

Feature

Perspectives on Interdisciplinary Science Education

Preparing High School Students for the Interdisciplinary Nature of Modern Biology

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Fostering interdisciplinary learning in biology will require significant changes in the way we teach science to K–12 students. The perspective on interdisciplinary biology teaching and learning in this essay is based on my experiences as a former research cell biologist, high school science teacher, and developer of secondary science curricula and teacher professional development programs used in a variety of school districts nationwide. I currently direct the Science Education for Public Understanding Program (SEPUP), a secondary science curriculum project within the Center for Curriculum Development and Implementation at University of California–Berkeley’s Lawrence Hall of Science. We develop science modules and courses that use inquiry approaches to teaching and learning and include a strong focus on the relationship between science and health and environmental issues relevant to students’ lives. Lawrence Hall of Science curricula are developed with the input of scientists and field-tested by teachers at national sites who teach the curricula in their classrooms and provide detailed feedback.

On the basis of these experiences, I am enthusiastic about the importance of preparing students for the interdisciplinary nature of modern biology, yet concerned about the challenges faced by teachers and school districts as they move toward a modern curriculum.

Transforming interdisciplinary biology teaching at the secondary level must include changes in curriculum, instruction, assessments, and teacher professional development in order to support teaching for conceptual understanding and for making cross-disciplinary connections. To prepare students for the nature of modern biology, biology educators must provide them with frequent opportunities to engage in studying

interdisciplinary scientific questions or problems. Students will need sufficient time and support to explore, analyze, and reflect on the contributions of various disciplines to advances in modern biology.

An essential feature of any program intended to prepare students for the interdisciplinary nature of modern biology is a focus on teaching for deep understanding. This type of teaching focuses on students’ ability to make connections and apply what they have learned in meaningful situations. It is not enough to include the occasional vignette about the discoveries of interdisciplinary teams, a unit on chemistry early in a biology course, or a brief description of the chemistry of DNA. Instead, interdisciplinary concepts should be more deeply woven into instruction and integrated by explicit consideration of cross-cutting themes, such as scale, structure, and function.

INTERDISCIPLINARY HIGH SCHOOL SCIENCE

Interdisciplinary teaching at the secondary level comes in a variety of forms (Biological Sciences Curriculum Studies [BSCS], 2000). *Integrated* science courses typically use overarching themes, problems, or socioscientific issues to present science in authentic contexts. In an integrated science course, students explore concepts from more than one discipline within individual lessons and across units. Such courses often ask students to apply what they have learned to solving a problem or answering a question. For example, in an integrated science unit on global climate change, students might explore within the unit concepts in the earth sciences (atmosphere, weather, and climate), physics (heat and temperature), and life sciences (effects of climate change on ecosystems). These might be tied together by cross-cutting concepts, such as stability and change. Students might be asked to apply what they have learned to make recommendations about future research or actions to minimize the impact of global climate change. In *coordinated* science courses, several disciplines are taught in a year in a logical sequence, with linkages between content-focused units. In this approach, a physics unit that includes a focus on heat and temperature might be

DOI: 10.1087/cbe.13-03-0047

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followed by a unit on weather and climate that refers back to some of the concepts in the physics unit. These might then be followed by an ecology unit that refers back to the physics and earth sciences concepts. *Subject-focused* courses on a single discipline, such as biology, can also include substantive interdisciplinary examples built around scientific questions, themes, problems, and personal or societal issues. For example, a unit that focuses on ecology might include explicit connections to the earth sciences (weather and climate and their influence on ecosystems) and chemistry (water chemistry and its effect on living organisms). Through our work, SEPUP has gained experience developing curricula and assessments, and in working with teachers implementing each of the above approaches to interdisciplinary teaching, we have observed some of the strengths and pitfalls of each approach.

CHALLENGES TO INTERDISCIPLINARY TEACHING

In our efforts with teachers and school districts, we have observed several forces that work against interdisciplinary teaching in secondary science classrooms. One significant factor is teachers' and administrators' perceptions of what students need in preparation for the next phase of their education. Middle and high school educators are committed to preparing their students for the next phase of their education, and ultimately for successful admission to and graduation from college. Ideas about what will help students to succeed in the future are formed by educators' own prior experiences in education, the science standards in their state and district, and the standardized tests that their students must take and that are often used to evaluate teachers. While national and some state standards have moved toward deeper understanding and connected knowledge, most standardized tests do not fully reflect this direction. Instead, they focus on recall of declarative knowledge, such as the ability to recognize definitions or identify examples of phenomena. As long as educators believe that broad familiarity with many topics is a better preparation for these tests and for the next phase of schooling than in-depth exploration of fewer topics, and lack clear guidance about what is most important, they will hesitate to focus in depth on fewer topics. In the push to provide broad content coverage, there is little time to spend making connections even within biology, much less to other disciplines. This problem manifests in both integrated and subject-specific courses that aim to provide more relevant contexts for learning and include interdisciplinary content. In either case, making time for students to make sense of and reflect on what they learn requires making choices about what specific content is most important and what can be omitted without jeopardizing learning.

