Physics Education Research as a Guide to Application-based Curriculum Development

N. Sanjay Rebello
(srebello@phys.ksu.edu)

Department of Physics
Kansas State University
Manhattan, KS 66506-2601

Supported in part by the U.S. National Science Foundation
Grants REC-0133621, REC-0087788

Acknowledgements

Graduate Students
- Alicia R. Allbaugh
- Edgar G. Corpuz
- Kara E. Gray
- Zdeslav Hrepic
- Darryl J. Ozimek

Faculty
- Dean A. Zollman

Post-docs
- Paula V. Engelhardt
- Salomon F. Itza-Ortiz
What is Physics Education Research?
A scientific way of looking at how people learn about physical phenomena and how we can help them.

Our Goals
- Investigate ...
  - introductory undergraduate students’ ‘mental models’ of everyday devices.
  - how students apply these mental models in various contexts.
- Develop application-oriented curricula based on our research results.
- Pilot-test these curricula to evaluate their impact on student learning and transfer.
What We Do

- RESEARCH
- CURRICULUM DEVELOPMENT
- PILOT & FIELD TESTING
- MODEL OF THE LEARNER

Models of Student Knowledge

Researchers have used models of various ‘grain sizes’

- diSessa
- Mistrell
- Hammer
- Redish
- Taber
- Vosniadou
- Glasersfeld
- Driver

- Knowledge in Pieces
- Knowledge as Theory

- Increasing ‘grain size’

- A model of a single grain size can be self-limiting.
- We do not select a grain size a priori.
But Remember....

“....It’s only a model.”

-- ‘Monty Python & the Holy Grail’

Some Thoughts on Models

- “The sciences do not try to explain, they hardly even try to interpret, they mainly make models.”
  John Von Neumann

- “Models are to be used, not believed.”
  H. Theil, ‘Principles of Econometrics’
Building the Model

We examine what the student says, not what she thinks. We interpret what she says to construct a model of what she thinks.

Student has some thoughts

She describes what she is thinking in her own words.

Our Research Tools

Clinical Interviews
Explore ideas that students bring from prior experiences.

Teaching Interviews
Investigate how students interact in groups to build their ideas in a mock instructional setting.

Surveys
Large scale probes.
Clinical Interviews

- Semi-structured Protocol
  - Individual student.
  - Begin with a general question
  - Follow-up questions based on response.
  - Avoid cues & hints.

- Analysis
  - Avoid pre-existing hypotheses.
  - Phenomenological approach:
    - Classify and describe responses.

- Typically done pre- and post-instruction.

Teaching Interviews

- Mock Instructional Setting
  - Protocol adapted from clinical interview.
  - Two or Three students together.
  - Teaching episodes: Provide instruction.
  - Cues & hints are a part of the protocol.

- Analysis
  - Similar to Clinical Interviews
  - Also focus on how students...
    - React to instruction provided.
    - Interact with each other and instructor.

- Over one week or several weeks.
Advantages of Teaching Interviews

- Students open up more than in clinical interviews.
- Show how students...
  - *dynamically* formulate their ideas as they learn new material.
  - *transfer* information that they have just learned to new contexts.
  - *interact* with other students and the instructor as they learn.
  - *respond* to instruction.
- Are a useful bridge between research and curriculum development.

Teaching Interviews better suited to our goals than Clinical Interviews

Making Sense of Student Responses

- How do students construct their reasoning dynamically *during* an interview?
- What factors mediate students’ sense-making processes *during* an interview?

Need an ‘Analytical Framework’
Creating an Analytical Framework

Data from five researchers with diverse research goals, participants, and interview formats was used.

Examined data from all five researchers & focused on the dynamics of reasoning.

Analytical Framework Emerged!

Analytical Framework

Elements connected via various possible reasoning paths

- External Inputs
- Tools
- Answer
- Workbench
External Inputs

- Interviewer
  - Protocol question.
  - Follow-up question
  - Clarification question
  - Other Cues.
    (verbal & non-verbal)

Interview Materials

- Written text of question.
- Pictures or diagrams.
- Demonstration equipment (e.g. bicycle)

The sphere is moving at velocity $v$ towards the Electric field.
Draw the trajectory of the sphere.

Tools

What do students use in their reasoning?

