PHYSICS EDUCATION RESEARCH GROUP

Evaluating Student Reasoning in the Context of a Modified Modern Physics Curriculum[1]

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A New Model Course in Applied Quantum Physics

- **Motivation**

  Scientists and engineers will be using many tools and devices that are fundamentally quantum in nature:

  - *Transistors*
  - *SQUID's*
  - *Lasers*
  - *MRI*
  - *STM*
  - *. . .*

- **Traditional QM courses are not well matched to non-physics majors.**

PER based conceptual & device approach

- **Real examples used to teach basic QM rather than abstract math problems.**
  - » photoelectric effect $\rightarrow$ photomultiplier tubes
  - » LEDs and conductivity model $\rightarrow$ diodes
  - » Quantum tunneling $\rightarrow$ scanning tunneling microscopes
- **Reliance on physics education research:**
  - » design
  - » refine
  - » evaluate
  - » … $(re)^n$design, $(re)^n$fine, $(re)^n$evaluate,

Modular course design

- **Tutorials**

  Modeled after UW-style tutorials[1]

- **Just-in-Time-Teaching[2] web essay assignments**

- **Applied HW**

  Based on our experience with alternative homework assignments (AHA) in the Activity Based Physics Project[3]

- **Software**

  Simulations, MBL, interactive programs, etc.

[1] L.C. McDermott, P.S. Shaffer, and the Physics Education Group at the University of Washington, *Tutorials in Introductory Physics*, Prentice Hall, Upper Saddle River, NJ, 1998.
[2] G.M. Novak, E.T. Patterson, A.D. Gavrin, and W. Christian, *Just-in-Time-Teaching: Blending Active Learning with Web Technology*, Prentice Hall, Upper Saddle River, NJ, 1999.
[3] E.F. Redish and the Physics Education Research Group, University of Maryland. Materials available on the web at http://www.physics.umd.edu/rgroups/ripe/perg/abp/aha/.

Course Implementation

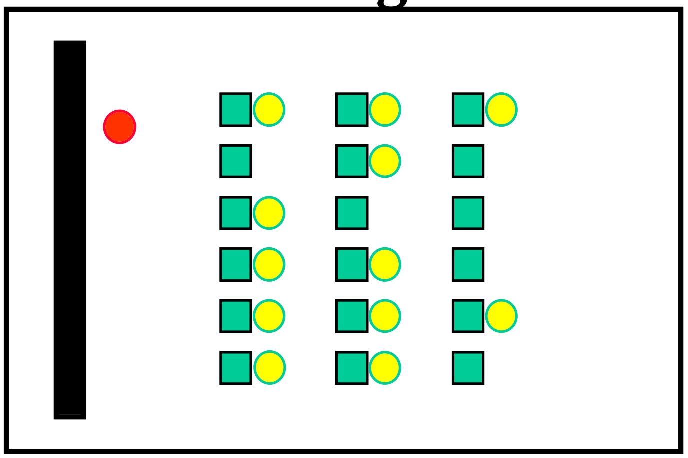
Junior level quantum physics course:

» Lecture: 2 hours / week

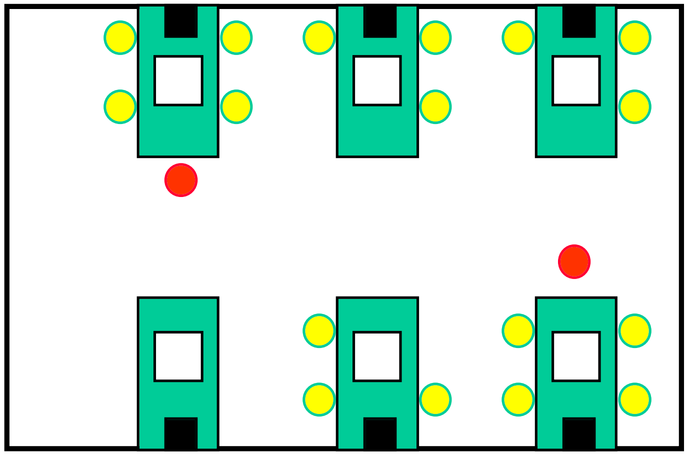
» Tutorial: 1 hour / week
UMD-developed tutorials which often
make use of appropriate software packages*

