What can astronomy education learn from physics education research?

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Outline

- What have we learned from PER?
  - Field specific vs. general issues
  - Cognitive theory
  - Basic cognitive principles and guidelines
- Application to astronomy
  - An example
  - Designing a course

Preamble

- PER has learned a great deal about how students learn (and fail to learn) physics in the past two decades.
- What of this knowledge has implications for teaching other sciences — such as astronomy?

What we have learned: Extracting the core

- Developing effective instruction depends on our understanding
  - what students know when they come in
  - students' learning styles and expectations
- Both our <u>goals</u> and our <u>approaches</u> for instruction are strongly dependent on the populations involved.

A barrier

- Most of PER on university students has been carried out with the population of engineers taking calculus-based physics.
- Most of the need in AER at the university level is for the population of non-science majors taking non-mathematical astronomy.
- Therefore, most results are <u>not</u> directly applicable.
- We can learn something useful by working through the general theory of thinking and learning.

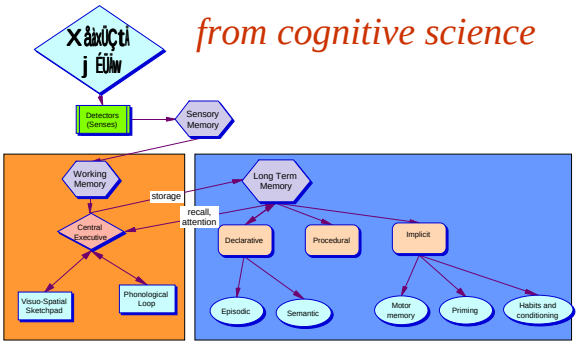
A Model of Student Learning

Bill Watterson, *Calvin & Hobbes*

This model may look ridiculous, but we often behave as we believe it!

- Students fail to be able to recognize the use of a physical principle in an exam question, so we rephrase the question so as to give "keywords" or "triggers". Almost all students can now respond correctly, so we are satisfied.
- In designing a computer-based homework system, problems #1 and #5 use the same physical ideas. When starting the HW, the student does #1 incorrectly. Returning to the assignment on the next day, she does #5 correctly. Should we now have the computer give her credit for both? After all, by the next day "she learned the principle". (What if the situation had been reversed?)

A better model from cognitive science



Adapted from A. Baddeley, *Human Memory: Theory and Practice* (Allyn & Bacon, 1998). and L. R. Squire and E. R. Kandel, *Memory: From Mind to Molecules* (Scientific American Library, 1999).

Learning is about building long-term memory

- Long-term memory
  - contains data, procedures, and rules about when to use them
  - has various degrees of activation (active, primed, inert)
  - is activated via cascading chains of association
  - is productive / generative
  - is structured
- The key structures are patterns of association
  - links may be weak or strong
  - both connections and reasoning are context dependent

Key implications

- **1. Learning is productive / constructive.**
  - The brain tries to make sense of new input in terms of existing mental structures.
  - ➢ *We learn by analogy / metaphor*
  - -- *New constructions tend to be based on the model of existing structures.*
- **2. Cognitive response is context dependent.**
  - The productive response depends on the context in which new input is presented, including the student's mental state (expectations).
  - ➢ *Students can use multiple models*
  - -- *Confusion about appropriate context can make it appear as if students hold contradictory ideas at the same time*

This is a …?

This is…

Which picture has more information? Which is easier to interpret?

Implications

- We interpret what we see by matching to templates and patterns that exist in our long-term memory.
- The pattern is not a recorded instance. We can interpret objects we have never exactly seen before.
- The closer the input is to an existing pattern, the easier it is to interpret.
- Too much information can make a complex pattern more difficult to interpret.

Physical reasoning maps primitive elements onto specific situations

Example:

Primitive: Closer is stronger

Facet: You can get warmer by standing closer to the fire.

Primitives
Irreducible functional pieces based on direct interpretation of experience

Facets
Inferred physical principles for specific situations

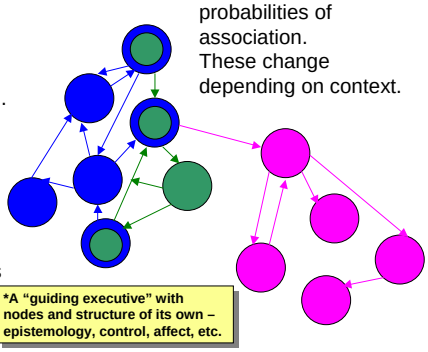
Context
Both internal and external

** diSessa and Minstrell*

Organization of Long-Term Memory: Schemas

Links represent probabilities of association. These change depending on context.

This picture is an oversimplification. "Nodes" have structure in multiple dimensions. There are "metanodes" that control what links appear when.*



***A "guiding executive" with nodes and structure of its own – epistemology, control, affect, etc.**

Resources

- The context dependence of schema generation implies that <u>how a situation is presented may affect how an individual responds</u> — in particular, what resources they have access to.
- *Resource* = a cognitive knowledge element including data (facts), reasoning methods, metaphors, analogies, etc.

