Designing Effective Introductory Biology Labs: Fostering a Spirit of Inquiry

John S. Peters, Ph.D. (petersj@cofc.edu)
College of Charleston, Department of Biology
http://petersj.people.cofc.edu/CCLI/

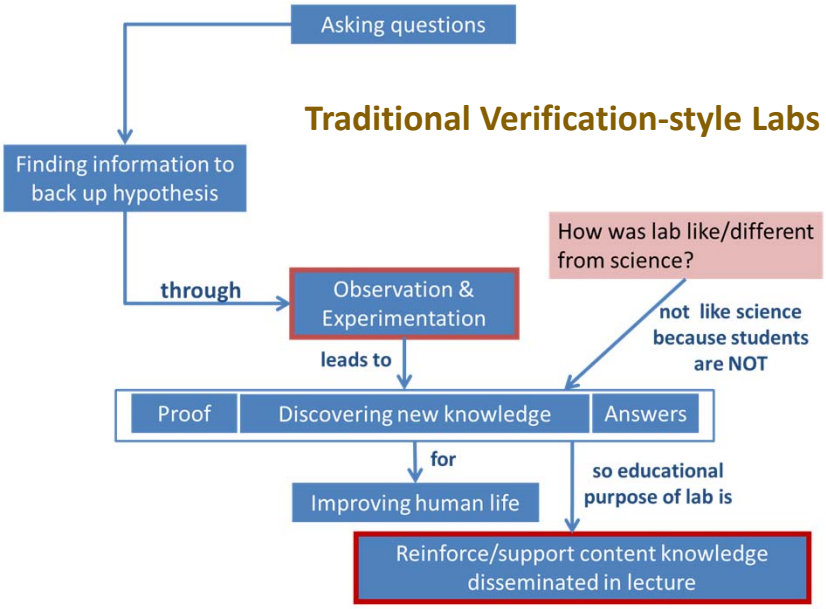
Introductory Biology Lab at the College of Charleston, SC

- Liberal Arts and Sciences Institution (~10K Undergraduates).
- Labs are taught by Master's Level Graduate Teaching Assistants.
- Separate majors and non-majors labs/classes.
- ~800 biology majors go through our 2 course introductory lab/class each year.
- ~300 non-science majors go through the 2-course general education biology sequence each year.
- I coordinate the labs with help from another faculty member and a lab manager.

Think back to your science labs when you were in college. What was your experience more like?

	Guided verification-style lab	Inquiry-based lab
What was the initial context for the lab	Concepts/processes initially discussed in lecture	Student observations of nature or relevant science-related issues
How was knowledge required to perform the lab acquired by students?	Class or pre-lab lecture or assigned textbook chapter	Independent research of questions leading from initial lab context
What was source of experimental question, hypothesis, methods and predictions.	Explicitly provided by the lab manual or instructor	Students formulate; guided by prior research, and with support from the instructor & lab manual
What support was provided to help students explain their findings?	The lab manual or instructor provided specific conceptual questions to answer.	Instructor or lab manual served as a guide to assist students with interpreting & explaining findings.
How did students communicate findings?	Lab report with specific questions to answer or topics to address.	Authentic assignments (i.e. scientific article, presentation, poster, policy statement, stakeholder letter)

What do scientists do? What do they produce?



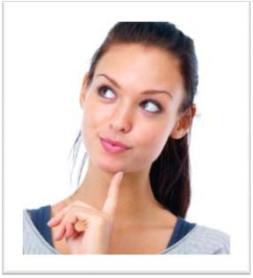
How was lab like/different from science?

Savannah - I think most scientists…are looking for new things and I think what we did was to learn what's already known. So it wasn't in a sense really research or what I would consider research…, I was also really disappointed in the labs…it was just a lot that we did that just wasn't really that exciting.

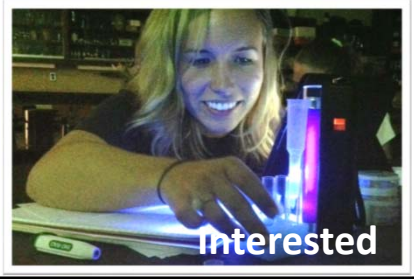
Lindsay - …we're not really coming up with anything on our own, like John was saying, we're just like doing something in a book that's been done numerous times. We're not …applying anything that we've learned. We're just… following a procedure, which is like part of the scientific method I guess but we're not coming up with our own ideas. I guess we're only in an intro class so I guess we wouldn't…

Spirit of Scientific Inquiry…what is it?

