Comparable Benefits of an Inquiry Driven Introductory Biology Course and a Summer Research Experience

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Abstract

There is interest in using investigative learning in courses to generate the benefits found for research experiences, in a way that is more broadly available and less resource intensive. In this study, we look at whether a single introductory biology course can provide students with comparable learning gains to a summer research experience. Grinnell College's BIO150 Introduction to Biological Inquiry course introduces students to how biologists pose questions, design experiments, analyze data, and communicate. Individual sections have different topics, but all sections involve intensive student-directed investigation and are taught in a workshop format. Since the course design was modeled on research, it is expected that outcomes from such a course would be comparable to those of an undergraduate summer research experience. Learning gains reported from the CURE (Classroom Undergraduate Research Experience) survey by students from multiple sections of BIO150 are compared to those reported on the SURE (Survey of Undergraduate Research Experiences) by students from multiple institutions who recently completed a dedicated undergraduate research experience. Mean student responses (n≤137) to 17 out of the 21 learning gains listed in the CURE survey were higher than the same learning gains reported from SURE (n≤ 2,657, national respondents during 2012). On a 5 point scale, with 5 being the largest gain, the highest gains reported by the BIO150 students were in the categories of skill in science writing (4.17 2SE=0.164), ability to read and understand the scientific literature (4.16 2SE=0.171), and learning laboratory techniques (4.1 2SE=0.161). The BIO 150 gains in these categories and 5 others were significantly higher than those reported in SURE. Learning to work independently was the only gain that was rated significantly lower in BIO 150 than research. These data support the hypothesis that a single introductory biology course can provide comparable learning outcomes to a dedicated research experience.

Please note that this abstract and the data reflected in the presentation represent analysis of a larger data set than was used for the published abstract. The major conclusions are the same but are better supported with the larger data set presented here.

BIO 150 Introduction to Biological Inquiry

Development:
All of the introductory science courses at Grinnell have been reformed to be more inquiry-driven, utilizing modern pedagogies to make science appealing and accessible to students with a wide range of learning styles. The Grinnell Science Project, an effort to promote diversity among students in the sciences, was a major force in this widespread curricular reform and was recently awarded a Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring (PAESMEM).

BIO 150 Introduction to Biological Inquiry exemplifies this approach in which the old survey courses were replaced with a one-semester, project driven introduction to Biology and Biological Chemistry.

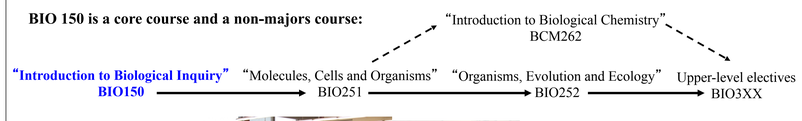
Catalog description:
BIO150 Introduction to Biological Inquiry (Fall and Spring) 4 credits

An introduction to **how** biologists pose questions, design experiments, analyze data, and communicate scientific information, for prospective biology and biological chemistry majors as well as non-majors. Although individual sections will have different topics and formats, all sections will involve intensive **student-directed investigation** and include a laboratory component. Prerequisite: none.

Common goals assist students to develop skills in:
- Utilizing scientific publications in the primary and secondary literature
- Formulating testable hypotheses & designing properly controlled experiments
- Collecting and analyzing data
- Presenting scientific papers and posters to communicate research

Format:
The course is taught in a workshop format, in which lecture and lab are combined. When possible, classrooms are adjacent to laboratories. There are up to 24 students in each section. Sections are coordinated with use of a common manual called *Investigations* that guides students through common elements of scientific research, sharing research proposals and a course-wide poster session.

BIO 150 is a core course and a non-majors course:



CRE vs REU

CURE vs SURE

Take the CURE? SURE!

The Classroom Undergraduate Research Experience (CURE) survey is designed to measure student experiences in "research-like" or other science courses.

The Survey of Undergraduate Research Experiences (SURE) is a survey for undergraduates who have recently completed a research experience, usually in the summer.

The learning gain items below are the same as a list of gains students self-assess when they complete the SURE survey. The parallel between the two surveys permits an analysis of how well the course experience emulates the gains of a research experience. A consistent result is that mean rankings on most items on the CURE, except for writing and ethics, are lower than SURE means. In addition, courses with a research-like component yield means higher than courses with no research-like component. The means shown for the "CURE: All Students" benchmark are for all CURE participants completing an introductory course. The scale is 1 to 5, with 5 being the largest gain. These items appear only on the post-course survey.

The CURE and SURE surveys, descriptions, and analyses were provided by David Lopatto and Leslie Jaworski. These assessment tools are supported by the HHMI.

