A Biology Curriculum Model for Integrating the Three Dimensions of the Framework and NGSS Using Data from Published Scientific Research

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Abstract

The *Framework for K-12 Science Education* and the *Next Generation Science Standards* call for curricula that integrate disciplinary core ideas, science practices and crosscutting concepts. However, there are very few models for high school biology curriculum materials—and associated, closely-aligned assessment tasks—that address all three of these dimensions. To address this issue, the Genetic Science Learning Center (GSLC) at the University of Utah and AAAS Project 2061 collaborated on a project in which the GSLC developed curriculum materials and Project 2061 developed associated assessment items. The six lessons on natural selection, which were designed for grades 9-10, integrate (a) the Life Science Disciplinary Core Ideas of Biological Evolution and concepts from Heredity needed to understand evolution, (b) the Science Practices of Analyzing and Interpreting Data, Using Mathematics and Computational Thinking, and Engaging in Argument from Evidence, and (c) the Crosscutting Concepts of Patterns, and Cause and Effect. Throughout the lessons and assessment tasks students work with skill-level-appropriate data from published scientific research. The natural selection lessons underwent several iterations of revision and pilot testing in 10 teacher's classrooms across the country with diverse student demographics. In the largest study, students ($n=308$) showed significant learning gains from pre-test to post-test ($t=4.265$, $p<0.001$). Additionally, student ability measured via Rasch modeling also reflected improvement ($t=9.289$, $p<0.001$). On the post-enactment survey teachers reported that although the materials were quite different from their typical natural selection lessons they would use the materials again. Taken together, these data show that this approach holds preliminary evidence of promise for increasing students' understanding of natural selection.

Keywords: biology education, evolution education, curriculum development, high school

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The *Framework for K-12 Science Education* (NRC, 2011) and the *Next Generation Science Standards* (*NGSS*) (NGSS Lead States, 2013) delineate a vision for science education that integrates Disciplinary Core Ideas, Science Practices and Crosscutting Concepts. However, there are very few models for high school biology curriculum materials—and associated, closely-aligned assessment tasks—that explicitly address all three of these dimensions. The empirical evidence supporting the efficacy of curriculum materials that embody the vision described in the *Framework* and *NGSS* also is still quite small.

Despite the importance of evolution as a Disciplinary Core Idea (Dobzhansky, 1973; NRC, 2011) and the numerous research studies that have documented students' misconceptions about evolution (reviewed in Gregory, 2009), only a few studies have reported research on instructional methods that have shown promise for increasing students' understanding of evolution, particularly at the secondary level. Studies at the undergraduate and high school level found that the explicit integration of heredity and genetics with evolution instruction led to increases in accepted scientific explanations and reductions of student misconceptions (Banet & Ayuso, 2003; Geraedts & Kerst, 2006; Kalinowski, Leonard & Andrews, 2010). Indeed, the *NGSS* makes many explicit ties between these two Core Ideas, as a robust understanding of the evolutionary process requires a foundational understanding of the genetic variation upon which evolution acts (NGSS Lead States, 2013). Two studies that engaged students with data analysis and simple statistics to understand variation and selection suggest that the Science Practices of Analyzing and Interpreting Data and Using Mathematics and Computational Thinking improve student understanding of natural selection (Passmore & Stewart, 2002; Tabak & Reiser, 2008). The practice of Engaging in Argument From Evidence challenges students to evaluate their ideas and has produced genetics learning gains in high school (Zohar & Nemet, 2001) and evolution learning gains and retention at the undergraduate level (Asterhan & Schwarz, 2007). Finally, researchers have reported that interactive, web-based simulations and learning experiences can decrease undergraduates' evolution misconceptions (Abraham, Meir, Perry, Herron, Maruca & Stal, 2009) and significantly increase understanding of micro and macro evolution (Heitz, Cheetham, Capes & Jeanne, 2010; Perry, Meir, Herron, Maruca & Stal, 2008).

Research Objectives and Purpose

To begin to address these issues, the Genetic Science Learning Center (GSLC) at the University of Utah and AAAS Project 2061 collaborated on a project in which the GSLC developed curriculum materials for high school evolution instruction and Project 2061 developed associated assessment items. We sought to (a) develop prototype lessons that build upon evolution education research and integrate the three dimensions of the *NGSS* and (b) test whether this approach holds promise for eliciting student learning gains. Our intention was to develop curricula that could serve as a model for operationalizing the three dimensions of the *NGSS*.

Theory of Change for Curriculum Development

Based on the research summarized above, our lesson development was guided by a theory of change which posits that students will better understand the Disciplinary Core Ideas about Evolution when curriculum materials and instruction:

- Integrate the Core Ideas about Heredity that are essential for understanding evolution.
- Engage students in the Science Practices of (a) Analyzing and Interpreting Data and (b) Using Mathematics and Computational Thinking while they work with skill-level-

appropriate data from published research studies, and (c) Engaging in Argument From Evidence, particularly arguments involving quantitative data.
- Include interactive, multimedia learning experiences that engage students in collecting, working with, and analyzing data.