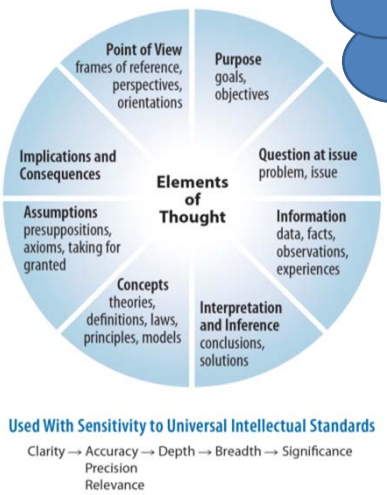
Some of the obvious ones we started with in the reform of our lab curriculum…



Questioning



Requiring proper reasoning, empirical, verifiable evidence before making or agreeing with a new claim.



Skeptical

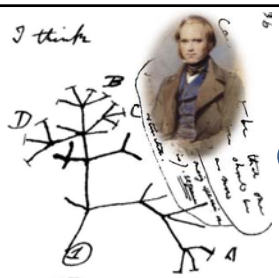
From the Mini-guide to Critical Thinking - https://www.criticalthinking.org/files/Concepts_Tools.pdf

Creative

Questioning, hypothesizing, devising experiments, seeing patterns require thoughtful observation, insight, imagination, careful planning and use of learned skills.

Confidence in reason

People can learn to form rational viewpoints, draw reasonable conclusions, think logically, and be persuaded using proper reasoning.

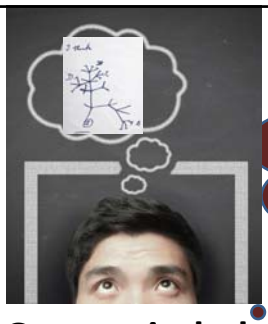


Seeks new intellectual insights in spite of difficulties, obstacles & frustrations.

Intellectual Perseverance & Courage

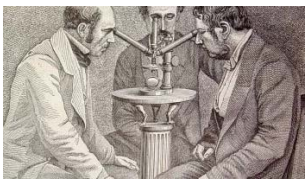
Honestly admit discrepancies & inconsistencies in ones thought, or conclusions.

Intellectual Integrity



Open to; not threatened by new understandings that sit outside deeply-held views

Open-minded

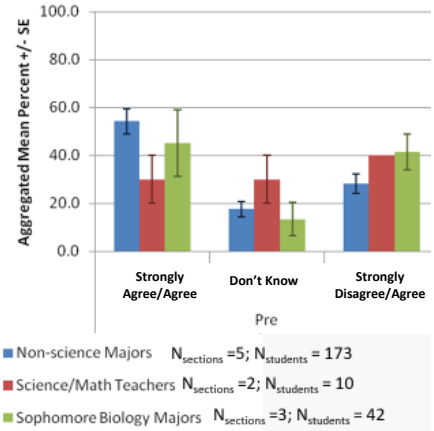


Values intellectual autonomy but also understands the value of collaboration.

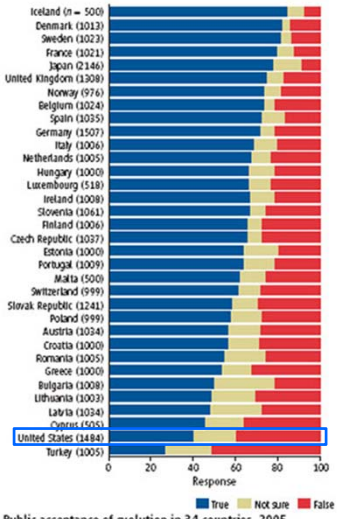
Independent & Collaborative

Why does fostering a spirit of scientific inquiry matter?

"Intelligent Design" should be taught as a valid alternative theory in addition to evolutionary theory in public high school biology classes.