A small problem: What is 3 ½ divided by ¼?

$$\frac{3\frac{1}{2}}{\frac{1}{4}} = \frac{\frac{7}{2}}{\frac{1}{4}} = \frac{\frac{7}{2}\times 4}{\frac{1}{4}\times 4} = \frac{7\times\frac{4}{2}}{1} = 7\times 2 = 14$$

A group of students have 3 ½ small pizzas, each divided into ¼-pizza parts. How many students can have a piece?

Each pie can serve 4 students, so the 3 pies can serve 12. The remaining ½ can serve 2, so a total of 14 can be served.

Summary: Basic cognitive principles

- #1: Individuals build their knowledge by using their existing knowledge and productively creating a response to the information they receive.
- #2: What people construct depends on the context – including their mental states.
- #3: It is reasonably easy to learn something that matches or extends an existing schema, but changing a well-established schema is difficult.
- #4: Different students have different mental responses and different approaches to learning.
- #5: For most individuals, learning is most effectively carried out via social interactions.

Summary: Instructional implications

- *Seeing is not believing*. Because they are using what they know to interpret what we tell them, students often misinterpret even a clear and compelling lecture or demonstration. More mentally engaging activities are required to have a more reliable effect.
- *Students are not blank slates*. We can use what we learn about students' knowledge to create lessons that build from appropriate starting points. (e.g., cognitive conflict, bridging, etc.)
- *There's more to a course than content*. Students use their learning to build (and confirm existing) expectations and understanding of what science is about and how to do it. To affect these components, we have to pay explicit attention to these issues in how we teach content.

An example from astronomy

- The study summarized in the film "A Private Universe" demonstrated that both high school students and graduating Harvard seniors had confusions about why it was warmer in summer than in winter.
- Many thought that the sun was closer to the earth in summer than in winter.

Analysis

- If we we want to teach this point, we could have a number of distinct goals, depending on what cognitive structures we want to help our students build.
  - learn an isolated fact
  - construct a model that coherently explains a number of distinct facts
  - construct a model that relates a mental model to students' personal and direct experience

Possible goals

- We could teach the isolated fact: "the tilt of the earth's axis is responsible for the change of seasons."
- We could teach that science is about the construction of models that coherently and consistently explain many facts (such as the fact that when it is summer in the northern hemisphere it is winter in the southern).
- We could teach that science is a refinement of everyday experience and get them to think about the implications of short winter and long summer days.

Resource analysis

- Why might students commonly suggest that the sun might be closer in summer than in winter?
  - Is it something they have been incorrectly told by an ignorant elementary school teacher? (possible but unlikely)
- Possible Explanations
  - They incorrectly (but plausibly) access a correct "closer is stronger" reasoning primitive and map it onto a "closer to the fire is warmer" analogy.
  - They recall the "tilt" picture but misinterpret the critical issue as "closeness" (the N. hemisphere is tilted towards the sun — "closer" in the summer daytime)

Designing a course: A question

- To further understand the implications of the ER approach for astronomy, let's consider redesigning an introductory astronomy class with laboratory for a population of non-science majors.

Designing a course: Premise

- Let's suppose that the main point of the course is to introduce students who have a weak background in science (but not necessarily in other fields) to the scientific view of the world.

Designing a course: Choosing goals

- In a typical course, one might choose learning goals from a list of content materials — the properties of the solar system, the objects in our universe, etc.
- In an ER-based course, one might choose learning goals that are broader — based on our understanding of thinking and learning theory.

Designing a course: Some cognitive goals

- Some goals might be to help the students to:
  - understand that science is based on careful observation and is not just a plausible account that may or may not be true
  - understand that a critical element in building a scientific view is building a consistent and coherent picture of a large body of disparate phenomena
  - understand that science is not just a description of exotic phenomena but builds on and refines our everyday experience and intuition
  - appreciate the power and grandeur of our current understanding of our place in the universe.

Designing a course to achieve these goals

- Content needs to be chosen not only because "it's important to know" but because it offers opportunities to develop activities that address the broader goals.
- Content needs to be restricted so that there is sufficient time for active learning (making mistakes, correcting them, and reflecting on the implications).
- Learning activities and environments must be developed that encourage mental activity, perhaps through social interaction.
- You cannot assume students will "automatically" make "natural" connections to goal items. The connections must be self-constructed, explicit, and frequent.

Designing a course: A few specifics

- For the course described I would
  - tie laboratories to explicit questions of "how we know astronomical information"
  - tie laboratories to personal experiences
  - build hierarchical class discussions (small groups, then whole class discussion) on topics such as
    - what makes the seasons?
    - what makes the phases of the moon?
    - what do the phases of the moon tell us about the structure of the solar system?
  - develop estimation skills.

Designing a course: Some details

- In designing specific lessons, I would
  - listen to students to try to understand what they know and think about specific issues (through informal discussions and formal interviews)
  - try to understand both what they are thinking and what they know that they can possible use to reach the desired goals (available resources)
  - develop lessons that use well-tested principles
    - group discussion
    - prediction / observation / resolution / reflection
    - cognitive conflict and bridging
  - observe what works and what doesn't and fix what doesn't.

Summary

- What has been learned from PER is often
  - specific to particular physics content
  - specific to physics goals that are appropriate for a specific population of physics students.
- The general ideas and principles may help
  - if you identify and understand your population
  - if you identify and understand your goals.
- Good luck!