Cognitive Research and the Practical Classroom: Bridging the Gap

1. Student expectations and beliefs about learning physics

Findings from cognitive studies:

- Students have attitudes, expectations, and beliefs about learning physics that affect what they pay attention to in a course and how they study. These include:
  - Expectations about how to succeed in a physics class
  - Beliefs about the relationship of physics to experiences outside of class
  - "Epistemological" beliefs about knowledge and the nature of learning:
    - Beliefs about the structure and content of physics knowledge (isolated facts and formulas or coherent system of concepts and relationships)
    - Beliefs about the certainty of scientific knowledge as fixed and unchanging or tentative and evolving
    - Beliefs about the nature of learning as receiving information from an authority or actively constructing your own understanding
    - Beliefs about their own ability to learn math / physics
    - Beliefs about the speed of learning: "you either know it or you don't"
  - Goal orientations (Why are they taking physics and what are their goals?)
- Instructional practices can reinforce or dispel these expectations and beliefs.

Questions:

- In your own teaching experiences, what attitudes, expectations, and beliefs about learning physics are common among students? Give specific examples.

- What implications does this have for classroom practice? 

Additional Research & References:

A common student approach to learning physics (Redish, 1994)

1. Write down every equation the teacher puts on the board that is also in the book.
2. Memorize these, together with the list of formulas at the end of each chapter
3. Do enough homework and end-of-the-chapter problems to recognize which formula is to be applied to which problem
4. Pass the exam by selecting the correct formulas for the problems on the exam
5. Erase all information from your brain after the exam to make room for the next set of materials.

Types of goal orientations in school include: (Lin, 1982; Woolfolk, 2004)

1. *Mastery* – actively seeks to learn and improve; focuses on mastering the task or solving the problem
2. *Performance* – seeks to look competent or perform well in the eyes of others
3. *Work-avoidant* – seeks to complete assignments and activities as quickly as possible with minimal effort
4. *Social* – seeks to be connected to others and part of a group

Effects of epistemological beliefs:

- Students' beliefs about the *source of knowledge* and *nature of learning* affect their level of engagement in a course, such as passively taking notes or trying to actively construct understanding (Hammer, 1989)
- Students' beliefs about *ability* and *speed of learning* affect their persistence during a challenging task (Ormrod, 2004; Prosser, Walker, & Millar, 1996; Woolfolk, 2004)
- Students' beliefs affect their choice of learning strategies and approaches to studying, such as rote memorization of formulas and example problems versus meaningful elaboration (Elby, 1999; May & Etkina, 2002; Ormrod, 2004; Prosser, Walker, & Millar, 1996; Woolfolk, 2004)
- Students often fail to use skills and knowledge they clearly possess, such as comparing the results of a calculation with their intuition (Hammer, 1989; Lising & Elby, 2004)

References:

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2. Cognitive conflict and conceptual change theory

Findings from cognitive studies:

- People have ideas about the world that are different from scientific views, referred to as alternative conceptions, naïve conceptions, or misconceptions.
- These ideas usually come from everyday experiences, and are resistant to change.
- People's ideas about the world might be weakly formed ("fuzzy conceptions"), or unarticulated prior to instruction.
- Cognitive conflict (contradiction of ideas) does not imply conceptual change will occur.
- In order for *conceptual change* to occur, the following conditions must be met: there must be dissatisfaction with a current conception, and a new conception must be seen as intelligible, plausible, and fruitful.

Questions:

- In your own teaching experiences, what alternative conceptions have you observed?

- What implications does this research have for classroom practice?

Additional Research & References:

Techniques for probing students' thinking include: (Driver et al., 2000)

- *Posters* - Make posters in small groups to share with the class
- *Card sort* - Sort cards into piles or categories based on specific characteristics
- *Thought experiment* - Engage in thought experiments and report ideas to the class
- *Design & make* - Design a test or make something with given materials to meet criteria
- *Explain* - Write down an explanation for a phenomenon using words and diagrams
- *Checklist/questionnaire* - Select items on a checklist or questionnaire that meet specified criteria
- *Predict & Explain* - Make predictions about a phenomenon, explain their thinking, and try it out

Teaching strategies using the conceptual change model: (Hewson, Beeth, & Thorley, 1982; Posner, Strike, Hewson, & Gertzog, 1982)

- Probe students' thinking to diagnose their existing conceptions about a topic
- Provide opportunities for students to articulate existing conceptions, and critically examine them
- Provide opportunities for students to test out their ideas in experiments and/or interactive demonstrations

Conditions of Accommodation (Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985, 1992)

1. There must be *dissatisfaction* with existing conceptions
2. A new conception must be *intelligible* (minimally understood)
3. A new conception must appear initially *plausible*
    a. Consistent with past experience and one's sense of what the world is or could be like
    b. Consistent with other theories or knowledge
4. A new concept should be *fruitful*
    a. Have the potential to open up new areas of inquiry (new approaches or ideas)
    b. Have potential for explanatory and predictive power

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3. Learning is an active, constructive process

Findings from cognitive studies:

- People interpret new information in light of their existing knowledge.
- People organize things they learn into meaningful interconnected categories.
- People are in control of learning, and actively *construct* their own understanding.
- Knowledge is internally constructed, but socially and culturally mediated.
- Students differ in their responses to instruction and have different approaches to learning.