Public Acceptance of Evolution



Public acceptance of evolution in 34 countries, 2005.
From the Pew Research Center

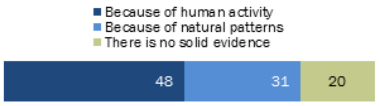
What do you think are the justifications students most often use to advocate teaching ID in addition to evolution?

1. So that students can make up their own minds as to what they want to believe. This creates well-rounded students who think critically.
2. Because evolution has not been proved and schools should be open to teaching other explanations.
3. Because ID is viewed as a valid theory by many people.

Why does fostering a spirit of scientific inquiry matter?

About half of Americans say Earth is warming due to human activity

% of U.S. adults saying climate change is mostly due to human activity/mostly due to natural patterns/there is no solid evidence that Earth is getting warmer

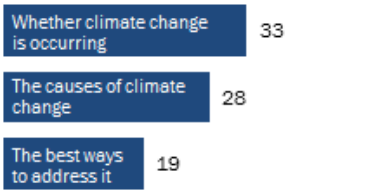


Note: Beliefs about climate change include those who "lean" toward each response. Those who did not give an answer are not shown.
Source: Survey conducted May 10-June 6, 2016.
"The Politics of Climate"

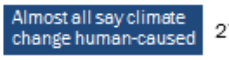
PEW RESEARCH CENTER

http://www.pewinternet.org/2016/10/04/public-views-on-climate-change-and-climate-scientists/

Climate scientists understand very well ...



Perception of scientific consensus



Information on causes of climate change

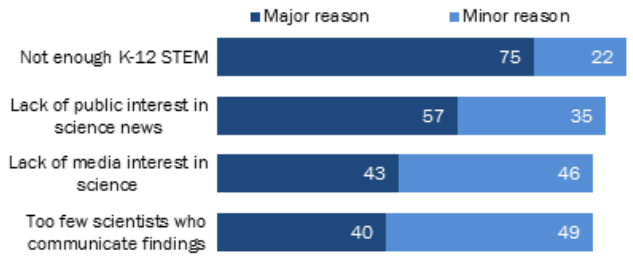
When [her teacher], ascribed the recent warming of the Earth to heat-trapping gases released by burning fossil fuels…she asserted that it could be a result of other, natural causes.
When he described the flooding, droughts and fierce storms that scientists predict within the century if such carbon emissions are not sharply reduced, she challenged him to prove it. "Scientists are wrong all the time," she said with a shrug.

Climate Science Meets a Stubborn Obstacle: Students
NY Times, June 4 2017 https://nyti.ms/2sFhOTI

Gwen Beatty in James Sutter's classroom at Wellston High School in Ohio, where she and Mr. Sutter battled heads over the issue of human-caused climate change. Maddie McGarvey for The New York Times

Scientists' Perspective: Too Little K-12 STEM Linked to Limited Public Science Knowledge

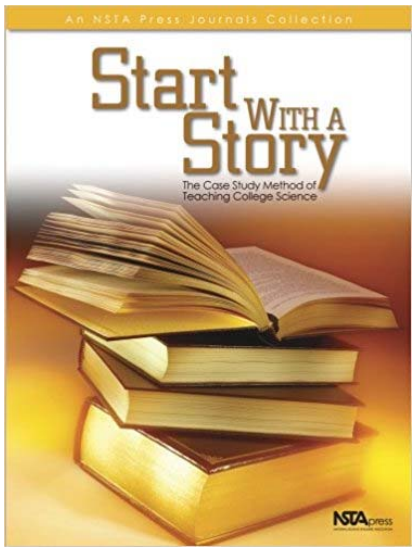
% of AAAS scientists saying each is a major/minor reason for the U.S. public having limited knowledge about science



AAAS scientists survey Sept 11-Oct 13, 2014. Q6a-d. Those saying not a reason or giving no answer are not shown.

