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

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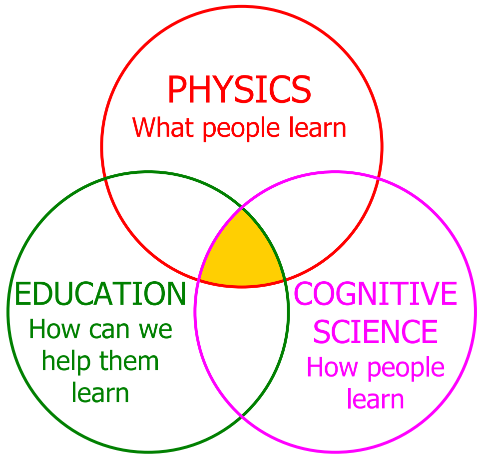
Supported in part by the U.S. National Science Foundation
Grants REC-0133621, REC-0087788

Acknowledgements

- Graduate Students
  - Alicia R. Allbaugh
  - Edgar G. Corpuz
  - Kara E. Gray
  - Zdeslav Hrepic
  - Darryl J. Ozimek
- Post-docs
  - Paula V. Engelhardt
  - Salomon F. Itza-Ortiz
- Faculty
  - Dean A. Zollman

What is Physics Education Research?

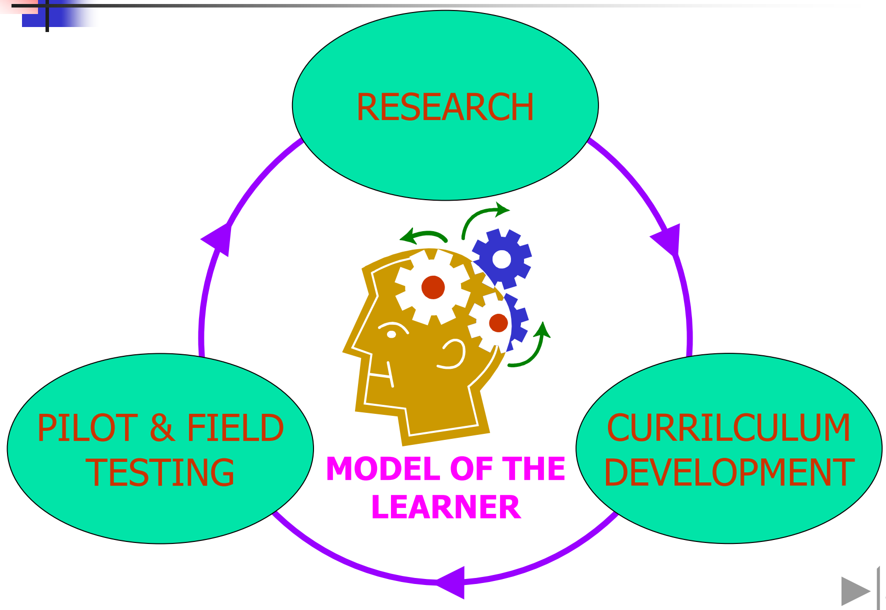
A scientific way of looking at how people learn about physical phenomena and how we can help them.



Our Goals

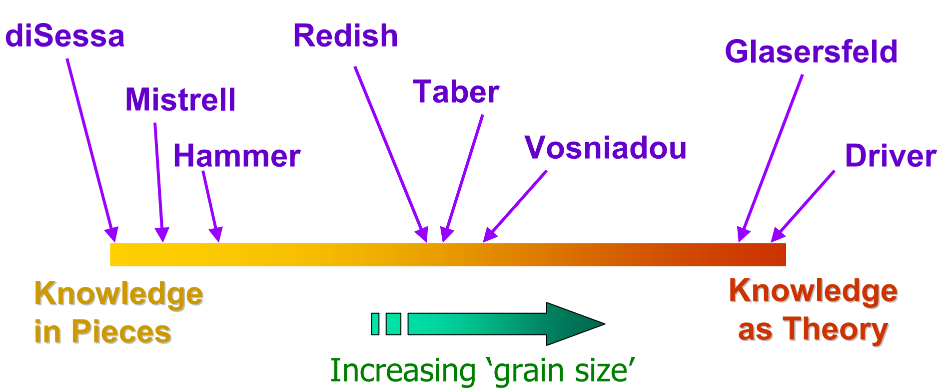
- Investigate ...
  - introductory undergraduate students' 'mental models' of everyday devices.
  - how students apply these mental models in various contexts.
- Develop application-oriented curricula based on our research results.
- Pilot-test these curricula to evaluate their impact on student learning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

What We Do



Models of Student Knowledge

Researchers have used models of various '**grain sizes**'



- 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."

