Development and Pilot Testing of an NGSS-Aligned Unit that Integrates Evolution and Heredity

Dina Drits-Esser[1], Sheila Homburger[1], Molly Malone[1], Kristin M. Bass[2], Jo Ellen Roseman[3], George E. DeBoer[3], Joseph Hardcastle[3], Amy J. Hawkins[1], Louisa A. Stark[1]

[1] University of Utah, Genetic Science Learning Center; [2] Rockman et al; [3] American Association for the Advancement of Science, Project 2061

Contact: Dina Drits-Esser, dina.drits@utah.edu

Abstract

This paper describes the development and pilot test results of a Next Generation Science Standards-aligned eight-week evolution unit for ninth- and tenth-grade introductory biology students, titled *Evolution: DNA and the Unity of Life*. The unit helps students build a coherent understanding of evolution through (a) inclusion of pertinent heredity core ideas; (b) analysis and interpretation of skill-level-appropriate data from published scientific research; (c) the construction of evidence-based arguments, and (d) the integration of crosscutting concepts such as patterns. Preliminary pilot test results in the classrooms of 20 teachers around the U.S. indicate statistically significant increases with large effect sizes in students' conceptual understanding of evolution and genetics, along with increased skillfulness in understanding and applying the scientific practices used in the unit, particularly in scientific argumentation from evidence.

Objectives and Purpose

The *Framework for K-12 Science Education* (NRC, 2011) and the *Next Generation Science Standards* (NGSS) (Achieve Inc., 2013) derived from the *Framework* delineate a vision for science education that integrates disciplinary core ideas, science practices and crosscutting concepts. Our project team has responded to the *Framework's* call for new curriculum materials that integrate these dimensions and assessments that are closely aligned to these learning goals. We addressed widespread misunderstandings related to biological evolution by developing and testing a new high school curriculum unit and assessment measures focusing on this science idea and related concepts.

This paper presents the results from a pilot test of the curriculum and explores two research questions. The study corresponds to the Design and Development phase of educational research (IES & NSF, 2013) requiring a theory of action, articulation of design iterations, and initial evidence of effectiveness. The research questions were:

(1) How can a curriculum unit be designed so that it has the potential to guide students' conceptual understanding from the disciplinary core ideas of Heredity to those of Evolution?

(2) To what extent does the new unit show promise for increasing student achievement?

Theoretical Framework

An understanding of evolution is fundamental to biology (NRC, 2011), yet students have a poor grasp of this essential science idea (reviewed in Gregory, 2009). Students misunderstand common ancestry (Flanagan & Roseman, 2011; Staub, Pauw, & Pauw, 2006), misinterpret evolutionary trees (Meir, Perry, Herron, & Kingsolver, 2007), and poorly understand evolutionary time (Catley, Novick, & Shade, 2010). They also have difficulty applying their knowledge of evolution to everyday issues (Catley, Lehrer, & Reiser, 2004). The most common student-held alternative conceptions about natural selection are rooted in misunderstandings about heredity (Bishop & Anderson, 1990; Nehm & Schonfeld, 2008). The genetic mechanisms of mutation and random variation—key to understanding evolution—are particularly difficult for students to grasp (Morabito, Catley, & Novick, 2010). Therefore, researchers have called for a stronger genetics connection in students' study of evolution (Catley et al., 2010; Dougherty, 2009).

Three studies on curricula that integrate evolution and heredity found gains of 66-74% in students' understanding (Banet & Ayuso, 2003; Geraedts & Boersma, 2006; Kalinowski et al., 2010). Recent research (Mead, Hejmadi, & Hurst, 2017) found that teaching genetics before evolution to high school students significantly increased evolution understanding compared to teaching evolution before genetics. This difference was especially seen in lower ability students, where an improvement in evolution understanding only occurred if genetics was taught first. Some literature has described practitioners integrating these topics in their classroom (e.g., Brewer & Gardner, 2013; Heil, Manzano-Winkler, Hunter, Noor, & Noor, 2013). However, few widely-available curriculum materials foster this integration, preventing students from easily making conceptual connections (Biggs et al., 2009; Miller & Levine, 2008; Postlethwait & Hopson, 2009).

