Developing Scientific Thinking through Constructivist Learning

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“A new survey finds that two-thirds of Americans agree with some of our political leaders that “intelligent design theory” should be taught as an alternative scientific explanation of biological evolution”

“By changing the way we teach the introductory science courses in our colleges and universities, we can attract many more talented students to science careers. At the same time, we will be fostering positive public attitudes about science that are critical for a successful modern society.”
It's not what you tell your students that counts, but what they take away from the classroom.

Objectives

Participants will be able to:

- describe the data that advocates constructivist and active learning,
- apply their understanding of how people learn to design a research based course, and
- analyze student work to describe specific learning goals.
A story
Chapter one

Andrew
Scientific teaching of science

- Evidenced based
- Hypothesis driven

Scholarship of Teaching and Learning (SoTL)

- Appropriate methods
- Significant results
- Reflective
- Share with colleagues
Evidence
Eye Openers

- 50% of traditional college students have not yet developed the ability to think abstractly.
- Most people neither absorb nor retain material very well by simply reading or hearing it.
- Cognitive development – college students have not reached, and may not reach, cognitive maturity.
  - Most freshmen, and many upper class students, are very superficial learners.
Undergraduates as abstract thinkers

- Genetics is a course where it is important for students to be able to think abstractly.
- “Molecules dancing in their heads”
- Literature – 50% of my 18-20yo have not transitioned from concrete thinkers to abstract thinkers.
- Classroom data – my students fit that profile.
R. Hake, "…A six-thousand-student survey…” AJP 66, 64-74 (‘98).
Cognitive development


- Cognitive – of, relating to, being, or involving conscious intellectual activity (as thinking, reasoning, remembering)

- Stages of intellectual development in college students
  - Dualism
  - Multiplicity
  - Relativism
  - Commitment
William Perry – Cognitive development

**Dualism-right answers only**

- Just give me the facts
- Division of meaning into two realms
  - Good/bad, right/wrong, success/failure
- There is no uncertainty and ambiguity – only TRUTH
- Authority knows the RIGHT answer
  - The teacher knows all
- Knowledge is quantitative
Diversity of opinion and values is recognized as legitimate in areas where right answers are not yet known.

 Authorities are right, others are wrong

 All opinions are equal

 Where authorities don’t know the right answers, everyone has a right to his own opinion; no one is wrong
Beginning of shift from certainty to uncertainty

Some truth remains unknown—even to true authorities

Some opinions may be found worthless

Knowledge is qualitative
William Perry – Cognitive development

Commitment

- Acknowledges ambiguity as alternative views
- Can see, understand, and argue both sides of an argument while recognizing that both may be equally “right”.
- Understand that commitments are ongoing activities which may change with new/different/more information
And thus started my teaching career
Long Term Memory Boost

- Think about what was just discussed and identify something that was surprising to you.
- Turn to your neighbor and tell them what it was.
Chapter 2

More research and a deeper understanding of student learning
Turning to the literature

- Behavioral
  - Education
  - Cognitive psychology

- Biological
  - neuroscience
Fish is Fish

Leo Lionni
…”Birds,…who had wings, and two legs and many, many colors”
“Cows! They have fours legs, horns, eat grass and carry pink bags of milk.”
“And people! Men, women, children”
A neuroscientist sees this picture and immediately envisions a 3-D structure, not just a bunch of slices.

The students are building on prior knowledge and misconceptions as they construct their knowledge of the spinal cord. They mostly see the spinal cord as a flat 2-D, blue and white image, not distinct structural pathways, etc.
Kristen’s model building exercise

We need to help the students construct their knowledge.
Biological changes – cognitive neuroscience literature

- Functional organization of brain and mind
  - Depends on and benefits positively from experience
- Development of brain/mind is dependent on biological processes and experiences
- Some experiences have most powerful effects during specific sensitive periods. Others can effect brain over longer period of time
- Difficult, at this time, to dictate that specific activities lead to neural branching – i.e. specify specific teaching practices to produce specific learning.