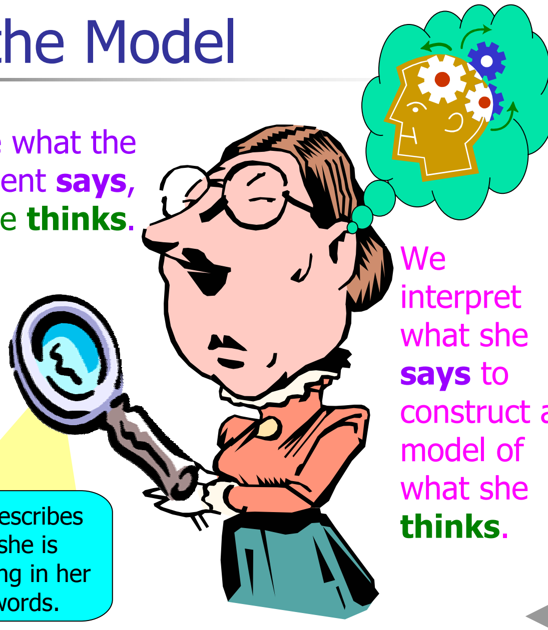
  H. Theil, `Principles of Econometrics'

Building the Model

Student has some thoughts

We examine what the student **says**, not what she **thinks**.

She describes what she is thinking in her own words.



We interpret what she **says** to construct a model of what she **thinks**.

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'

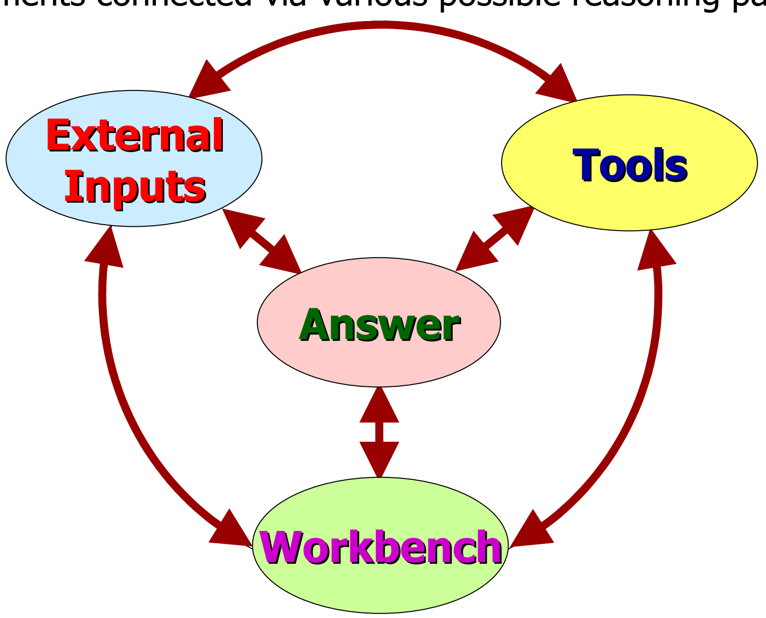
Creating an Analytical Framework

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 !**

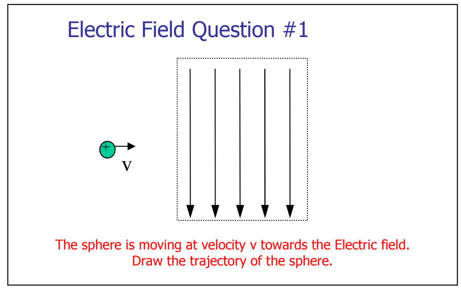
Analytical Framework

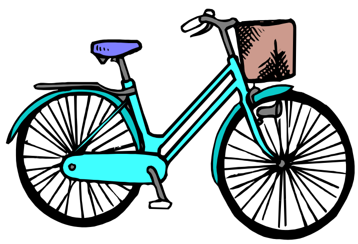
Elements connected via various possible reasoning paths



External Inputs

- 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)

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.