Questions:

- What active teaching strategies have you used?

- What implications does this research have for classroom practice?

Active Learning Strategies

Think/Write-pair-share	Students reflect on a question individually and then share ideas with a partner. The instructor can randomly select students to share their answers with the whole group.
Student summaries	Students explain to a partner the central concepts that were just presented.
Question & answer pairs	Students prepare content questions (before or during class) and take turns quizzing each other.
1-minute paper / free write	Students briefly write about a topic or in response to a question (to explore ideas before a discussion, or summarize the class session)
Reciprocal questioning	The instructor provides question stems; (What does…mean? Why is …important? How does …tie in with what we learned before?) Students develop questions from the stems and answer them.
Roundtable	A question is posed to a group of students, and each person writes one answer on a paper. Then the answers are shared within the group and with the class.
Corners	Posters or a flipchart with questions are placed in each corner of the room. Groups of 3-6 students move from corner to corner and answer the questions.
Problem-based learning	Partners or small groups use information from class to address an authentic problem situation.
Ten-Two strategy	The instructor presents for ten minutes and then stops for two minutes to encourage listeners to share ideas or clarify misunderstandings.
Cognitive Mapping	The instructor selects a key question, idea, issue, or concept for students to map by drawing a web diagram in small groups.
3-2-1- Format	Students write down and share 3 ideas/issues presented, 2 examples or uses of the information covered, and 1 unresolved question.
Note Check	Students compare notes with a partner or small group.
Background Knowledge Probe	Questionnaire that asks for basic, simple responses (short answer/circle/vote) at the beginning of a new topic.

Adapted from the University of Minnesota Center for Teaching and Learning: http://www.teaching.umn.edu
http://www1.umn.edu/ohr/teachlearn/tutorials/active/strategies.html

References:

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Instructional Resources for Teaching Physics:

General Resources:

- Arons, A.B. (1990). *A guide to introductory physics teaching*. New York: John Wiley & Sons, Inc.
- Knight, R.D. (2002). *Five easy lessons: Strategies for successful physics teaching*. San Francisco, CA: Pearson Education Inc.
- University of Maryland Physics Education Research Group Web Site: http://www.physics.umd.edu/perg/
    - Redish, E.F. (2003). *Teaching physics with the physics suite*. Hoboken, NJ: Johns Wiley & Sons, Inc. Available online at http://www2.physics.umd.edu/~redish/Book/
- McDermott, L.D., & Redish, E.F. (1999). Resource letter: PER-1: Physics Education Research. *American Journal of Physics*, *67*(9), 755-767.
- Hsu, L., Brewe, E., Foster, T.M., & Harper, K.A. (2004). Resource Letter RPS-1: Research in problem solving. *American Journal of Physics*, *72*(9), 1147-1156.

Lecture-based models:

- Peer Instruction / ConcepTests
    - Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall, Inc.
    - Project Galileo: http://galileo.harvard.edu
    - Interactive Teaching DVD companion site: http://www.teachingdvd.com/
- Just-in-Time Teaching (JiTT) and Physlets
    - http://www.jitt.org
    - Novak, G.M., Patterson, E.T., Gavrin, A.D., & Christain, W. (1999). *Just-in-Time Teaching: Blending active learning with web technology*. Upper Saddle River, NJ: Prentice Hall, Inc.
    - Christian, W., & Belloni, M. (2001). *Physlets: Teaching physics with interactive curricular material*. Upper Saddle River, NJ: Prentice Hall, Inc.
- Interactive Lecture Demonstrations (ILDs)
    - Sokoloff, D.R., & Thonton, R.K. (2006). *Interactive lecture demonstrations: Active learning in introductory physics*. Hoboken, NJ: John Wiley & Sons, Inc.
    - University of Maryland ILDs: http://www.physics.umd.edu/perg/ILD.htm
- Audience Response Systems ("clickers")
    - InterWrite Learning Personal Response System (PRS) http://www.interwritelearning.com/products/prs/index.html

Recitation-based models:

- Tutorials in Introductory Physics (University of Washington)
    - McDermott, L.C., & Shaffer, P.S. (2002). *Tutorials in Introductory Physics*. Upper Saddle River, NJ: Prentice Hall, Inc.
    - http://www.phys.washington.edu/groups/peg/tut.html
- Tutorials at the University of Maryland
    - http://www.physics.umd.edu/perg/tutorials.htm
- Activity-Based Physics (ABP) Tutorials:
    - http://perlnet.umaine.edu/abt/
    - http://www.physics.umd.edu/perg/abp/abptutorials/

- Wittman, M.C., Steinberg, R.N., & Redish, E.F. (2004). Activity-based tutorials volume 1: Introductory physics. John Wily & Sons, Inc.
- Wittman, M.C., Steinberg, R.N., & Redish, E.F. (2004). Activity-based tutorials volume 2: Modern physics. John Wiley & Sons, Inc.

