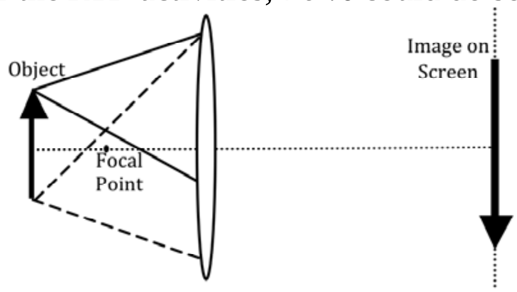


Figure 6. Modified ray-diagram question from Light and Optics Conceptual Evaluation (LOCE)

Interactive Lecture Demonstrations (ILDs)

ILDs [5, 6] are designed to enhance conceptual learning in large (and small) lectures. An eight-step procedure is used to enhance learning with simple, single-concept lecture demonstrations. Real physics demonstrations are shown to students, who then make predictions about the outcomes on a prediction sheet, and collaborate with fellow students by discussing their predictions in small groups. The instructor then solicits predictions from volunteers. Students then observe the results of the live demonstration (often displayed as real-time graphs using computer data acquisition tools), compare these results with their predictions, and volunteers attempt to explain the observed phenomena to the class. The eight-step *ILD* procedure incorporating the learning cycle is included in Table I. It is followed for each of the basic demonstrations in an *ILD* sequence. Besides data acquisition, computers are sometimes used for video analysis. Complete materials – including student sheets and teachers' guides – are available for most introductory physics topics in the book *Interactive Lecture Demonstrations* [5].

Table I: The Eight Step Interactive Lecture Demonstration Procedure

1. The instructor describes the demonstration and – if appropriate – does it for the class without measurements displayed.
2. The students are asked to record their individual predictions on a Prediction Sheet, which will be collected, and which can be identified by each student's name written at the top. (The students are assured that these predictions will not be graded, although some course credit is usually awarded for attendance and participation at these *ILD* sessions.)
3. The students engage in small group discussions with their one or two nearest neighbors.
4. The instructor elicits common student predictions from the whole class.
5. The students record their final predictions on the Prediction Sheet.

6. The instructor carries out the demonstration with results clearly displayed.
7. A few students describe the results and discuss them in the context of the demonstration. Students may fill out a Results Sheet, identical to the Prediction Sheet, that they may take home with them for further study.
8. If appropriate, the students (or the instructor) discuss analogous physical situation(s) with different "surface" features. (That is, different physical situation(s) based on the same concept(s).)

The *Image Formation with Lenses ILD* sequence [5, 8] is modeled after the *RTP* image formation activities. The *ILDs* are designed to help students understand the function of a lens in forming images. The lecture apparatus is shown in Figure 7 (a), with a large, acrylic cylindrical lens used in place of the small lens used in the *RTP* activities. Figure 7 (b) shows the situation with the bulbs lighted. (Compare these to Figure 3.) The *ILD* sequence—just like its *RTP* equivalent—consists of changes in the situation. Figure 8 shows an excerpt from the Prediction Sheet.