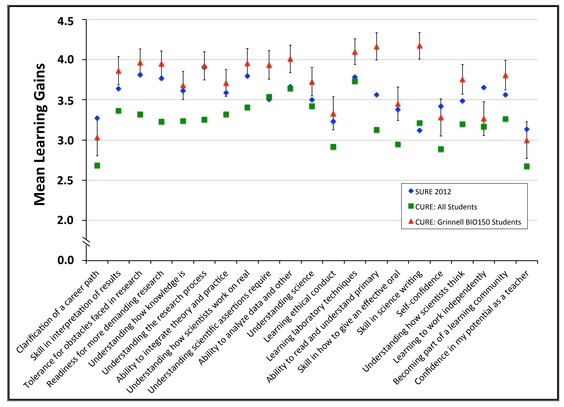


Figure 1. Students taking Bio150 report increased learning gains equal or greater than those reported by summer research students in multiple key competencies. CURE data represent self-reported learning gains after taking BIO 150. The mean student responses (n≤137) to 17 out of the 21 learning gains listed in the CURE survey were higher than the same learning gains reported from SURE (n≤ 2,657, national respondents during 2012). Error bars represent 2 standard errors around the mean (2SE) for the CURE BIO 150 data. For each mean reported from SURE, 2SE are less than 0.05.

Eight of the gains were significantly higher:

	Grinnell BIO150 Students	Difference BIO150 vs SURE
Skill in science writing	4.17	1.05
Ability to read and understand primary literature	4.16	0.60
Understanding scientific assertions require evidence	3.93	0.43
Ability to analyze data and other information	4.01	0.34
Learning laboratory techniques	4.10	0.32
Understanding how scientists think	3.75	0.27
Becoming part of a learning community	3.81	0.25
Understanding science	3.73	0.23

Other measures of the impact of BIO 150

Analysis of student responses to the same question asked pre-course vs later stages of the course also indicate learning gains in the scientific method.
(Hare, J., B. Voyles, D. Lopatto, and L. A. Gregg-Jolly. "Teaching Introductory Biology at Grinnell College with Microbiology and Inquiry-Based Methods" Annual Meetings of the American Society for Microbiology, Salt Lake City, Utah, May 2002.)

Success in BIO 150 positively correlates with success in Organic Chemistry
In an analysis of factors correlated with success of Grinnell Science students in organic chemistry I (CHM 221), grade in BIO 150 was the only factor that had a statistically significant impact. Other factors that did not have a significant impact included grade in the chemistry pre-requisite (CHM 129), gender, ethnicity, scores on ACT math exams, high school GPA, parents education, and drive to succeed (Office of Analytic Support and Institutional Research at Grinnell, personal communication). Since there is not overlap of content between Organic Chemistry and BIO 150, this interesting finding suggests that skill development including critical thinking can enhance performance in future courses.

Bio 150 addresses the recommendations described in *Vision and Change*
Each faculty member reported addressing each of the 5 recommended content areas (evolution, structure and function, information flow, pathways and systems). The mean for each content area was at least 3 on a 5 point scale where 1=not addressed and 5=deeply addressed. Each of the 6 core competencies were reported to be addressed also, with faculty giving 5's to the process of science and quantitative reasoning.

Discussion

Relatively high learning gains (greater than 2.5) were reported by students who took the SURE and the CURE surveys. The reason for the higher learning gains in Grinnell's BIO 150 compared to other introductory courses including research is unknown, and may be related to the in-depth projects being the primary focus of BIO 150 compared to many courses that include a possibly less-developed and shorter research "module", or there could be a significant difference in the student make up or institutional structure. The pre-post CURE gains indicate that Grinnell students develop these skills in BIO 150.

Learning to work independently was the only category that was lower by a statistically significant amount in the BIO 150 CURE vs. the SURE data. In fact, fostering collaboration including peer review is emphasized in BIO 150. Besides being necessary for logistical reasons, collaboration is promoted as a critical skill in research.

A recently published article describes similar results for the HHMI SEA-PHAGES (Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science) project-driven introductory course. Those data present even higher learning gains in many categories than BIO 150, but the gains reported for SURE in that data set from 2008 were also higher than the SURE comparison group presented here (2012). There is also some variation in the categories reported on.

The increased learning gains for BIO150 and the SEA-PHAGE course compared to those reported after participating in a dedicated research program are especially remarkable considering the relative structures of courses and summer research.
- Compared to courses, summer research programs are usually competitive to get in to, involve more time (often with a singular focus as opposed to balancing multiple other classes, typically 3 additional courses at Grinnell), use more resources, have a much lower student/faculty ratio, and participants are more likely to be dedicated to the biological sciences.
- One likely important difference in student experiences in course vs. summer research is that the BIO 150 projects are often entail a lower technical level than summer research projects in which the research product is the primary objective. It is possible that this simplification combined with student learning as the primary objective of a course like BIO 150 contributed to the relative high learning gains reported here.

Resources