- Existing Tools
  - Internal Knowledge in dormant state.
    - Memorized or Familiar ...
      - Rules, Procedures.
      - Formulae, Definitions.
      - Facts, Data.
    - P-Prims (diSessa), Resources (Hammer), Facets (Minstrell), Mental Models (Vosniadou, etc.)
  - Prior Experience.

- Created Tools
  - Answers to previous questions.
  - Other dynamically created knowledge & experiences.
Decision Making

Restructuring & Recombining Knowledge
- Assimilation.
- Accommodation.
- Replacement.
- Conceptual Combination (Hybridization).

Transferring & Applying Knowledge/Experiences
- Deduction.
- Induction.

Possible Types:
- Decisive
  - Provides a single answer (correct or incorrect).
- Indecisive
  - Unable to decide between two or more answers.
  - Requests more information.
- None
  - Unable to arrive at any answer (e.g. “Don’t know”).
Some Caveats

- Items listed in **External Inputs, Tools, Workbench, Answer** are...
  - Non-exhaustive
  - Not mutually exclusive
- Boundaries between elements may be difficult to distinguish.

Cognitive Workshop Metaphor

Elements of our framework are analogous to those in a workshop.

- **External Input** → Work order given by client (e.g. build a chair)
- **Tools** → Shop implements (e.g. saw) & skills.
- **Workbench** → Work area (e.g. work table) & fabrication process (e.g. sawing)
- **Answer** → Finished product (e.g. chair)
Connections with Cognitive Psychology

Our framework is supported by theories in *Cognitive Information Processing* (CIP).

Elements of our framework are analogous to those in CIP:

- **External Input** → Sensory Input
- **Tools** → Information stored in Long Term Memory
- **Workbench** → Processes in Short Term / Working Memory
- **Answer** → Response

Connections with Cognitive Psychology (continued)

Our framework is also analogous to a commonly used metaphor in CIP – a computer.

- **External Input** → Input device (e.g. keyboard)
- **Tools** → Stored data and/or software on hard disk
- **Workbench** → Active processes in processor or RAM
- **Answer** → Output device (e.g. monitor)
## Advantages of Our Framework

- Derived from and applied to an interview setting.
- Our framework helps in various stages of a research project:
  - **Research Design**
    - Helps focus overall protocol to satisfy goals.
    - Helps phrase individual interview questions.
  - **Research Implementation**
    - Prompts appropriate follow-up questions based on goals.
  - **Data Analysis**
    - Shows trends of reasoning.
    - Allows for multiple grain sizes of analysis (See next e.g.)
Limitations of Our Framework

Limitations of qualitative research that apply to our framework

- Sometimes it is difficult to categorize an element exclusively as an *Input*, *Tool*, *Workbench* or *Answer*.
- Analysis is highly susceptible to researcher’s inferences.

Curriculum Development

- Based on Real-World devices, because...
  - they motivate students to learn.
- Criteria for selecting Real-world devices:
  - Can students of all backgrounds relate to it?
  - Are underlying physical principles in clear view?
  - Can principles also be applied to other devices?
- Models of Instruction
  - Learning Cycle (*Karplus*).
  - Modeling Cycle (*Hestenes*).
Learning Cycle

EXPLORATION -> CONCEPT INTRODUCTION -> APPLICATION

Modeling Cycle

EXPLORATION -> CONCEPT INTRODUCTION -> MODEL DEVELOPMENT -> MODEL DEPLOYMENT -> APPLICATION
Pilot & Field Testing

**Pilot Testing:**
- Introductory classes at K-State
  - Conceptual-based physics
  - Algebra-based physics.
- High school physics classes.

**Field Testing:**
- Large scale studies using diverse populations (not a part of this project)
What devices did we use?

- **Light Bulb & Electrical Appliances**
  - Research: Clinical Interviews & Surveys.
  - Curriculum Development: Complete.
  - Pilot Testing: Complete.

- **Bicycle**
  - Research: Clinical Interviews.
  - Curriculum Development: In progress.
  - Pilot Testing: In progress.

- **Musical Instruments**
  - Research: Clinical & Teaching Interviews (in progress)

---

Two very common circuits activities:
Students easily complete the two wire activity, but struggle with the one wire activity. Why?

**One Wire Activity**

**Two Wire Activity**
Previous Research

(McDermott & Shaffer, 1992)

Student difficulties with the one wire activity are a symptom of their misunderstanding of complete circuits.