PEW RESEARCH CENTER

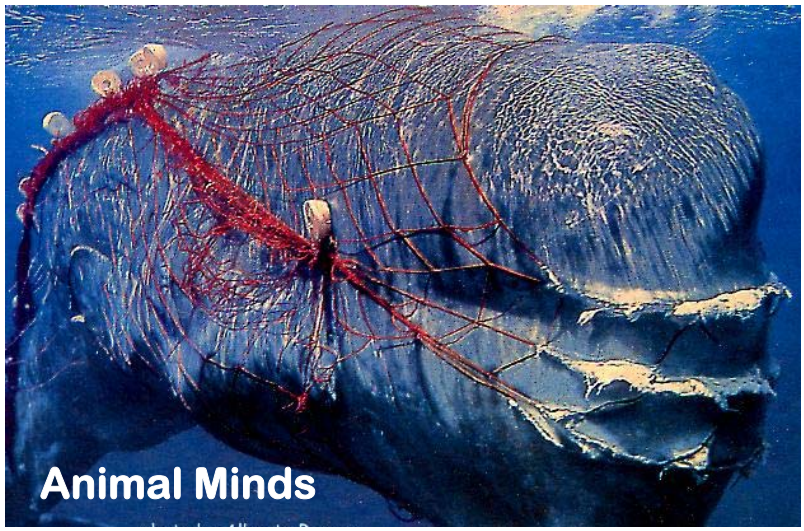
Fostering a spirit of inquiry in lab from DAY ONE…



- ✓ …which engages the learner.
- ✓ …elicits wonder.
- ✓ …encourages students to reveal their thinking about scientific inquiry.

http://pal.lternet.edu/docs/outreach/educators/education_pedagogy_research/start_with_a_story.pdf

RADIOLAB



https://www.wnycstudios.org/story/91701-animal-minds

Do you think that whale was saying "thank you" (exhibiting gratefulness)?

A. Yes

B. No

Is “gratefulness for the divers’ actions” a valid scientific hypothesis explaining the whales behavior at the end of the story?

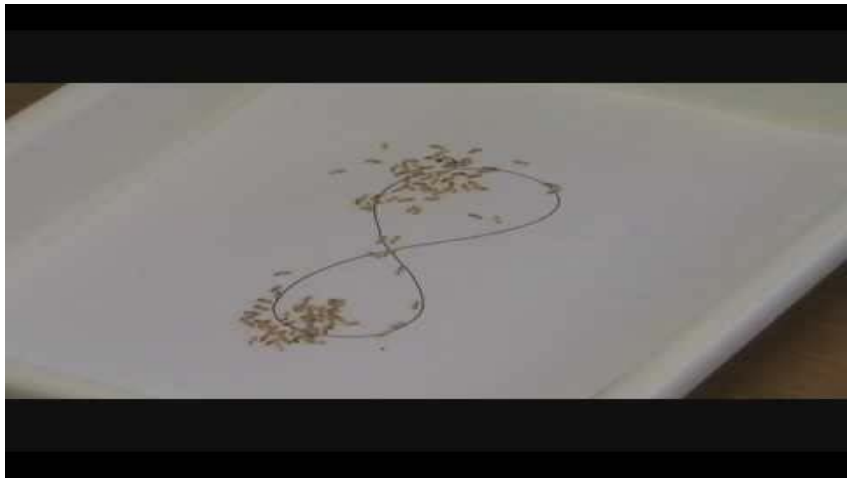
A. Yes it is.

B. No it is not.

C. Not sure?

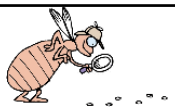
What justifications do you think students would use to explain their choice?

Termite Trails



https://youtu.be/4ClwpgtWP_Y

Termite Trails Lab

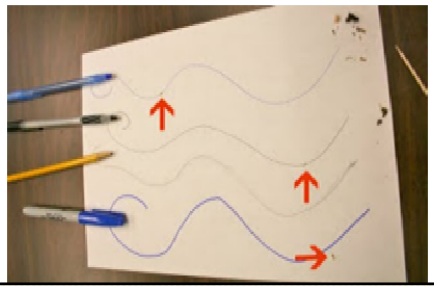


Team Work

- ✓ Pose hypothesis
- ✓ Plan experiment
- ✓ Develop prediction
- ✓ Conduct experiment
- ✓ Summarize results
- ✓ Share with class