In addition to integrating genetics and evolution, researchers also have advocated for science practices that can foster student learning of evolution. Research has shown that students need more opportunities to analyze and interpret data and argue from evidence. In their evolution learning progression, Catley et al. (2004) specifically advocate having students analyze data. Students have difficulties with argumentation, despite the importance of evidence-based arguments in science (McNeill, Lizotte, Krajcik, & Marx, 2006; Sandoval & Millwood, 2005). Several studies have shown that students' content understanding increases when argumentation is an explicit part of instruction (Bell & Linn, 2000; Zohar & Nemet, 2001). In a genetics unit that included argumentation, ninth grade students scored significantly higher in both genetics and argumentation than the comparison group, and they were able to transfer their skills to everyday situations (Zohar & Nemet, 2001). A study with undergraduates showed that explicit engagement in argumentation significantly improved evolution learning gains and retention (Asterhan & Schwarz, 2007).

In response to the calls for new curriculum materials that integrate the three major dimensions of NGSS and for curricula that integrate genetics and evolution, the project team has developed and pilot tested an 8-week curriculum unit for introductory high school biology. The unit helps students build a coherent understanding of evolution through inclusion of pertinent heredity core ideas, analysis and interpretation of skill-level-appropriate data from published scientific research, use of models, and the construction of evidence-based arguments, along with integrating crosscutting concepts throughout. This paper describes this unit and preliminary classroom pilot test results.

Theoretical Framing of the Curriculum

The unit is based on the assumption that students will better understand the disciplinary core ideas about Biological Evolution (LS.4A, B, C & D) when curriculum materials and instruction:

- integrate disciplinary core ideas about Heredity (LS.3; inheritance and genetic variation) that are essential for understanding evolution; and
- build students' abilities in the science practices of Analyzing and Interpreting Data and Engaging in Argument from Evidence within the context of working with skill-level-appropriate data from published scientific research.

Our framework for developing the unit draws on constructivist, conceptual change, and situated cognition theories of learning (AAAS, 1993; Driver, 1995; Strike & Posner, 1992) and is informed by multiple learning progressions (e.g., Berland & McNeill, 2010; Catley et al., 2004; Duncan, Rogat, & Yarden, 2009).

The Unit: *Evolution: DNA and the Unity of Life*

Through online and paper-based lessons, the five-module unit engages students in three-dimensional learning, building on Disciplinary Core Ideas (DCIs) to progressively engage students in Science Practices and identifying Crosscutting Concepts. Specifically, the unit explores DCIs with a storyline that progresses from the shared biochemistry of life, through common ancestry, heredity, natural selection, and speciation, using non-human examples (Table 1). Students engage in the practices of using models, analyzing and interpreting real data, and constructing arguments from evidence. To learn the latter practice, students use a scaffolded claims-evidence-reasoning framework to develop and evaluate arguments over the course of the modules. The unit also incorporates the crosscutting concepts of patterns, and cause and effect. The overall focus of the unit is on DNA as a blueprint for all living things, and as underlying variations in traits that are acted upon by natural selection.

Table 1: Overarching learning objectives for each module.

Module	**Driving Question**
Shared Biochemistry	*What shapes the characteristics of all living things?*
Common Ancestry	*What is the evidence that living species evolved from common ancestral species?*
Heredity	*How do the differences in DNA that lead to differences in characteristics of organisms arise?*
Natural Selection	*How do species change over time?*
Speciation	*How do new species arise?*

Methods and Data Sources

Development and testing of the unit followed an iterative, multi-step, multi-year process. The curriculum materials were developed by the Genetic Science Learning Center at the University of Utah (GSLC) and the assessment items were developed by AAAS Project 2061. To maintain the rigor of the research studies, neither partner saw the other's work; i.e., the GSLC curriculum developers did not see the assessment items and Project 2061 did not see the unit.