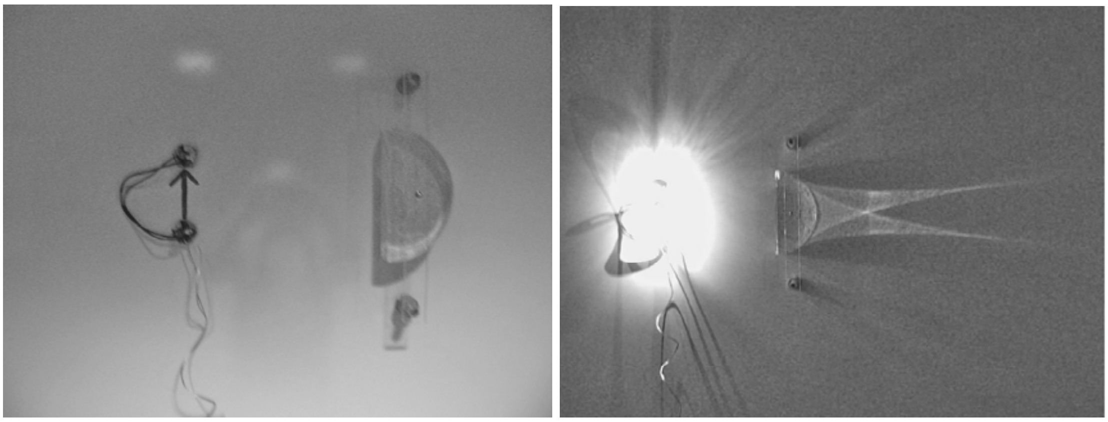
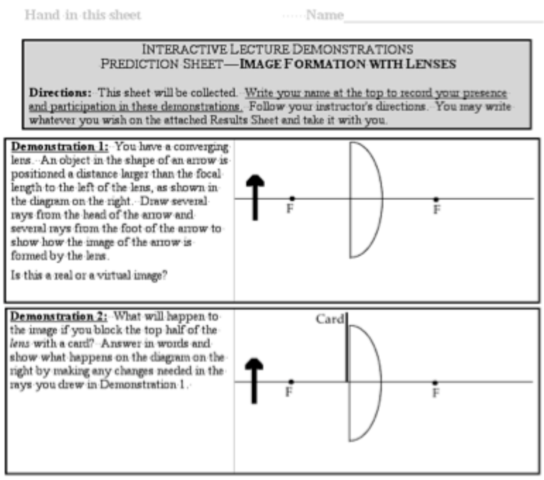


Figure 7. (a) Apparatus for the Image Formation *ILD*s consisting of two light bulbs (point sources at the top and bottom of the object), and a large acrylic cylindrical lens. (b) The apparatus with both bulbs lighted.



Hand in this sheet Name____________

INTERACTIVE LECTURE DEMONSTRATIONS
PREDICTION SHEET—**IMAGE FORMATION WITH LENSES**

Directions: This sheet will be collected. Write your name at the top to record your presence and participation in these demonstrations. Follow your instructor's directions. You may write whatever you wish on the attached Results Sheet and take it with you.

Demonstration 1: You have a converging lens. An object in the shape of an arrow is positioned a distance larger than the focal length to the left of the lens, as shown in the diagram on the right. Draw several rays from the head of the arrow and several rays from the foot of the arrow to show how the image of the arrow is formed by the lens.

Is this a real or a virtual image?

Demonstration 2: What will happen to the image if you block the top half of the *lens* with a card? Answer in words and show what happens on the diagram on the right by making any changes needed in the rays you drew in Demonstration 1.

Figure 8. Excerpt from the Prediction Sheet for the Image Formation *ILDs*.

Do students learn optics concepts from *ILDs*? As reported previously, students in the algebra-trigonometry-based general physics course at the University of Oregon had only a 20 % normalized learning gain on the *LOCE* after all traditional instruction on image formation. With just one additional lecture consisting of the Image Formation *ILD* sequence, their learning gain from the pre-test was 80 %. And the learning gain on the last question (Figure 6) was also comparable to that with *RTP*. (These results are for students who were not also enrolled in the *RTP* laboratory.)

ILDs with a Personal Response System

Personal response systems (clickers) have become available at many schools and universities around the world, and are used by many educators. Their availability inspired a project to develop and test *ILDs* in which students use clickers to record their predictions rather than paper and pencil. There are many different commercially-available clicker systems. We chose i-Clickers [9] because of their ease of use. They are limited by only allowing five choices.

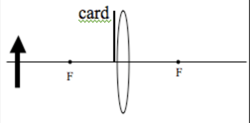
We developed a modified procedure for clicker *ILDs* that is shown in Table II.