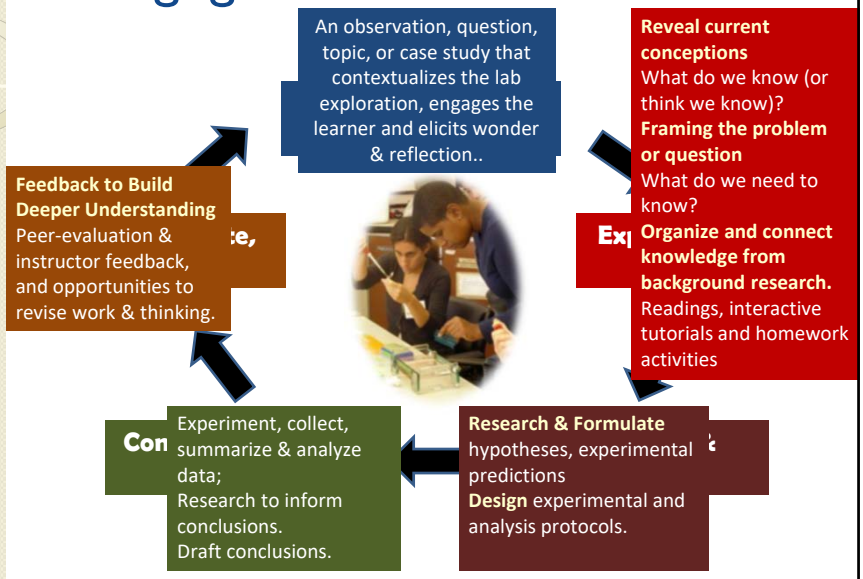
Individual Work

- ✓ Use EXPLICIT feedback from post-lab discussion & follow-up readings to revise protocols and predictions



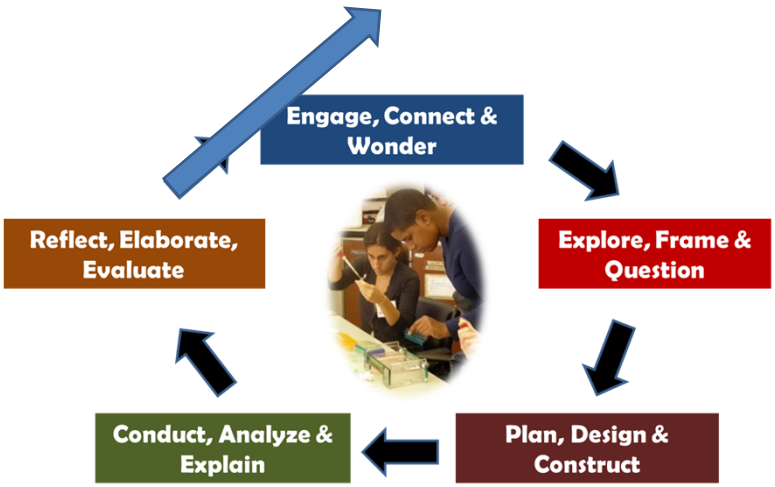
Which aspects of a "spirit of scientific inquiry" do we begin to foster in this opening lab?

Pedagogical structure of labs…



Evaluative Assignments which:

- Connect lab finding to science-related issues AND encourage action!
- Foster communication of science BOTH to scientists and to the public.



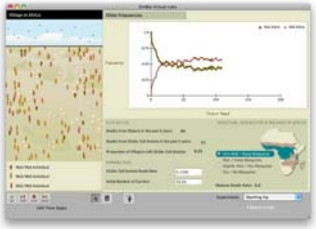
Connecting inquiry & action…

Engage, Connect & Wonder

Case Study: [The Evolution of Intelligent Design]

Inquire

SimBio: Darwinian Snails & Sickle Cell Alleles Labs



Action

Students use what they have learned in lab and class to develop a **policy brief** to the local school board regarding teaching evolution and ID in biology classrooms.

Connecting inquiry & action…

Engage, Connect & Wonder

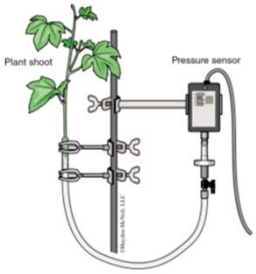
Case Study

Part 1: Amazon Deforestation, Once Tamed, Comes Roaring Back

Part 2: Hahai no ka va i ka ululáau

Inquire

Exploring Water & Nutrient Transport in Plants



Students, working in teams, devise an experiment exploring factors they hypothesize may influence transpiration.