Methods

Curriculum Materials: Natural Selection Lessons

The curriculum materials consist of six integrated lessons on natural selection that model the type of instruction outlined in the *Framework* and *NGSS*. These lessons will form part of a larger curriculum replacement unit on biological evolution designed for use in grades 9-10, which was recently funded by NSF for complete development. The six prototype lessons on natural selection (available at http://learn.genetics.utah.edu/content/evo/) integrate the following dimensions of the *Framework* and *NGSS*:

- Life Science Disciplinary Core Ideas: LS4: Biological Evolution and the concepts from LS3: Heredity (Inheritance and Variation of Traits) needed to understand evolution
- Science Practices: Analyzing and Interpreting Data, Using Mathematics and Computational Thinking, and Engaging in Argument from Evidence (SP4, 5, 7)
- Crosscutting Concepts: Patterns, and Cause and Effect (CC1, 2)

In the lessons a multimedia presentation with teacher-led discussion introduces students to the three-spine stickleback fish, which has variability in the lateral plate number (side armor) trait. Students are invited to become researchers, investigating whether a new population of highly-plated fish in Loberg Lake, Alaska, will change over time to become more like the low-plated sticklebacks in other lakes. An online, virtual lab (based on published scientific data) allows students to collect and analyze data from the stickleback population in the Lake over several years, observing changes in lateral plate numbers. Students are introduced to a checklist that scaffolds their collection of data-based evidence for three criteria for determining if natural selection is acting on a trait in a population over time—variation in the trait, heritability of the trait, and selection (differential reproductive success). As students learn about these criteria they use skill-level-appropriate mathematics to work with data from published scientific studies. Students conclude their stickleback study by using a scaffold to construct a written argument, supported by data-based evidence, about whether or not natural selection is acting on plate number in the Loberg Lake stickleback population. Finally, small groups of students work with data about a trait in one of seven other examples (four natural selection and three not). They use the natural selection checklist and argumentation scaffold to construct an evidence-based argument about whether or not the trait is undergoing natural selection in the population they examined. The lessons conclude with groups presenting their example and argument to the class.

These lessons underwent several iterations of testing and revision prior to the pilot test study. Initially the GSLC's Senior Education Specialist, an experienced high school teacher, led two enactments in Salt Lake City, UT schools. The first identified places where the materials needed clarification, and the second identified how the materials and draft assessment items could better align to the module's learning goals. A third enactment at a private school in Tulsa, OK, provided feedback from a teacher who was not involved in developing the materials or teacher guides.

Study Design

We used a treatment-only pre/post test design to look for learning gains associated with the natural selection lessons. This research design was deemed appropriate since the study was a proof of concept study for an exploratory, curriculum development grant. As a part of our iterative design model, this small-scale study will inform further revisions and lay the groundwork for the complete evolution unit which will undergo randomized control testing.

Participants

The curriculum materials were pilot tested with 461 students in 20 biology classes, taught by seven teachers. The teachers were recruited through the GSLC's email list as well as past GSLC curriculum design course participants and were chosen to represent a broad array of teaching settings and student demographics.

Table 1: Student demographics for curriculum enactments

Location	School Setting	# Students	Asian	Black	Cau-casian	His-panic	LD	F/R Lunch
Salt Lake City, UT	Urban	37			67%	33%	5%	47%
Bend, OR*	Suburban	159			88%	7%	3%	22%
Draper, UT	Private	33	8%		75%	15%	15%	nd
Rexburg, ID	Rural	38			93%	4%	8%	30%
Grenada, MS	Rural	94		25%	65%	9%	3%	67%
St. Louis, MO	Suburban	100	5%	45%	35%	15%	9%	70%

LD = Learning Disabled; F/R Lunch = Free or Reduced Lunch; nd = no data * = 2 teachers

Data Collection and Procedure

The instruments used in the study were: a 15-item pre-test, a 15-item post-test, a student activity checklist, a daily teacher activity checklist, a daily teacher lesson log, and a post-enactment teacher survey.

Multiple choice items used in pre- and post-tests were developed and piloted with 1012 students in a national sample according to established assessment procedures (Herrmann-Abell & DeBoer, 2014; DeBoer, et al., 2008). The assessment tasks are aligned with the learning goals for curriculum materials and associated dimensions of the *Framework* and *NGSS* and incorporate published scientific data but do not use the same phenomena as the lessons. Assessment item pilot testing included student feedback on any difficulties understanding the items and explanations of why they chose a particular response. Item difficulties were assessed by Rasch modeling. Following iterative item testing and revision, 15-item pre- and post-tests were created to target key concepts in natural selection and data analysis with a range of item difficulties. Pre- and post-tests used essentially the same items (in different order), with two items being substituted in the post-test for similar questions with different biological contexts.