Workbench

How do students use the tools?

- Decision Making
- Restructuring & Recombining Knowledge
  - Assimilation.
  - Accommodation.
  - Replacement.
  - Conceptual Combination (Hybridization).
- Transferring & Applying Knowledge/Experiences
  - Deduction.
  - Induction.

Answer

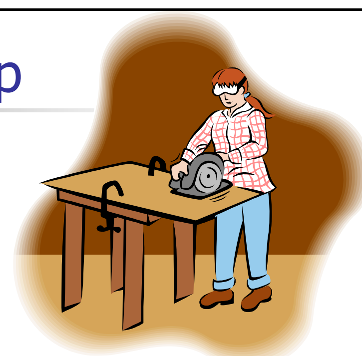
Possible Types:

- 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

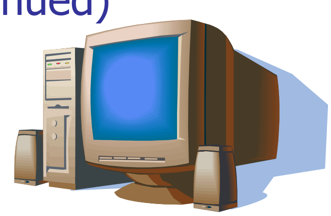
Cognitive Information Processing (**CIP**).

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.)

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Limitations of Our Framework

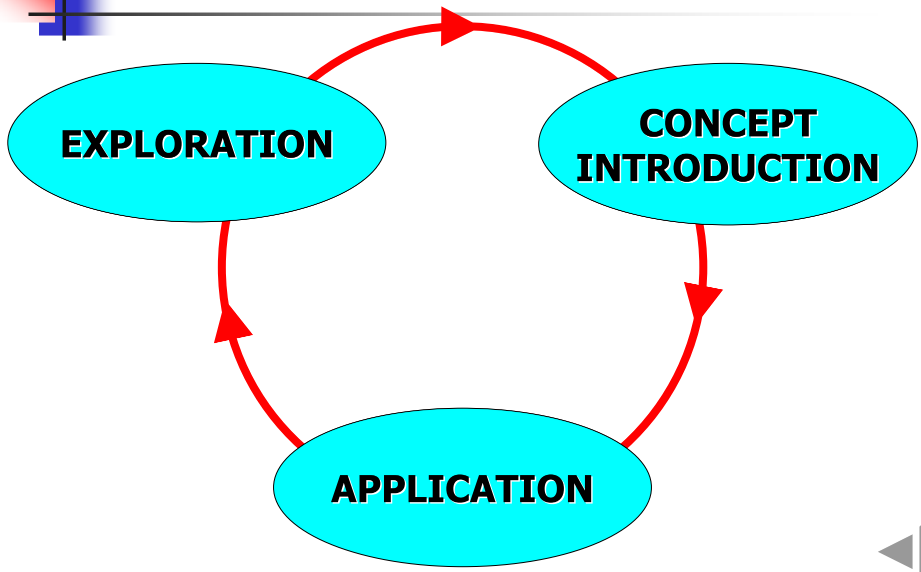
Limitations of qualitative research that apply to our framework