Action

Students use what they have learned in lab and class to evaluate the "rain follows the forest" hypothesis; it's implications for preserving/restoring rainforests.

Amazon Deforestation Roars Back

Part 2: Hahai no ka va i ka ululáau

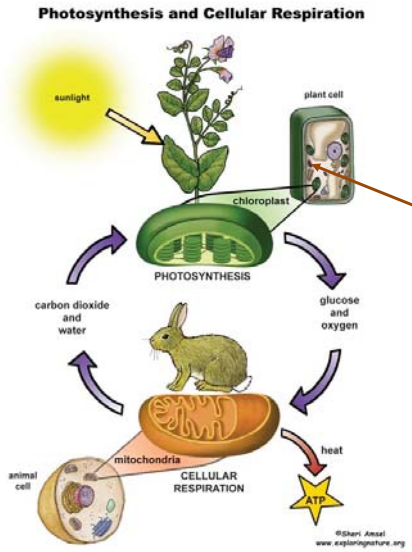
Why do rainforest exist where they do? Do they exist where they are solely because it happens to rain a lot where these forests occur? Or, is it as the ancient Hawaiian proverb states – "*Hahai no ka va i ka ululáau*" – **the rain follows after the forest**. That is, the rain is there because of the forest. If the latter is true, how could rainforests produce rain? And what are the implications of this for rainforest protection & reforestation?

Independent Research Projects

Lab curricular structure

Stage of Inquiry	Traditional →	Guided-Inquiry (Practicing inquiry) →		Student-directed Inquiry (Performing inquiry)
Context for Inquiry	Concepts or processes covered in lecture or textbook	Student observations of nature or a relevant issue or case-study.		
Background research	Initial content lecture or reading provided to student		Assigned reading supplemented with independent research.	Students decide what background knowledge is required, and what learning resources to use.
Scientific question	Question provided by teacher	Students generate questions with some guidance		Students pose their own question
Evidence	Experimental methods and analysis procedures are provided to students	Students make some methodological and analysis decisions with guidance from the lab		Students decide on what evidence to collect and how to collect it.
Explanations	Students are provided questions to answer about their findings.	Students are provided general guidelines on what to discuss in their explanations		Students independently formulate their own explanations
Connections to concepts	Students are explicitly told which concepts to use through specific questions.		Students coached to make certain concept connections through independent research	Independently decided on in student research teams.
Communication of findings	Answering lab follow-up questions	Written discussion of findings with guidance from lab or instructor coaching.		Independently by students. Multiple forms of communication or media can be used. Peer review is stressed.

Independent Research Projects



Ahoy!!…there are some mitochondria in there!

Independent Research Projects

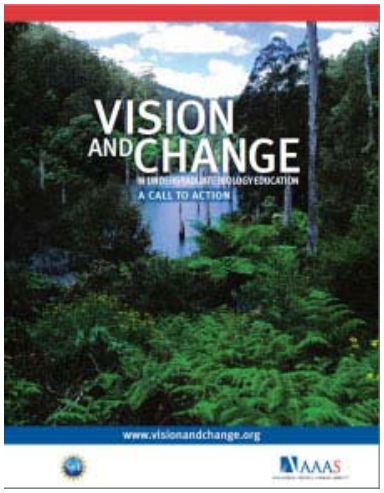
Independent Projects Labs

- Multi-week and in-depth exploration
- Done in both biology majors' and non-majors' labs
- Student-directed:
  - Student observations, experiences and interests set the context for the project.
  - Students
    - formulate questions, hypotheses, experimental predictions.
    - design procedures
    - summarize and analyze quantitative data
    - draw conclusions
    - authentically communicate findings
    - work collaboratively and independently
  - Model how the scientific community works to strengthen studies and validate knowledge.