First, GSLC developed the Natural Selection module as a “proof of concept”; it underwent several rounds of classroom testing and revision. The module was then beta-tested with over 1200 students taught by seven teachers across the U.S. and revised again.

Next, GSLC developed the remaining modules; sections were classroom tested and revised. As an external reviewer, AAAS Project 2061 evaluated the unit for alignment to the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric (Achieve Inc., 2016), and GSLC refined the unit based on the results of the analysis. During the 2016-2017 school year the entire five-module unit was pilot tested. The purpose of this study was to gather information to refine and improve the unit. Twenty teachers from around the country were selected from nearly 400 applicants. In selecting the teachers, the GSLC chose ones who were assigned to teach at least two sections of introductory or honors biology (9^{th}/ 10^{th} grades) in order to increase the number of participating students and so that teachers would have two experiences teaching the lessons. Since the primary goal of the pilot test was to obtain feedback on how the unit performed with a broad range of students, teachers were selected whose student demographics provided a broad representation of racial/ethnic, socioeconomic, geographic, and achievement levels, including two teachers with special education classes.

Pilot test participation procedures for teachers were:

- Participating in a 3.5-day in-person training on the materials in summer 2016.
- Teaching the entire unit in each introductory or honors biology section.
- Administering pre and post content knowledge tests and collecting student work samples from embedded assessments and argumentation exercises.
- Completing daily feedback logs and an end-of-implementation survey to gauge classroom experiences with the materials, including issues or problems.
- Participating in follow-up telephone interviews (n = 8 teachers, purposefully selected based on their range of experiences with the unit).

Multiple choice assessment items were developed by Project 2061, which received the unit/module learning objectives but did not see the actual materials. Items were pilot tested nationally with 200-1200 students, revised, and re-tested. Four test forms were created for online pre/post-testing students during the 2016-2017 curriculum pilot test. Each test contained 25 items including seven linking items. Items assessed students’ understanding of the unit content and skills, including argumentation. Each test contained the same number of items per topic and the same average item difficulty.

Rasch analysis was conducted using the software package WINSTEPS (Linacre, 2016) to obtain measures of item difficulty and student performance level, and to determine the reliability of the measures. All items had acceptable infit and positive point-measure correlations, indicating a good fit to the Rasch model.

During the 2017-2018 school year we are conducting a randomized controlled trial to compare learning gains made by students whose teachers are assigned to either the treatment or control (business as usual) condition. Forty-four teachers, representing 23 states are participating.

Preliminary Results

RQ1: Curriculum Development Process

As feedback arrived from pilot test teachers during the fall semester through logs and end-of-unit surveys, the unit was revised (sometimes substantially), and re-tested by teachers piloting in the spring. Revisions included:

- streamlining lessons to better align learning gains with the classroom time required in order to reduce the overall time teachers spent on the unit from ten weeks to eight;
- developing additional interactive online activities to support student learning;
- creating videos that are closely aligned to module content to replace ones from other sources that were not as well-aligned;
- creating less time-consuming formative assessments for each module; and
- reformatting copy masters to save paper.

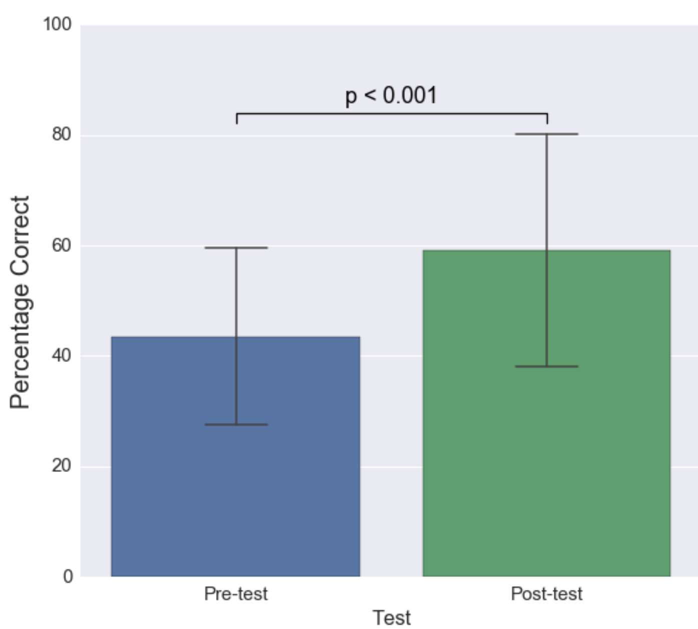
The unit is available online at the following URLs. However, it will not be publicly released until summer 2018, after the RCT is completed.