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

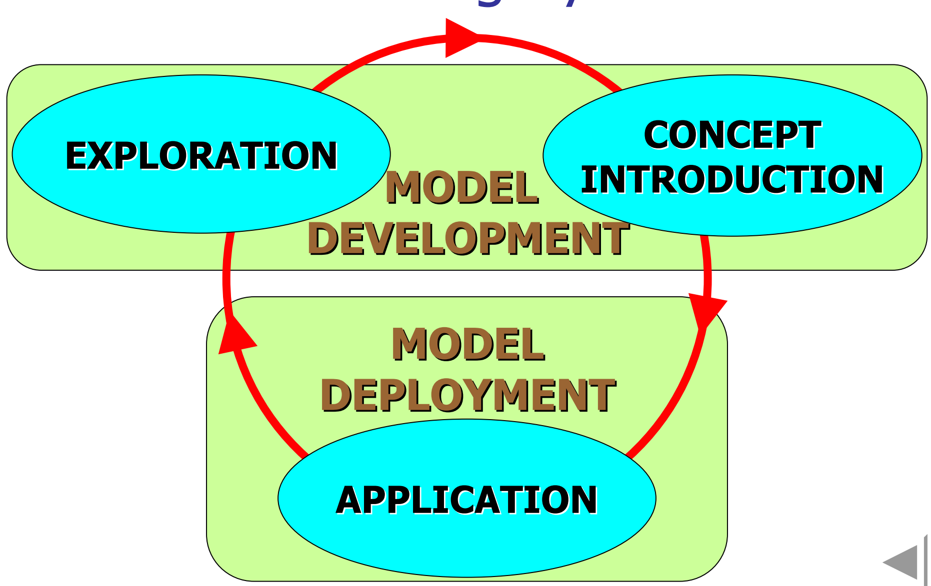
Curriculum Development

- 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

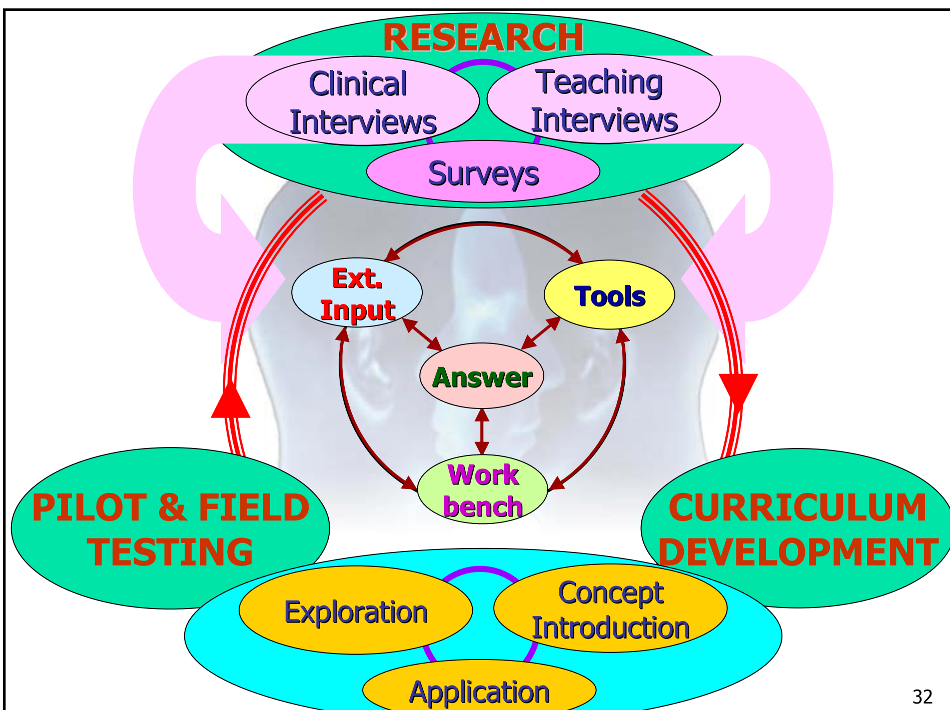


Modeling Cycle



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)

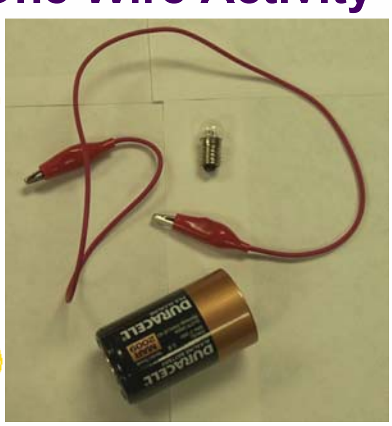


What devices did we use?

- 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 a misunderstanding of complete circuits.