- Cooperative Problem Solving (University of Minnesota)
  - http://groups.physics.umn.edu/physed/Research/CGPS/CGPSintro.htm

Laboratory-based models:

- RealTime Physics
  - David Sokoloff's home page http://www.uoregon.edu/~sokoloff/homepage.html
  - Sokoloff, D.R., Thornton, R.K., & Laws, P.W. (2004). *Real Time Physics active learning laboratories module 1: Mechanics* (2nd ed.). Hoboken, NJ: John Wiley & Sons, Inc.
  - Sokoloff, D.R., Thornton, R.K., & Laws, P.W. (2004). *Real Time Physics active learning laboratories module 2: Heat and thermodynamics* (2nd ed.). Hoboken, NJ: John Wiley & Sons, Inc.
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- Investigative Science Learning Environment (ISLE)
  - http://www.islephysics.net/
- University of Minnesota Problem Solving Labs
  - http://groups.physics.umn.edu/physed/Research/PSL/pslintro.html

Workshop models:

- Physics by Inquiry (University of Washington)
  - McDermott, L.C. (1996). *Physics by inquiry*. New York: John Wiley & Sons, Inc.
    - Volume I: Properties of Matter, Heat and Temperature, Light and Color, Magnets, Astronomy by Sight: The Sun, Moon, and Stars
    - Volume II: Electric Circuits, Electromagnets, Light and Optics, Kinematics, Astronomy by Sight: The Earth and the Solar System
  - http://www.phys.washington.edu/groups/peg/pbi.html
  - Physics by Inquiry: A Video Resource: http://www.phys.washington.edu/groups/peg/video.html
- Workshop Physics
  - Laws, P.C. (2004). *Workshop physics activity guide modules 1-4* (2nd ed.). Hoboken, NJ: John Wiley & Sons, Inc.
  - http://physics.dickinson.edu/~wp_web/WP_homepage.html
- Explorations in Physics (EiP)
  - Jackson, D.P., Laws, P.C., & Franklin, S.V. (2003). *Explorations in physics: An activity-based approach to understanding the world*. John Wiley & Sons, Inc.
  - http://physics.dickinson.edu/~eip_web/EiP_homepage.html
- Physics and Everyday Thinking (PET)
  - http://petproject.sdsu.edu/

Web/Computer-based Resources:

- Physics Education Technology (PhET) at University of Colorado at Boulder: http://phet.colorado.edu/new/index.php (Interactive Physics Simulations)
- Tycho web-based homework system: http://research.physics.uiuc.edu/PER/Tycho.html
- ANDES physics tutor: http://www.andes.pitt.edu/
  - Gertner, A.S., & VanLehn, K. (2000). Andes: A coached problem solving environment for physics. In G. Gauthier, C. Frasson, & K. VanLehn (Eds.). *Intelligent Tutoring Systems 2000 Vol. 1839* (pp. 133-142). Berlin, Heidelberg: Springer-Verlag.
- PALS tutorials (Personal Assistant for Learning)
  - Reif, F., & Scott, L.A. (1999). Teaching scientific thinking skills: Students and computers coaching each other. *American Journal of Physics*, *67*(9), 819-831.
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Alternate Problem Types:

- Active Learning Problem Sheets (ALPS)
  - Van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based strategies. *American Journal of Physics*, *59*(10), 891-897.
- Context-rich problems (University of Minnesota):
  - Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, *60*(7), 637-644.
  - http://groups.physics.umn.edu/physed/Research/CRP/crintro.html
- Estimation or "Fermi" problems (University of Maryland)
  - http://www.physics.umd.edu/perg/fermi/fermi.htm
- Experiment problems
  - Van Heuvelen, A. (1999). Experiment problems for mechanics. *The Physics Teacher*, *33*, 276-280.
  - Van Heuvelen, A., Allen, L.D., & Mihas, P. (1999). Experiment problems for electricity and magnetism. *The Physics Teacher*, *37*, 482-485.
- Jeopardy problems
  - Van Heuvelen, A., & Maloney, D. (1999). Playing physics jeopardy. *American Journal of Physics*, *67*(3), 252-256.
- Ranking tasks
  - O'Kuma, T.L., Maloney, D.P., & Hieggelke, C.J. (2004). Ranking task exercises in physics: Student edition. Upper Saddle River, NJ: Pearson Education, Inc.

Surveys / Diagnostic Exams:

- Information about concept surveys and attitude surveys available at: http://www.physics.umd.edu/perg/restools.htm