- Teacher materials: http://teach.genetics.utah.edu/beta/evolution/
- Student materials: http://learn.genetics.utah.edu/beta/evolution/

RQ2: Evidence of Curriculum Promise

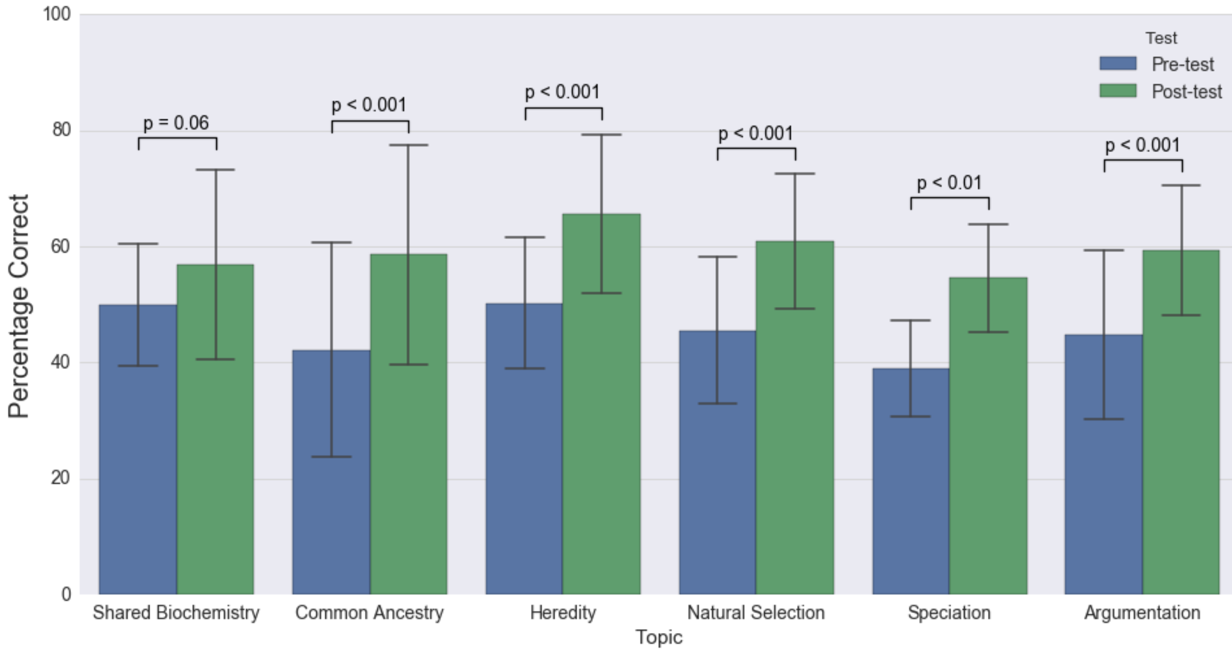
Student content assessment pretest and posttest. 944 students completed both pre and post-tests during the national pilot test of the unit. Students answered a statistically significant greater number of items correctly on the post-test, with an average gain of 17 percentage points (Figure 1; $t(943) = 29.6$, $p < .001$, Cohen's $d = 0.96$).

Figure 1: Average pre/post student test results for *Evolution* unit.