Teachers are key to any change in the classroom, including the implementation of new standards, teaching for understanding, and the inclusion of more interdisciplinary approaches to biology. Teacher preparation is a second significant force working against interdisciplinary teaching. Even within biology, most secondary teachers feel more confident teaching in some areas than others. Research reviews indicate that teachers need more preparation in both content and instructional strategies in order to teach for understanding, and that classrooms rarely offer students enough time to make

sense of the content that is presented (National Research Council [NRC], 2003; Banilower *et al.*, 2006). Interdisciplinary teaching presents additional conceptual demands on teachers (Ratcliffe, 2004), who often lack preparation to teach across disciplines (BSCS, 2000). Preservice preparation and credentialing of secondary teachers typically focus on highly discipline-specific programs, and in-service professional development for updating teachers' science backgrounds and changing instruction is becoming more and more limited. Teachers lack models of and experience with interdisciplinary teaching, which makes it difficult for them to envision and implement such a program. A significant obstacle to interdisciplinary or integrated science courses is the perception by some educators and college admissions committees that they are less rigorous than subject-specific courses, which discourages districts from offering them and strong students from selecting them. Finally, truly integrated science courses would most often need to be multiyear courses to ensure inclusion of essential content from all science disciplines (BSCS, 2000). This can make it difficult for students to switch into subject-specific general, honors, and advanced placement (AP) courses. Any effort to promote a large-scale increase in interdisciplinary teaching must include adequate preservice teacher preparation and in-service professional development.

POTENTIAL IMPACT OF THE 2011 SCIENCE EDUCATION FRAMEWORK

Given these challenges, what can be done? Is there any reason to hope that this situation can improve? Several recent events suggest there is an opportunity to bring about change in the near future. In the 1990s, both the American Association for the Advancement of Science (AAAS) *Benchmarks for Science Literacy* (AAAS, 1993) and *National Science Education Standards* (NSES; NRC, 1996) set forth standards that promoted a greater degree of connections among the sciences and between the sciences and other disciplines. Both documents included a focus on the practices of science and on cross-cutting ideas or themes. They promoted more focus on important science concepts and key ideas, along with teaching approaches supported by research on how students learn and assessments to probe deep understanding (NRC, 2001). The NSES also promoted inquiry approaches to teaching (NRC, 1996, 2000). Although research suggests the NSES and AAAS *Benchmarks* have had an impact on science education, most evidence suggests the magnitude and reach of this impact are not as extensive as was hoped (NRC, 2003; Banilower *et al.*, 2006).

The 2011 *Framework for K–12 Science Education* (NRC, 2011) has guided the development of new Next Generation Science Standards (NGSS; Achieve, 2013). These new standards include recent scientific advances and are based on what has been learned about science education since the release of the NSES and *Benchmarks*. Although the NRC *Framework* has much in common with these earlier documents, there are some key differences. One difference is the focus on both scientific and engineering practices in the new science framework. Another is the inclusion of three dimensions from the NRC *Framework*—practices, cross-cutting concepts, and disciplinary core ideas—in each standard. These three dimensions, considered essential for an understanding of

science, include *practices*, which describe behaviors and practices engaged in by scientists and engineers, *cross-cutting concepts*, which apply across and integrate the scientific disciplines, and *disciplinary core ideas*, which focus on important content (NRC, 2011).

Twenty-six states have partnered with the lead organizations in developing the standards, which were released in April 2013. Clearer guidance on how a disciplinary core idea can be integrated with practices and with cross-cutting concepts should spark new approaches to curricula, instruction, and assessments. Many school districts have anxiously awaited release of the standards and are planning to adopt curricula that align with them as soon as possible. From a curriculum developer's perspective, the outlook is both encouraging and daunting. Integrating practices with disciplinary content is essential if students are to understand how to do science and how scientists learn about the natural world. But the NGSS are complex and include a great deal of content (see Coffey and Alberts, 2013). School districts faced with the number and complexity of the standards may continue to focus on content coverage at the expense of time for the scientific and engineering practices emphasized in the NGSS. Developing high-quality, research-based curricula that address all three dimensions of each standard will require a significant effort to interpret the standards, develop new instructional activities and support for teachers, and field-test and revise the materials. Effective implementation of these new materials will require an ongoing professional development program. Yet districts feel pressure to move forward quickly and frequently lack the resources to support ongoing professional development. Another concern related to developing or revising curricula relates to questions about how well the practices in the final NGSS match to the disciplinary core ideas within specific standards. Finally, the impact of the NGSS on classroom practices will depend on the advancement of assessment practices and whether the states adopt assessments aligned with the new emphasis of the standards.