» Class assignments: JITT essays due each morning before class

lecture setting:



tutorial:

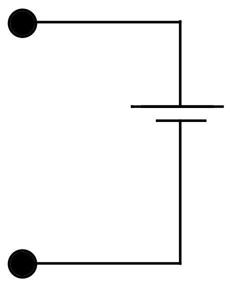


* *Photoelectric Tutor, Visual Quantum Mechanics, Physlets, MUPPET, MBL (Vernier, Pasco), CUPS*

Previous research: electron jump model

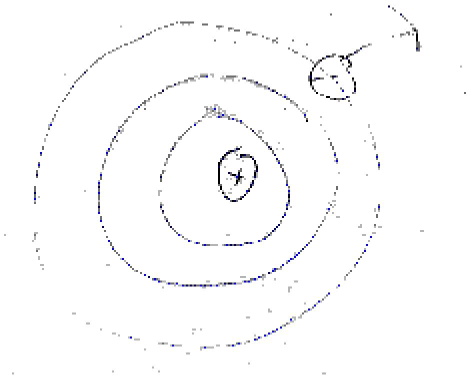
Origin and motion of conducting electrons:

Consider placing a steel wire in an open circuit:



Inter.: *How do [electrons in the steel wire] move?*

Thomas: *… Just the ones on the most outer shell would move. They'd get pulled off the atom… by the electric field.*



David: "Electrons get out from one atom…
This electron takes the place of this electron here,
this one takes the place of this one, and then this one,
… [The electron] comes again out of the atom
and it moves to the next one."

Frequency of electron jump model

Pre-instruction interviews:

» 4 of 9 students in a modified instruction classroom

Post-instruction interviews:

» 2 of 4 students in a traditional instruction classroom

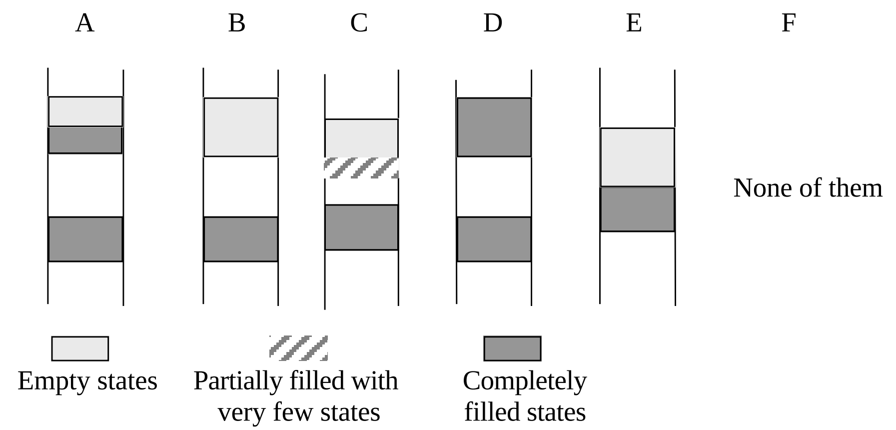
Commentary:

**Students use single atoms (not solid state)
to describe the source of free electrons, and
build on this interpretation to describe electron flow.**

Previous research: band jump model

Choose the appropriate band diagram for the corresponding material:

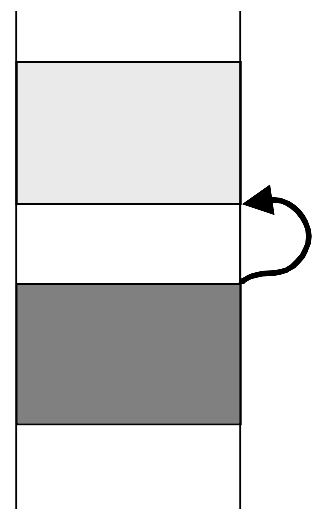
conductor, insulator, semiconductor, resistor



Consider the following band diagrams. For the different materials, select one of the diagrams that can best represent the band structure of the corresponding material . (If you choose "F", please sketch your own diagram). Explain your reasoning.

a) Conductor
b) Insulator
c) Semiconductor
d) Resistor

In original modified semester, 12 of 25 gave "modified Bohr" response:

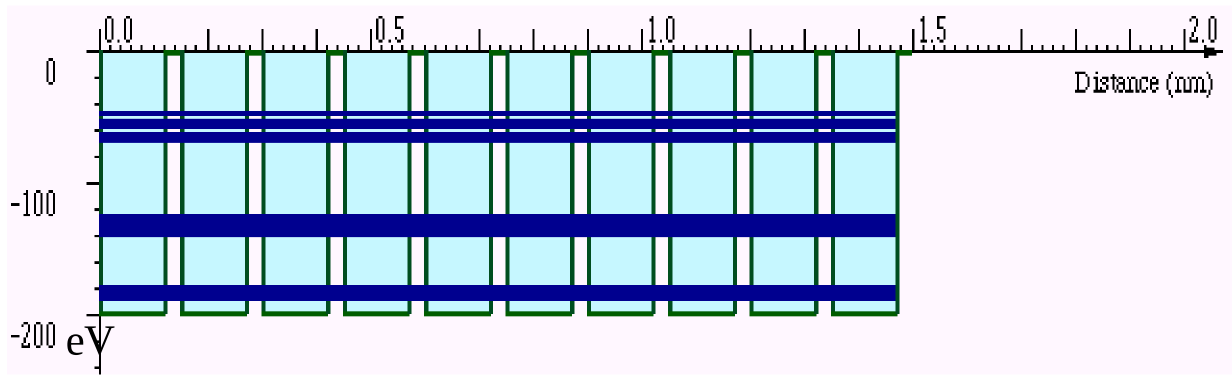


"Similar to semi-conductor … It takes very small energy to excite the electrons into the upper band."

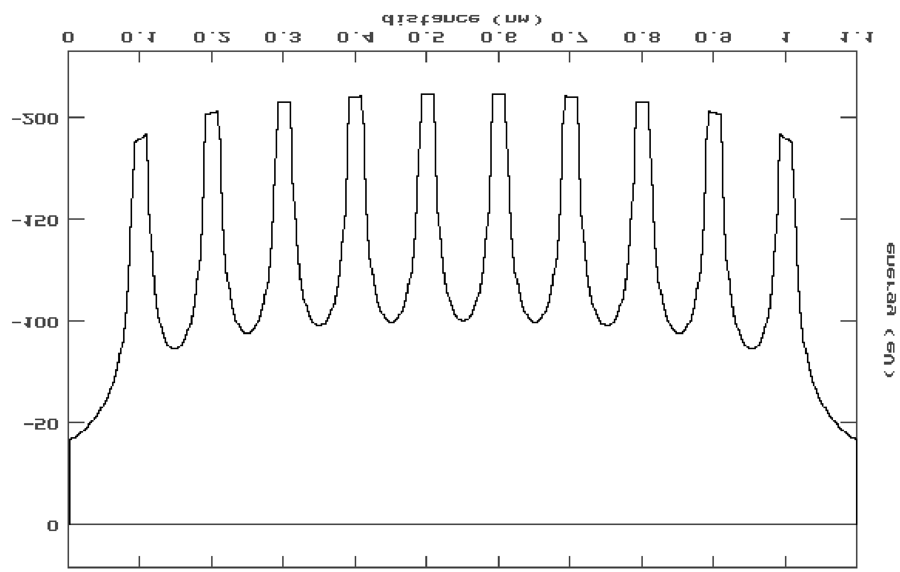
Modified curriculum: free electrons first