In addition, we collected students' written arguments and digital photos of their poster presentations from the lessons. Classroom observations were conducted in the two Utah schools.

Data Analysis and Validation

A quantitative approach was taken to determine student learning gains. Students' pre-tests and post-tests were matched (tests for 153 students could not be matched). Paired *t*-test analysis was conducted to look for differences in test scores after completing the lessons. Assessment items were also grouped by the themes of math-based data analysis, natural selection and heredity/genetics for paired *t*-test analyses. Analysis of the students' written arguments and posters is underway.

Teacher activity checklists, teacher lesson logs, student activity checklists, post-enactment teacher surveys, and classroom observations in the two Utah schools were used to assess fidelity of implementation. Daily teacher lesson logs and post-enactment surveys were also used to solicit teacher feedback on the lessons and their usual practice.

Results

Fidelity of implementation measures indicated that although there was variability in the amount of time teachers spent on some lessons, on the whole, the natural selection lessons were implemented as intended. Students ($n=308$) showed significant learning gains from pre-test ($mean=52.92\pm1.20\%$) to post-test ($mean=61.58\pm1.41\%$, $t= 8.544$, $p<0.001$). Further analysis revealed student learning gains in data analysis ($t=6.359$, $p<0.001$), knowledge of natural selection theory ($t=5.027$, $p<0.001$), and genetics and heritability ($t=5.711$, $p<0.001$). Additionally, chi-square analysis of misconception prevalence revealed a decrease in the selection of distractors associated with the deliberate development of advantageous traits by individuals ($\chi2=7.425$, $p=.007$) and misinterpretation of the x-axis as time ($\chi2=6.536$, $p=.007$).

Survey data from participating pilot test teachers revealed that although the materials were quite different from their typical natural selection lessons, the lessons were easy to enact, and contained appropriate math, language and science content. All of the teachers reported that they would use the materials again.

Discussion

The curriculum materials developed for this study provide one of the first models for integrating the three dimensions of the Framework and *NGSS*—Disciplinary Core Ideas, Science Practices and Crosscutting Concepts—in materials designed for high school biology classes. In addition, the lessons illustrate ways to authentically engage students in the science practice of Analyzing and Interpreting Data utilizing the same or similar methods that researchers used to analyze the data in published studies. The statistically significant learning gains students achieved through using the lessons show that the materials hold initial promise for supporting students in achieving the knowledge and skills delineated in the *Framework* and *NGSS*. Specifically, the data indicate that our approach holds preliminary evidence of promise for increasing students' understanding of natural selection and decreasing misconceptions about natural selection and graphs.

Our study outcomes support our theory of change and the findings of other researchers who found that explicitly connecting heredity and evolution concepts (Banet & Ayuso, 2003; Geraedts & Kerst, 2006; Kalinowski, Leonard & Andrews, 2010), utilizing interactive, web-based simulations and learning experiences (Abraham, Meir, Perry, Herron, Maruca & Stal, 2009; Heitz, Cheetham, Capes & Jeanne, 2010; Perry, Meir, Herron, Maruca & Stal, 2008), engaging students in analyzing and interpreting data and using mathematics (Passmore & Stewart, 2002; Tabak & Reiser, 2008), and engaging them in constructing evidence-based arguments (Asterhan & Schwarz, 2007; Zohar & Nemet, 2001) support students' increased understanding of evolutionary processes. The lessons we developed appear to be unique among those reported in the literature for combining all of these elements, which are congruent with the vision for K-12 science education in *NGSS*.

Through this curriculum development work we have learned that a key aspect of developing lessons that engage students in the science practices of analyzing and interpreting data and using mathematics is identifying appropriate published scientific studies on which to build the lessons. This involves identifying studies that (a) contain evidence that both relates to the targeted core idea(s) and is or can be simplified to be understandable to students of the intended grade(s), (b) use skill-level-appropriate mathematics for data analysis or data that can be presented in an accessible format, (c) encompass various life forms, to help students see that the disciplinary core ideas are broadly applicable and to serve as examples in both the lessons and assessments, and (d) focus on organisms that engage student interest. Once appropriate data are identified, decisions about the inclusion and weighting of specific math practices, science practices and crosscutting concepts must be made while maintaining a coherent story line for students with respect to the lessons' Disciplinary Core Idea(s). After making these decisions, as well as deciding which phenomena to use in the lessons and which to use for assessment, the assessment items can be developed.

The strength of our findings on student learning gains is tempered by the fact that 13 of the 15 items of the pretest and posttest were the same; some of the improvement in student scores on the posttest could have been due to the fact that students had previously seen most of the items.

This study provides useful lessons for curriculum writers about developing curricula and assessments that utilize published scientific data, as well as the advantages and challenges of integrating Disciplinary Core Ideas, Science Practices and Crosscutting Concepts.

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