Designing Effective Introductory Biology Labs: Fostering a Spirit of Inquiry

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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?

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

**What do scientists do? What do they produce?**

**Traditional Verification-style Labs**

- Asking questions
- Finding information to back up hypothesis

How was lab like/different from science?

Not like science because students are NOT

So educational purpose of lab is

Reinforce/support content knowledge disseminated in lecture

Observation & Experimentation

Proof

Discovering new knowledge

Answers

for

Improving human life
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...

- Curious
- Confident
- Engaged
- Questioning
-Interested
Requiring proper reasoning, empirical, verifiable evidence before making or agreeing with a new claim.

Skeptical

From the Mini-guide to Critical Thinking -

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

Creative

Questioning, hypothesizing, devising experiments, seeing patterns require thoughtful observation, insight, imagination, careful planning and use of learned skills.
Seeks new intellectual insights in spite of difficulties, obstacles & frustrations.

Intellectual Perseverance & Courage

Honestly admit discrepancies & inconsistencies in one's 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.

![Graph showing public acceptance of evolution across countries]

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

- Because of human activity: 49
- Because of natural patterns: 31
- There is no solid evidence: 20

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 8, 2016.
“The Perils of Climate”
PEW RESEARCH CENTER


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
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
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
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

[Image of termites trails]

[Video link: https://youtu.be/4ClwpqtWP_Y]
Which aspects of a “spirit of scientific inquiry” do we begin to foster in this opening lab?

**Pedagogical structure of labs…**

- **An observation, question, topic, or case study that contextualizes the lab exploration, engages the learner and elicits wonder & reflection.**
- **Reveal current conceptions**
  - What do we know (or think we know)?
  - Framing the problem or question
  - What do we need to know?
- **Organize and connect knowledge from background research.**
  - Readings, interactive tutorials and homework activities
- **Experiment, collect, summarize & analyze data; Research to inform conclusions.**
  - Design experimental and analysis protocols.
- **Feedback to Build Deeper Understanding**
  - Peer-evaluation & instructor feedback, and opportunities to revise work & thinking.
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

Inquire

SimBio: Darwinian Snails & Sickle Cell Alleles Labs

Case Study: The Evolution of Intelligent Design

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…

**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

**Engage, Connect & Wonder**

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.

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**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

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

Ahoy!!...there are some mitochondria in there!
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 positive interdependence among team members while facilitating individual accountability for learning concepts and intellectual skills.
Independent Research Project: Scientific Article & Symposium

Team Work
- Develop questions & initial hypotheses
- Develop proposal
- Proposal Peer-review
- Revise & conduct experiment, summarize and analyze date
- Share research and formulate general conclusions
- Research Symposium

Individual Work
- Background research to inform hypotheses, protocols & predictions
- Research to explain findings
- Write article abstract, introduction & conclusion
- 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.

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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?

**Traditional Verification-style Labs**

- Asking questions
- Finding information to back up hypothesis
  - through Observation & Experimentation
  - leads to Proof
  - Discovering new knowledge
  - Answers
  - for Improving human life
  - so educational purpose of lab is Reinforce/support content knowledge disseminated in lecture

- How was lab like/different from science?
  - not like science because students are NOT

**Inquiry-based Labs**

- Asking questions
  - Observation
  - Hypothesis testing
  - Experimentation
  - Theory development/ change
  - Scientific consensus
  - Improving human life
  - Discovering new knowledge
  - Finding answers

- Seeking to explain natural phenomena
- Interrelations between S&T
- Scientific collaboration
  - brings different perspectives/ideas
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/](http://petersj.people.cofc.edu/CCLI/)

Or visit Hayden-McNeil at Macmillan Learning -  