Build from QM models already addressed in class

Visual Quantum Mechanics



CUPS Lattice 1-D



Then describe how free electrons move

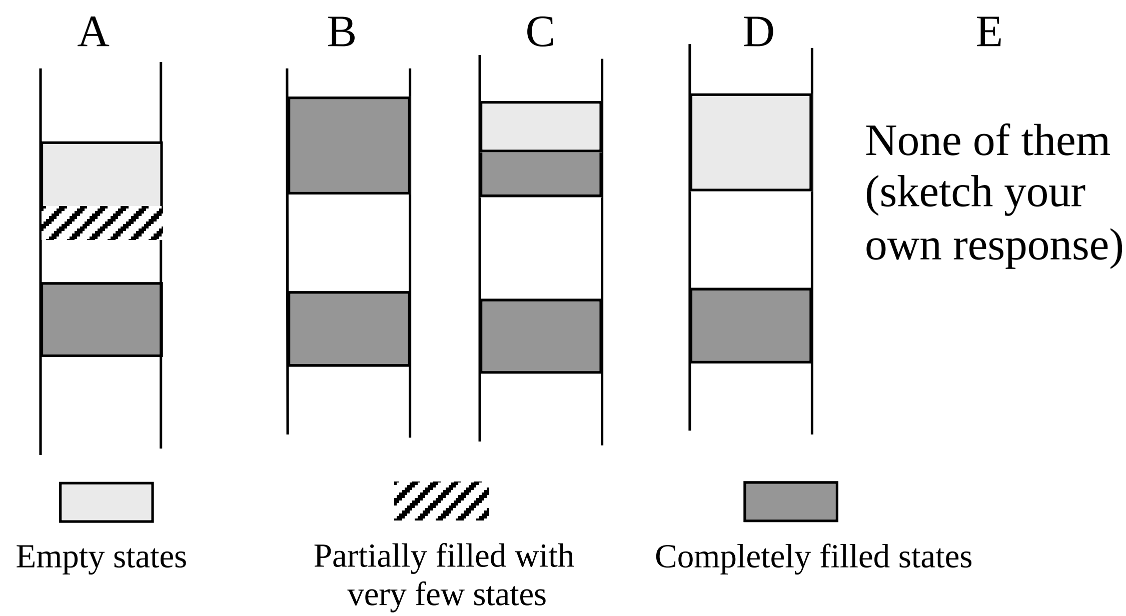
- **Introduce the Drude model**
  - » free electrons in an atomic lattice
  - » electrons accelerated by electric field
  - » collisions with lattice
  - » V = IR implies F ~ v…
- **Combine the two models**
  - » when is which appropriate?
  - » which helps describe what?

Subsequent research - are they consistent?

Identical questions asked on two following final examinations:

Traditional instruction
12 students

Modified tutorials
12 students



a. Consider the following band diagrams. For the each of the materials listed below the diagram, select the diagram that best represents the band structure of the material. For each material, **explain how you arrived at your answer.**

i. Conductor ii. Insulator iii. Semiconductor

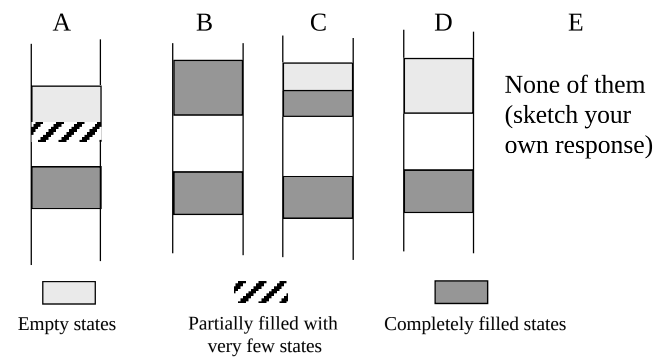
b. A potential difference is placed across a resistor. Describe what, if anything, happens to the individual electrons in the material. Include a sketch in your explanation.

Expected correct responses:

We expected students

» to correctly interpret band diagrams (e.g. insulator is D because electrons cannot easily move from one energy band to another and conduction band is empty)

» AND to correctly describe the Drude model in their description of individual electrons in a resistor.