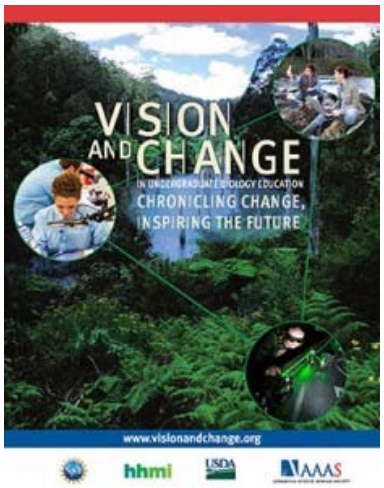
Effective team projects engender <u>positive interdependence</u> among team members while facilitating individual accountability for learning concepts and intellectual skills.

Independent Research Project: Scientific Article & Symposium

Team Work	Individual Work
Develop questions & initial hypotheses	
Develop proposal	Background research to inform hypotheses, protocols & predictions
Proposal Peer-review	
Revise & conduct experiment, summarize and analyze date	Research to explain findings
Share research and formulate general conclusions	Write article abstract, introduction & conclusion
Research Symposium	Peer Evaluation of Presentations & Publication



http://visionandchange.org/resources/



Core Competencies…

APPLY THE PROCESS OF SCIENCE:
Biology is evidence based and grounded in the formal practices of observation, experimentation, and hypothesis testing.

USE QUANTITATIVE REASONING:
Biology relies on applications of quantitative analysis and mathematical reasoning.

USE MODELING AND SIMULATION:
Biology focuses on the study of complex systems.

TAP IN TO THE INTERDISCIPLINARY NATURE OF SCIENCE:
Biology is an interdisciplinary science.

COMMUNICATE AND COLLABORATE WITH OTHER DISCIPLINES:
Biology is a collaborative scientific discipline.

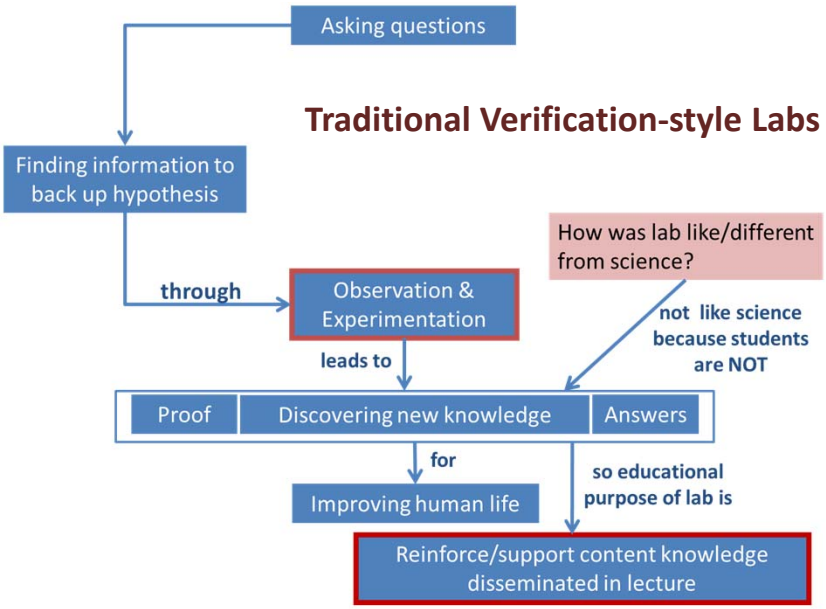
UNDERSTAND THE RELATIONSHIP BETWEEN SCIENCE AND SOCIETY:
Biology is conducted in a societal context.

From Vision & Change in Undergraduate Biology Education, 2011 - http://visionandchange.org/files/2015/07/VIChange2015_webFin.pdf

