Inquiry-Based Instruction for Elementary Physics: High-Tech and Low-Tech

David E. Meltzer
Department of Physics and Astronomy
Iowa State University
Ames, Iowa

Supported in part by NSF grants #DUE-9354595, #9650754, and #9653079

Inquiry-based Learning/ “Discovery” Learning

Pedagogical methods in which students are guided through investigations to “discover” concepts

- Targeted concepts are generally ***not*** told to the students in lectures before they have an opportunity to investigate (or at least ***think*** about) the idea.
- Can be implemented in the instructional laboratory (“active-learning” laboratory) where students are guided to form conclusions based on evidence they acquire.
- Can be implemented in “lecture” or recitation, by guiding students through chains of reasoning utilizing printed worksheets.

Pedagogical Themes of Inquiry-Based Physics Course

- ***"Active" Learning:*** Hands-on activities keep students engaged in learning process.
- ***Conceptual Conflict and Conceptual Change:*** students make predictions of experimental outcomes they anticipate, then test their predictions.
- ***Building of Mental Models:*** Students create detailed conceptual understanding through extended process of exploration and reflection.

Potential Obstacles to Student Learning

- Student have difficulties in relating abstract principles and formal representations to "real-world" objects and activities.
- Gaps in reasoning and specific "conceptual stumbling blocks" impede students' development of thorough conceptual understanding.
- Students need to rigorously examine and test their understanding of evidence derived from observations.

Guidelines for the Use of Pedagogical Equipment

- Equipment and instruments used in learning activities must not become obstacles to learning goals.

- Equipment must not ***exacerbate*** learning difficulties which are already present.

- Equipment must ***facilitate*** learning process by helping students to clarify their understanding of difficult concepts.

Prerequisites for Effective Pedagogical Use of Technology

- Use of technology must ***do no harm:*** conceptual objectives of activity must not be obscured by technical details.
- Use of technology must be ***beneficial in some specific way:*** no technology “for its own sake.”

Specific “Dangers” of High-Tech

- “Black boxes” with mysterious functions may confuse students about ***what*** is being measured, and about ***how*** measurement is defined.
- Sophisticated graphical displays may lack meaning for underprepared students.
- Subtle conceptual distinctions may be obscured by superficial technological similarities. (e.g.: voltmeter; ammeter)

Potential Benefits of High-Tech

- Rapid, efficient execution of repetitive, time-consuming operations.
- Immediate display of results when parameters are varied.
- Capability for striking visual display of otherwise abstract concepts.

Case Study: Measurements of Force and Motion

- ***Timing Measurements:***
  - Stopwatch
  - Photogate Timer
  - Ultrasonic Motion Sensor
- ***Force Measurements:***
  - Calibrated Spring Scale
  - Electronic Force Sensor
- ***Graphical Display:***
  - Hand-plotted on graph paper
  - Real-time computerized graphing

Timing Measurements

- ***First Objective:*** To understand velocity as ratio of *distance traveled* divided by *time elapsed*.
- ***Second Objective:*** To acquire measurements of velocity as a function of time.
- ***Third Objective:*** To understand acceleration as ratio of *change of velocity* divided by *time elapsed.*

Techniques of Timing Measurements

- ***Stopwatch Timing*** provides maximum clarity of *time elapsed during a process.*
  - ***Disadvantage:*** Inaccurate and imprecise.
- ***Photogate Timing*** provides maximum accuracy and precision, even for very short duration
  - ***Disadvantage:*** Not very clear ***what*** is being timed, or ***how*** timing operation is carried out
- ***Ultrasonic Motion Sensor*** carries out measurements at millisecond intervals for real-time displays of velocity/acceleration data.
  - ***Disadvantage:*** Actual mode of operation is completely obscured.

Force Measurements

- ***Calibrated Spring Scale*** provides clear and vivid sense of force as “push or pull,” and allows direct sensation of *force magnitude* being correlated with *pulling intensity*.
  - ***Disadvantage:*** very difficult to maintain constant pulling force when object is moving.

- ***Electronic Force Sensor*** provides accurate, precise, and continuously recordable data.
  - ***Disadvantage:*** No visual or tactile evidence of force being applied, nor of force magnitude variations.

Graphical Display

- ***Hand-plotted graphs on graph paper*** maximize opportunities for students to understand concepts of *scale markings, data points,* and *fitting lines.*
  - ***Disadvantage:*** Extremely tedious and time-consuming to create.

- ***Real-time Computerized Graphing*** provides instantaneous, accurate, and clear display of measured data.
  - ***Disadvantage:*** All details of graphing process are hidden from viewer.

Learning Outcomes Resulting from High-Tech Graphing Tools

- Excellent student response: they really enjoyed activities.
- Significant improvement in comprehension of graphs, in relation to classes where low-tech graphing was employed.
- Other learning outcomes consistent with classes in which low-tech tools were used.

Specific Learning Outcomes: ***Kinematics*** (velocity & acceleration)

- Learning gains in kinematics were generally good, particularly for velocity-distance-time relationships.
  - 60-90% correct on graphical questions
- Significant conceptual difficulties with *acceleration* persist.
  - Approximately 25% of students fail to grasp distinction between velocity and acceleration

Specific Learning Outcomes: ***Dynamics*** (Newton's 1st & 2nd laws)

- Overall, fewer than 50% correct responses on ***non-graphical*** questions.
- ***More than*** 50% correct responses on graphical questions (since adopting high-tech computer graphing tools)
- ***Fewer than 25%*** of students consistently give correct responses on dynamics questions.

(Some) Findings from Student Interviews

- Much greater confidence with dynamics questions posed in graphical representation.

- Evidence of “pattern matching”
  - Students learn to recognize familiar patterns appearing in graphs, and correlate those patterns with each other.

Summary

- ***Careful judgment*** is required to assess possible pedagogical risks and benefits of high-technology tools.
- “Low-tech” tools are often a superior means of achieving the primary goal of ***improved conceptual understanding.***
- ***Judicious*** use of high-technology tools may be beneficial in pedagogy.