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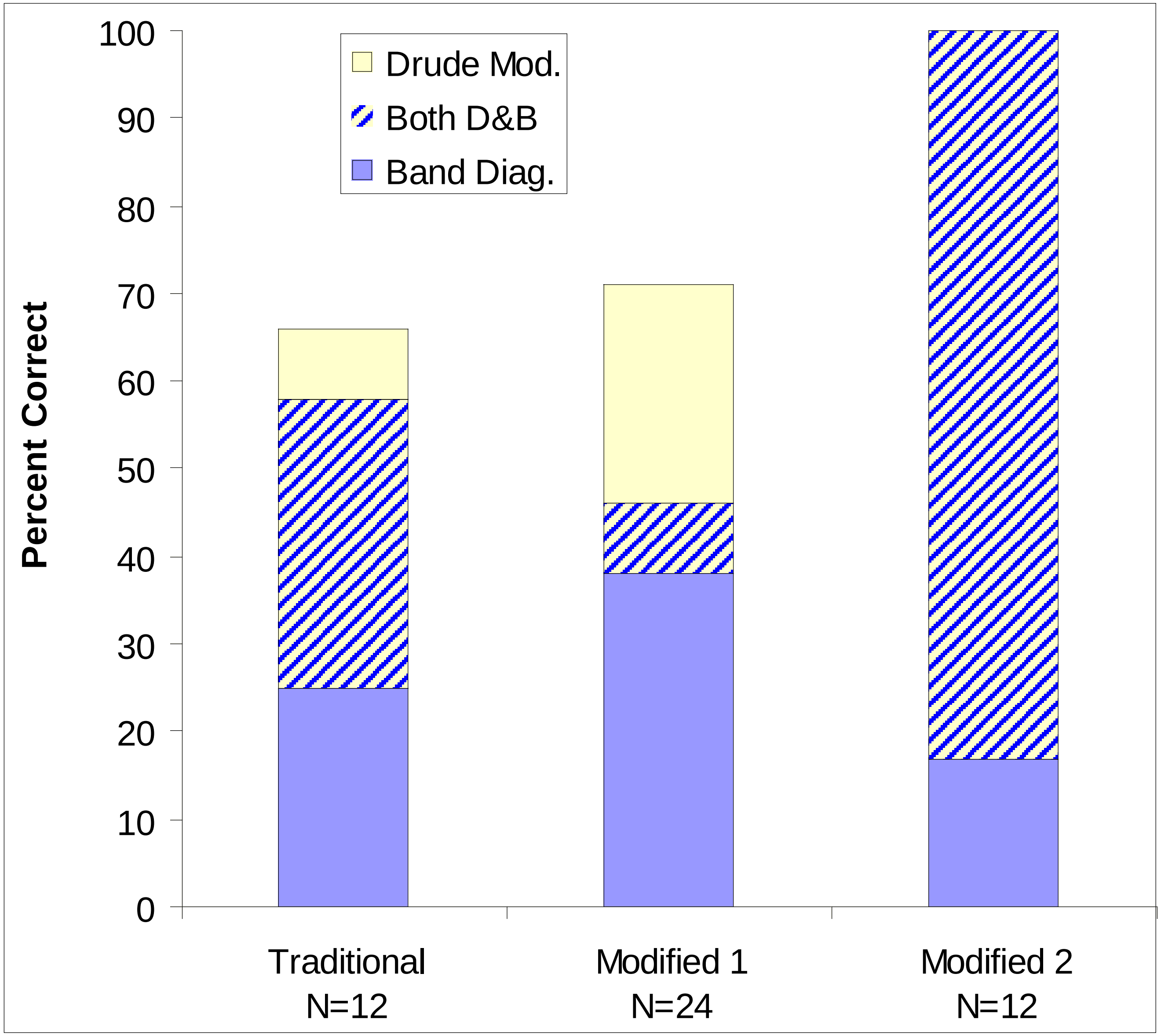
Comparison of 3 semesters:



Improving the curriculum: what matters?

Need for research-based revisions of interactive engagement curriculum materials.

» Original tutorial was no better than traditional instruction.

» Modified tutorial instruction was far more successful.

Caveat: was it the tutorial?

» Just In Time Teaching essay assignments addressed (i.e. asked about) models of conductivity.

» Essay assignments also focused on when to seek consistency and coherency in QM.

Are the “jump” models the same?

Original assumption (San Antonio meeting):

band jump model is the electron jump model (e.g. electrons get pulled off) expressed in context of band diagrams

Data breakdown from trad. instruction semester

	Band diagram OK	Band Jump Answer	Other
Drude model OK	3	1	0
electron jump answer	2	1	0
lack of mechanism	1	1	2
blank	1	0	0

No correlation among student responses

Conclusions:

- **Learning to juggle multiple models**
  - » When is it appropriate?
  - » How do you know to do it?
- **Using multiple instructional methods**
  - » What added value do they provide?
  - » How can they work together?