Table II: Modified Interactive Lecture Demonstration Procedure for Clicker ILDs

1. The instructor describes the demonstration and – if appropriate – does it for the class without measurements displayed.
2. The students are asked to record individual predictions with their clickers, but the histogram of the class's predictions is not shown. (The students are assured that these predictions will not be graded, although some course credit is usually awarded for attendance and participation at these *ILD* sessions.)
3. The students engage in small group discussions with their one or two nearest neighbors.
4. The students are asked to record individual predictions again with the clickers, and the histogram of the class's predictions is displayed.
5. The instructor carries out the demonstration with results clearly displayed.
6. A few students describe the results and discuss them in the context of the demonstration. Students may take notes on a piece of paper that they may take home for further study.
7. If appropriate, the students (or the instructor) discuss analogous physical situation(s) with different "surface" features. (That is, different physical situation(s) based on the same concept(s).)

In general, this procedure worked very well for the Image Formation *ILDs*. Figure 9 (a) shows the clicker question for the second *ILD*, and Figure 9 (b) shows a typical display from i-Clicker.

Demonstration 2: What will happen to the image if you block the top half of the *lens* with a card?



A. Half of the image will disappear

B. The image will be whole but half as large

C. The image will disappear

D. The image will be dimmer

E. The image will appear on the card

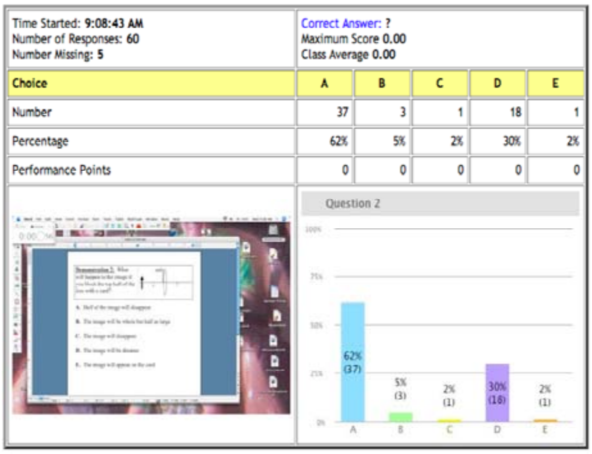


Figure 9. (a) Clicker Image Formation *ILD* #2 with the five choices available to students. (b) Typical display from i-Clicker [9] showing screen capture of the *ILD* question, and the histogram of student predictions.

How does student learning with the Clicker *ILDs* compare to that with the original, paper and pencil *ILDs*? It is not obvious that the procedure followed with clicker *ILDs* is the equivalent of paper and pencil *ILDs*. For the latter, students are required to provide open-ended descriptions of their predictions, while for the former, they are asked to choose their predictions from five research-based choices. Therefore, it is not obvious that the learning gains achieved with the original *ILDs* will be duplicated with the clicker *ILDs*.

Pre and Post-test results with the image formation questions on the *LOCE* show a learning gain of 59 % with the Clicker *ILDs*, as compared to 80 % with the paper and pencil *ILDs* (and 90 % with the *RTP* activities). On the ray-diagram question, the gains are 57 %, 76 % (and 76 %) respectively. While not quite as substantial as the learning gains with *RTP* and with the paper and pencil *ILDs*, these gains are still very significant.

As part of the clicker *ILD* project, we also experimented with clicker *ILDs* in mechanics. The situation here is more complicated since many of these require coupled graphs for different, related quantities, e.g., velocity and acceleration. Five choices often do not allow for all the combinations students normally predict. We have experimented with a procedure in which students first sketch graphs on a piece of paper, and then make choices separately for each quantity. This procedure has resulted in promising gains.

It appears from our research, that the use of clickers for students to record their *ILD* predictions can result in substantial conceptual learning gains.

Acknowledgments

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[9] For more information see http://www.iclicker.com/.

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