Our Hypothesis

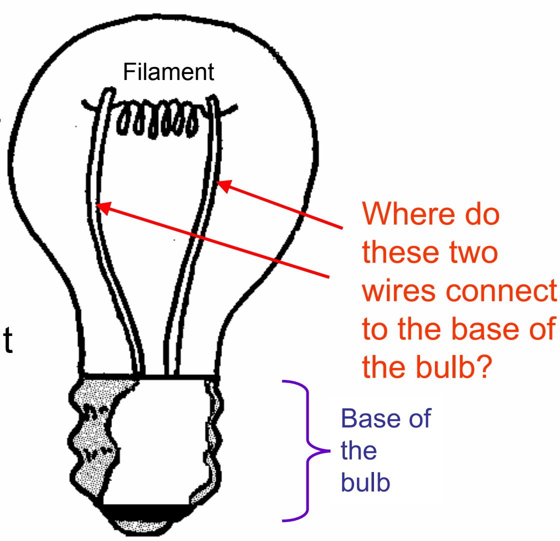
Student difficulties with the one wire activity are a sign of an unawareness of the wiring of a light bulb and not necessarily a misunderstanding of complete circuits.

Interview Results

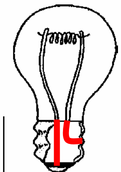
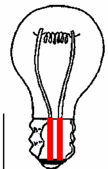
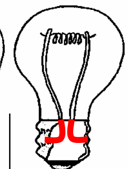
- Interviews conducted on student understanding of circuits and everyday objects.
- Student stated – "I thought a light bulb was a circuit in and of itself."
- Further interviews conducted to look for similar and related beliefs.

Survey

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



Survey Results

				N
Conceptual	27%	47%	20%	15
Algebra	25%	58%	9%	149
Calculus	72%	18%	5%	124
			Total	288

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

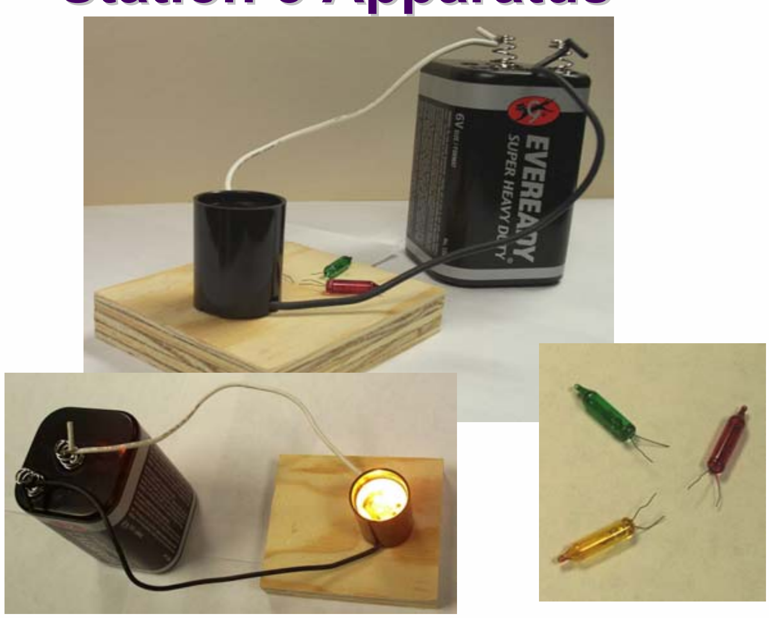
Station 2: *That Glowing Feeling*

- 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



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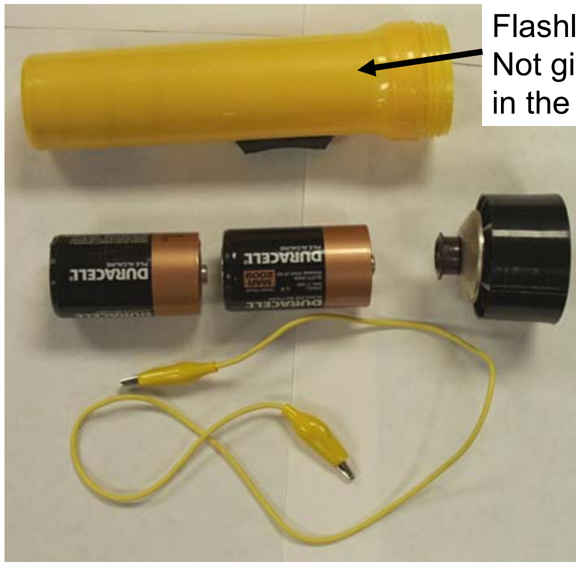
Post Lab:
Lighting Up the Night

- 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



Lab Results

- **<u>All</u>** 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

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- Visit our website:
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Thank You