Students also showed significant knowledge gains for four of the five modules (p<0.01-0.001; p=0.057 for Shared Biochemistry) and for the argumentation practice (p<0.001; Figure 2). Large Cohen's d effect sizes (1.15–2.29) were found for all curriculum topics.

Figure 2: Pre/post student test results for each of the five modules in the *Evolution* unit and for the argumentation practice.



Teachers' perceptions from using the unit. Interview and survey data showed that:

- All teachers indicated that they will use the unit in the future in sequence, but also embed some of their own materials.
- Teachers reported that the unit is unlike other curricula because it builds conceptual understanding of evolution by starting with the biochemistry underlying evolution and ending with speciation. The unit was thoughtfully and carefully designed to tell the story of evolution in a way that resonated with students.
- Teachers appreciated that students were engaging with phenomena and analyzing real data from research studies.
- Teachers appreciated the argumentation framework and scaffolding used in the unit because it simplified and structured what could be a very complicated process. It built students' capacity to argue from evidence, and provided opportunities to hear other students' perspectives.
- Teachers are applying the unit's argumentation scaffolds to other classes that were not involved in the study, and are sharing NGSS ideas with colleagues.
- Several teachers reported that students' constructed response scores on state tests increased from the previous year and attributed this to their experience with the unit.

Scholarly Significance

The pilot test results indicate that students who use the unit are learning the DCIs for evolution and heredity. The 3-dimensional nature of the unit appeared to support depth of understanding and contributed to increasing students' competency in several of the Scientific Practices. In particular, the carefully crafted scaffolding of claims, evidence, and reasoning, and opportunities for practicing these throughout the unit contributed to students' skillful use of argumentation. Consequently, this work suggests that teaching heredity and evolution in a coherent storyline, combined with exposure to numerous sources of evidence, enables students to create evolutionary arguments. This is consistent with our theory of action.

Thus, this project has developed an example of a full unit that aligns to the principles of NGSS, and carried out a study that conforms to the expectations for a Design and Development project. It sets the stage for a larger efficacy trial and raises new questions about the mediating factors (e.g. fidelity of implementation, prior knowledge) that might influence the observed outcomes.

References

AAAS Project 2061. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Achieve, Inc. (2013). *Next Generation Science Standards* (Vol. 2011): Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Achieve, Inc. (2016). EQuIP Rubric for Lessons & Units: Science, Version 2.0. Retrieved from https://www.nextgenscience.org/sites/default/files/EQuIP%20Rubric%20for%20Science%20v2.pdf

Asterhan, C. S., & Schwarz, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology*, *99* (3), 626-639. doi:10.1037/0022-0663.99.3.626

Banet, E., & Ayuso, G. E. (2003). Teaching of biological inheritance and evolution of living beings in secondary school. *International Journal of Science Education*, 25 (3), 373-407.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education, 22*, 797-817.

Berland, Leema K, & McNeill, K L. (2010). A learning progression for scientific argumentation:

Understanding student work and designing supportive instructional contexts. *Science Education*, *94* (5), 765-793.

Biggs, A., Hagins, W. C., Holliday, W. G., Kapicka, C. L., Lundgren, L., MacKenzie, A. H., et al. (2009). *Glencoe Biology National Geographic (Teacher Wraparound ed.)*. Columbus, OH: McGraw-Hill Companies, Inc.

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27*(5), 415-427.

Brewer, M., & Gardner, G. (2013). Teaching Evolution through the Hardy-Weinberg Principle: A Real-Time, Active-Learning Exercise Using Classroom Response Devices *The American Biology Teacher*, *75* (7), 476–479.

Catley, K. M., Lehrer, R, & Reiser, B. (2004). *Tracing a prospective learning progression for developing understanding of evolution*. National Academies Committee on Test Design for K-12 Science Achievement (http://www7.nationalacademies.org/bota/Evolution.pdf).