Another encouraging development that might foster more interdisciplinary teaching at the high school level is the release of a new *AP Biology Curriculum Framework* (College Board, 2011) and a new AP Biology Exam (College Board, 2012). The new AP framework changes the emphasis of AP Biology from broad content coverage to depth of understanding and emphasizes scientific inquiry, reasoning, and quantitative skills. The goals of these changes include providing more time, so students can develop understanding, and allowing teachers to choose contexts and examples that will be meaningful to their students. These changes should also provide an opportunity for teachers to choose interdisciplinary contexts. AP Biology's impact extends to teachers of pre-AP courses. One rationale frequently given for the broad emphasis on content in standard high school biology courses is the need to prepare students for success in AP or college courses. The recent AP Biology changes are supported by a broad range of colleges and universities and align well with the principles of the NRC *Framework*. Together, these documents convey a consistent message to all biology teachers that teaching for understanding will better prepare students for future study and for their lives.

The NRC *Framework* states that one of the four criteria for identifying core concepts should "relate to the interests and life experiences of students or be connected to societal

or personal concerns that require scientific or technological knowledge" (NRC, 2011, pp. 2–6). SEPUP has used personal and societal issues and problems as a focus for teaching and learning around a variety of topics. This approach offers one model for interdisciplinary science curricula. Issues related to human health or global sustainability are often interdisciplinary and provide authentic contexts for integrating across science disciplines; they can even be used to integrate the sciences with mathematics, language arts, and the social sciences. In a SEPUP unit on bioengineering in the middle school course *Issues and Life Science*, students explore concepts of biology and engineering, as they design and test models of artificial body parts, and the impact of technology on quality of life. At the high school level, a similar unit might include a greater focus on physics as it relates to the function of limbs and on the chemistry of materials. In our most recent high school course, titled *Science and Global Issues: Biology*, we have used sustainability issues as a theme throughout the course. For example, the course builds connections between ecology, genetics, and evolution as students consider biodiversity in the context of concepts from each field of biology. Evaluations of this course (Chung *et al.*, 2011) demonstrated large effect sizes for pretest/posttest gains for all four units. Disaggregation of the data showed that males and females and students from groups underrepresented in science, technology, engineering, and mathematics fields showed similar growth throughout the course.

RECOMMENDATIONS

Biology educators can take a number of steps both within and beyond their own institutions to foster preparation of students for the interdisciplinary nature of biology. Recommendations to foster teaching across disciplinary boundaries include:

- Develop rich examples of instructional activities in which students use concepts that cross disciplines to answer scientific questions, solve personal and societal problems, and illuminate ethical and societal issues that relate to the sciences. These examples must be age-appropriate in terms of the conceptual understanding required and engaging to diverse students.
- Encourage colleagues, administrators, policy makers, and the public to think differently about curricula, moving away from surveys of content to programs that focus on teaching for understanding. These programs should include examples of how biologists have worked together and with experts in other disciplines to solve problems. For example, the role of chemistry and physics in the advancement of both cellular and molecular biology is implicit in most treatments of these topics at the high school level. But to truly bring out the interdisciplinary nature of these topics will take time for students to reflect on the cross-disciplinary thinking and collaboration involved. This time will have payoffs in students' conceptual understanding of biology and the nature of science, but it will take time away from other topics.
- Emphasize the importance of evidence, logic, and argumentation in all sciences.

- Provide opportunities for students to experience how each scientific field uses approaches and methods suited to the problems under investigation, in order to avoid the development of misconceptions about the nature of science and rigid notions about the scientific method (such as those discussed in the companion essay by Michael Marder [2013]).
- Promote the development of classroom and standardized assessments that go beyond memorization of facts to assess connections between concepts and the ability to apply these concepts to scientific questions and problems.
- Support teachers to enact the curricula in ways that will help students develop deep understanding of and connections among concepts. Provide teachers with professional development to update their understanding of the most relevant interdisciplinary content and develop approaches for teaching that work for students.
- Encourage collaboration between teachers of different subjects, who can work together to adopt, adapt, and implement interdisciplinary materials and approaches for their classrooms. This will require teacher expertise, buy-in, and administrative support for the time needed to develop, adapt, and/or adopt curricula and become proficient in interdisciplinary teaching.
- Engage scientists and science education faculty working to modernize their college and university courses through discussions of what is most important to teach in order to help students build a strong foundation for future learning. The companion piece by David Van Wylen and colleagues (2013) demonstrates their institution's approach.
- At the school and system-wide levels, focus on developing a coherent K–12 science program to ensure a strong foundation. This will help to ensure that the high school program can build on previous learning and focus on interdisciplinary big ideas, rather than reviewing material that could have been taught in elementary or middle school.

Only through a concerted and long-term effort to change curricula, instruction, assessment, and the professional development of teachers are we likely to have a significant effect on the way secondary students are prepared for modern biology.

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