Action Items from Vision & Change

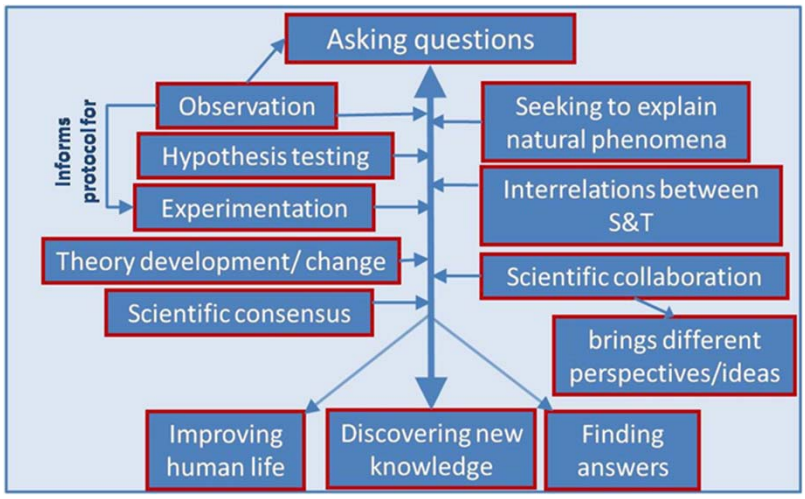
- Introduce the scientific process to students early, and integrate it into all undergraduate biology courses.
- Define learning goals so that they focus on teaching students the core concepts, and align assessments so that they assess the students' understanding of these concepts.
- Relate abstract concepts in biology to real-world examples on a regular basis, and make biology content relevant by presenting problems in a real-life context.
- Develop lifelong science learning competencies.
- Introduce fewer concepts, but present them in greater depth.
- Stimulate the curiosity students have for learning about the natural world.
- Demonstrate both the passion scientists have for their discipline and their delight in sharing their understanding of the world with students.

What do scientists do? What do they produce?



What do scientists do? What do they produce?

Inquiry-based Labs

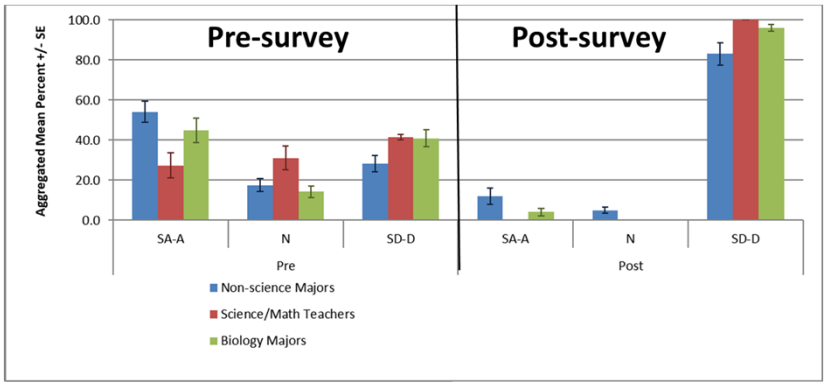


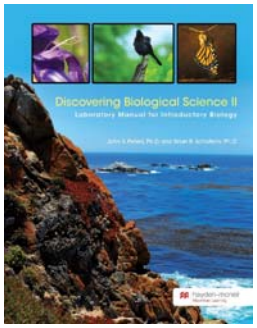
Classroom Undergraduate Research Experience (CURE) Survey Findings

- **Perceived Learning Gains** - IBL fostered greater perceived learning gains in **conducting open inquiry, conducting scientific investigations and nature and process of science literacy**. Traditional lab students valued **individual and whole class work** more than students in IBL.
- **Science Literacy** - Traditional lab students adopted significantly less literate views about the process of science in comparison to IBL students AND in comparison to their pre-course literacy. (small effect)
- **Perceived Benefits of Lab Experiences** – IBL fostered greater perceived benefits regarding **Doing Science, Understanding Science, Self Confidence, Creating a Learning Community, and Communicating Science** (moderate effect)

Why does fostering a spirit of scientific inquiry matter?

"Intelligent Design" should be taught as a valid theory in addition to evolutionary theory in public high school biology classes.





Student & Instructional Support Materials

- **Student Support Materials**
  - Team Lab Notebooks (TLNs)
  - Homework Activities
  - Interactive Tutorials
  - "Doing Science" Guides
- **Instructional Guides**
  - Conceptual and scientific skills goals
  - Materials & lab setup instructions
  - Pedagogical tips for facilitating student centered, inquiry-based & collaborative learning.
  - Assignment grading & feedback rubrics
  - Instructional PowerPoints
  - Ideas for connecting lab & class (coming soon)

For more information on the Discovering Biological Science labs…

Visit my website:
http://petersj.people.cofc.edu/CCLI/
Or visit Hayden-McNeil at Macmillan Learning - https://haydenmcneil.com/educators/inquiry-based-biology-labs