Catley, K. M., Novick, L. R., & Shade, C. K. (2010). Interpreting evolutionary diagrams: When topology and process conflict. *Journal of Research in Science Teaching*, 1-22. doi:10.1002/tea.20384

Dougherty, M J. (2009). Closing the gap: Inverting the genetics curriculum to ensure an informed public. *The American Journal of Human Genetics*, *85*, 6-12. doi:10.1016/j.ajhg.2009.05.010

Driver, R. (1995). Constructivist approaches to science teaching. In L. P. Steffe & J. Gale (Eds.), *Constructivism in education* (pp. 385-500). Hillsdale, NJ: Lawrence Erlbaum Associates.

Duncan, R. G., Rogat, A. D., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th-10th grades. *Journal of Research in Science Teaching*, *46* (6), 655-674.

Flanagan, J. C., & Roseman, J. (2011). Assessing middle and high school students' understanding of evolution with standards-based items. Paper presented at the *National Association for Research in Science Teaching,* Orlando, FL.

Geraedts, C. L., & Kerst, T. B. (2006). Reinventing natural selection. *International Journal of Science Education, 28*(8), 843-870.

Gregory, T. R. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and Outreach, 2*, 156-175.

Heil, C. S., Manzano-Winkler, B., Hunter, J., Noor, J. K., & Noor, M.A. (2013). Witnessing Evolution First Hand: A K–12 Laboratory Exercise in Genetics & Evolution Using Drosophila. *The American Biology Teacher*, *75*, (2), 116–119.

Heitz, J. G., Cheetham, J. A., Capes, E. M., & Jeanne, R.L. (2010). Interactive evolution modules promote conceptual change. *Evolution: Education and Outreach*, *3*, 436-442.

Institute of Education Sciences, U.S. Department of Education, and the National Science Foundation (2013). Common Guidelines for Education Research and Development: A Report from the Institute of Education Sciences, U.S. Department of Education, and the National Science Foundation. Washington, DC: Author.

Kalinowski, S. T., Leonard, M. J., & Andrews, T. M. (2010). Nothing in evolution makes sense except in the light of DNA. *CBE-Life Sciences Education, 9*, 87-97.

Linacre, J. M. (2016). Winsteps® Rasch measurement computer program. Beaverton, Oregon: Winsteps.com

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R.W. (2006). Supporting students' construction of scientific explanations by facing scaffolds in instructional materials. *Journal of the Learning Sciences*, *15*, 153-191.

Mead R., Hejmadi M., & Hurst L. D. (2017). Teaching genetics prior to teaching evolution improves evolution understanding but not acceptance. *PLoS Biology*, *15* (5), 1-30. https://doi.org/10.1371/journal.pbio.2002255

Meir, E., Perry, J., Herron, J. C., & Kingsolver, J. (2007). College student's misconceptions about evolutionary trees. *American Biology Teacher*, *69* (7), 71-76.

Miller, K. R., & Levine, J. (2008). *Prentice Hall Biology (Teacher Wraparound ed.)*. Boston, MA: Pearson Education, Inc.

Morabito, N.P., Catley, K. M., & Novick, L.R. (2010). Reasoning about evolutionary history: Post-secondary students' knowledge of most recent common ancestry and homoplasy. *Journal of Biological Education*, *44* (4), 166-174.
National Research Council. (2011). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.
Nehm, R. H., & Schonfeld, I. S. (2008). Measuring knowledge of natural selection: A comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching, 45* (10), 1131-1160.
Postlethwait, J. H., & Hopson, J. L. (2009). *Modern Biology (Teacher Wraparound ed.)*. Austin, TX: Holt, Rinehart, and Winston.
Sandoval, W. A, & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction*, *23*, 23-55.
Staub, N. L., Pauw, P. G., & Pauw, D. (2006). Seeing the forest through the trees: Helping students appreciate life's diversity by building the Tree of Life. *The American Biology Teacher*, *68* (3), 149-151.
Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology and educational theory and practice*. Albany, NY: State University of New York Press.
Zohar, A., & Nemet, F. (2001). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39* (1), 35-62.