Our Hypothesis

Student difficulties with the one wire activity are a sign of an unawareness of the wiring of a light bulb and not necessarily a misunderstanding of complete circuits.
Interview Results

- Interviews conducted on student understanding of circuits and everyday objects.

  Student stated – “I thought a light bulb was a circuit in and of itself.”

- Further interviews conducted to look for similar and related beliefs.

Survey

Draw how the two wires indicated connect to the base of the light bulb?
Survey Results

<table>
<thead>
<tr>
<th></th>
<th>14%</th>
<th>47%</th>
<th>20%</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual</td>
<td>27%</td>
<td>47%</td>
<td>20%</td>
<td>15</td>
</tr>
<tr>
<td>Algebra</td>
<td>25%</td>
<td>58%</td>
<td>9%</td>
<td>149</td>
</tr>
<tr>
<td>Calculus</td>
<td>72%</td>
<td>18%</td>
<td>5%</td>
<td>124</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>288</td>
</tr>
</tbody>
</table>

Making Sense of Incandescence

- Approximately 2 hour activity.
- Hands-on, discovery-based.
- Learning cycle-based.
- Students work in groups.
- Rotate between 3 stations.
- Includes pre- and post-lab activities.
Students

• High School Students (N=13)
  – Algebra based course.
  – Used to recipe-like labs.
  – 50 minute class period.
  – Could not complete all activities.

• Algebra Based University Students (N=30)
  – Used to recipe-like labs.
  – 2 hour lab period.

• Conceptually Based University Students (N=10)
  – Had used similar labs.
  – 2 hour class period.

Pre-Lab: Bright Ideas

• Done in-class, individually
• Asks students to explain what they know about
  – Light bulbs
  – Complete circuits
• Fill in a light bulb wiring diagram
  (same as survey diagram)
Station 1: **Getting Hot**

- **Equipment**
  - Light bulb in socket with dimmer switch attached
  - Hot plate with visible heating coil
- **Hypothesize how a stove and a light bulb work.**
- **Compare stove and bulb.**
- **Learn about…**
  - Number of connections on a light bulb
  - Light bulb is not polarized

Station 2: **That Glowing Feeling**

- Asks students to problem solve 3 identical looking circuits, only 1 of which works.
- **Possible problems:** blown bulb, bad battery, loose bulb, wire touching plastic not metal, battery connected backwards, tape blocking connection.
- **Tests and expands students’ definitions of complete circuits.**
Station 3: Getting Connected

- Goal: Make a Christmas tree light bulb light using a 6 Volt battery and large household socket
- After learning how a socket works, perform the one or two wire activity without a socket
- Explicitly confronts their hypotheses on the wiring of a light bulb

Station 3 Apparatus
Station 3: Getting Connected

- Goal: Make a Christmas tree light bulb light using a 6 Volt battery and large household socket
- After learning how a socket works, perform the one or two wire activity without a socket
- Explicitly confronts their hypotheses on the wiring of a light bulb

Post Lab: Lighting Up the Night

- Discuss internal wiring of bulb as a class.
- Review each station, focusing on definitions of complete circuits.
- Given a flashlight and a wire, construct a flashlight without using the plastic casing.
Post Lab Apparatus

Flashlight casing - Not given to students in the activity.

Lab Results

• All students who completed all the activities ended with the correct model of light bulb.

• Some students were not comfortable with the new type of labs.

• Students appeared to be learning and having fun.
Results of Study

• University students quickly and correctly completed the flashlight activity – a modified version of the one wire activity.

• Students demonstrated a clear understanding of complete circuits during trouble shooting station (station 2).

CONCLUSIONS

- Models of student knowledge provide a basis for curriculum development and instruction.
- Real-world applications are a useful research context to observe student knowledge dynamics.
- Teaching Interviews are a useful tool to investigate the dynamics of student knowledge.
- Analytical Framework helps make sense of student responses in an interview, and infer their reasoning.
- To be effective, curriculum must address critical details in student reasoning paths and target specific aspects of this reasoning.
FOR MORE INFORMATION

- Please contact:
  - N. Sanjay Rebello (srebello@phys.ksu.edu)
  - Paula V. Engelhardt (engelhar@phys.ksu.edu)

- Visit our website:
  - http://www.phys.ksu.edu/perg

Thank You