From: Bransford, How People Learn, 2000
Chapter 3

- The transformation of Alix Darden, scientific teacher

- How do I help my students develop to “think like a scientist (microbiologist, geneticist, etc.)”?
  - Impact of engaging in research
Critical Thinking

Knowledge
- Defines
- Describes
- Identifies
- Labels
- Matches
- Lists

Skills
- Define the problem
- Find sources of information
- Determine credibility of sources
- Distinguish between facts and claims
- Demonstrate, compare and explain
- Compute
- Relate
- Problem solving using pertinent information
- Ask appropriate questions

Cognitive Abilities
- Self-reflection
- Questioning and willingness to question
- Design
- Tolerance of other points of view
- Open-minded to other solutions
- Develop and defend a position on an issue
- Self-directed learner

CASTLE Critical Thinking Framework - 2003

Ref: Plemmons, JK., AG, 2004
Background-College Biology Courses

Presented as a stable body of knowledge

- Textbook driven
- Cookbook labs
- Generally not inquiry driven
- Learners discouraged from developing their own explorations
- Inaccurate view of the authentic process of science
Background, con’t

- Minimal opportunity to:
  - Make sense of contradiction
  - See disagreement among science experts
  - Evaluate scientific knowledge
  - Develop their own explanations of observations
  - Design experiments
  - Develop hypotheses and test them
My Goal/Hypothesis

- To structure a Biology course which will enable students to think and behave like scientists (critical thinkers).
Evaluating your knowledge

- How does a scientist think?
- What are 1-2 skills you would like your students to develop as they learn to “think like a microbiologist”?
How Experts Differ from Novices

Key principles

1. Experts notice features and meaningful patterns of information that are not noticed by novices.
2. Experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter.
3. Expert’s knowledge cannot be reduced to sets of isolated facts or propositions but, instead, reflects contexts of applicability: that is, the knowledge is “conditionalized” on a set of circumstances.
How Experts Differ from Novices

Key principles – con’t

4. Experts are able to flexibly retrieve important aspects of their knowledge with little effort.

5. Though experts know their disciplines thoroughly, this does not guarantee that they are able to teach others.

6. Experts have varying levels of flexibility in their approach to new situations.

Ref: Bransford, et.al., 2000, How People Learn. pp31-50
Thinking/acting like a scientist

- **Relevancy** - application of concepts, principles and processes of science to the environment.
- **Transfer** – apply knowledge/skills to new settings
- **Ambiguity** – acknowledging that our knowledge in not complete
- **Inquiry** - defining and investigating problems, formulating hypotheses, designing experiments, gathering data and drawing conclusions about problems.
- **Constructivism** - Knowledge is not passively received but built up, constructed
- **Collaboration** – science is not performed in isolation
- **Questioning** – good scientists ask good questions
My Hypothesis

- A Biology course can be designed which will enable students to think like scientists (critical thinkers).
  - In this course students will construct their knowledge, be able to ask good questions, acknowledge the ambiguity associated with science, be able to transfer that information to other settings.
Molecular Genetics - Biol 424

- Structured around instructors current molecular biology research, both lecture and laboratory
- No text – used original research articles and other selected readings
- Lab – using basic molecular genetics techniques design and execute experiments not previously done
- Students and teacher a team
- Students construct their knowledge as they read research articles, design lab experiments, interpret data
- Junior/senior level
- Small 4-9 students
Student Work

- Weekly homework – application questions
- Weekly lab write-ups
- 2X-Calibrated Peer Review™
- Synopsis of all journal articles presented
- Each student presents one journal article
- Write publication style research paper
- Create a poster of research project to present at Student Research Day
- Reflection on their learning in the course (meta-cognition)
Methodology – assessing students ability to think like scientists

- Observations
- Analysis of student writing
- Student reflections
- Scientific products

Remember the goal: To structure a Biology course which will enable students to think like scientists (critical thinkers)?

- In this course students will construct their knowledge, be able to ask good questions, acknowledge the ambiguity associated with science, be able to transfer that information to other settings.
A masters of education student observed my class for 10 weeks. Assessed the learning environment using three different rubrics looking at a “constructivist class”.

Conclusion: The majority of the activities in the class demonstrated a high level of constructivist learning.
“What defines long-term as compared to a thirty minute short-term stress?”

“What was the purpose of using salmon sperm in this experiment?”

“Would that DNA have an affect on the yeast DNA?”

“How precise were these cuts?”

“What was the smallest amount of DNA removed at one time?”

“One question that could come about is how functional would the bovine gene be if inserted into human photoreceptor cells? Is there anyway this could be tested?”

“Due to the normal conservation of the genes, how can they assume that these results would be the same in humans?”
“A view of mine that definitely changed as a result of this course was also, coincidentally, probably the hardest thing for me to learn in the last three months. That is the fact that not all experiments turn out like you think they will, and sometimes you just have to settle for the results you get. A lot of science is about making mistakes, and making the wrong guesses. … But all of those experiments I’ve ever done before, including in college… were kitchen-cookbook type experiments. They’ve been done millions of times before, they’re usually fool-proof, and it’s about as difficult as following the instructions on how to assemble a Lego set. This was hardest for me to learn because, I think, I had been so set in that cookbook style of thinking, and this was a radical departure from that. Here I was forced to think more, not just to memorize what should happen-I had to draw from all that knowledge I had to figure out, “well, if we have these things, and we do this to them, under these circumstances, then, according to what I remember about this substance, this should happen”.

Student Reflections

Ambiguity
“In this semester’s study, I would honestly say that I learned a vast amount of scientific information. While most classes serve as surveys in specific fields they are not able to get into much detail on any specific issues involved in that subject. However, this research based study did just that. Instead of merely surveying the study of Molecular genetics, we were specifically involved with the area of the promoter sequence of DNA, and genes in photoreceptor cells of the retina. While I am not, in fact a doctor in this area, there is no doubt in my mind that each member of the class could intelligently discuss the field of transgenic research and the background facts of opsin gene research. In many cases, the students could possibly supercede the intellectual knowledge of this study to those biology professors not directly involved with the study. Furthermore, at the senior level, in which the brain has more or less fully developed in the intellectual capacity, students could possibly apply the direct information studied in this class to successfully understand the complete survey of molecular genetics."
With respect to the laboratory, ... we were not always following a cookbook. While this provided numerous opportunities to fail, e.g. hour-long incubation of buffer and no DNA, this lab taught us a lot. Perhaps the most valuable thing learned was not even the material, but what was actually involved with research – how the scientific method works in the real world. If nothing else, this lab has given us a level of maturity higher than that of people who were not subjected to this style of lab - which will give us an advantage in further schooling or the science job world..."
Students Professional Scientific Products

- Oral and poster presentations by the students at local and regional science meetings
Student Reflections
Thinking Like a Scientist

“I can’t say we produced significant data as pertaining to our hypothesis, but what I can say is that everyone who was in that lab on Wednesday afternoons produced significant results contributing to the overall understanding each of us has for the world of research. There is the only way to cross the bridge from simple undergraduate students feeding on the information given to them by their professors into higher-level students taking an active role in their learning, and that is through courses like this one. All in all, after having completed this class and the atmosphere it placed us in, I feel that this is an experience all biology majors serious about their course of study should undertake. There is knowledge gained and an understanding achieved of things that just aren’t learned in standard lecture-based classes.”
Reflections

- What have you heard that you might apply to your teaching?
Conclusions

- The development of student learning (teaching) can be approached scientifically.
  - Hypothesis and data driven.
  - Based on previous literature
  - Results - Learning is the measurable outcome, not teaching
- My students and I are in this learning journey together.
Why should we care about a scientific approach to teaching?

- Time
- Next generation of scientists and scientifically literate consumers (voters)
- Tight budgets/accountability
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Biology Scholars Program

Scholars to Lead National Reform Efforts

*A Test of Leadership (The Spellings Report)*, published in 2006, calls for reshaping higher education demanding accountability and transparency in colleges and universities. The report challenges colleges and universities to change from a system based on reputation to one based on performance. In response, the life sciences professional societies established the Biology Scholars Program to enhance biologists’ understanding and practice of evidence-based teaching and learning. The Program is a multi-year leadership program for college biology faculty to bring about reforms in undergraduate education.

**Virtual Residencies**

The Biology Scholars Program is based on three independent, but intertwined virtual residency programs, where faculty employ rigorous evaluations of their own teaching with the goal of publishing results demonstrating improved student learning in the laboratory or classroom and leading colleagues in national efforts to sustain undergraduate biology education reform.

**Important Dates & Deadlines**

2008 Research Residency Applications Due → March 1, 2008

**Who Should Apply?**

The Research Residency seeks biologists who are asking questions about the effectiveness of their teaching approaches. The 2008 Research Residency begins with the Scholarship of Teaching and Learning Institute planned for July 16-19 in Washington, DC.

The Writing Residency, planned for 2009, seeks biologists who are conducting classroom research on learning. Competitive applicants have begun their studies, amassed data and are preparing to analyze their work for publication.

The Leadership Residency, planned for 2010, seeks biologists who are engaged in learning research and are ready to bring about changes locally on campus and nationally through their professional societies.
New NIH Initiative

- ARRA – American Recovery and Reinvestment Act
- Funding for administrative supplements to existing NIH grants and $21 over 2 years has been allocated for educational opportunities in NIH-funded laboratories for students and science educators.
- Signed into law by President Obama, Feb 17, 2009
Additional resources

- Journal of Microbiology and Biology Education. [http://www.microbelibrary.org](http://www.microbelibrary.org)
- Life Sciences Education (formerly Cell Biology Education) [http://www.lifescied.org/](http://www.lifescied.org/)
  - May 28-31, Colorado State University