What's next for the Pathways series?

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In the spirit of the New Year, we have taken this opportunity to reflect upon the past and to provide a preview of the future of the Pathways to Scientific Teaching series. In August 2004, we initiated this feature to offer readers a variety of instructional designs and assessments to use with the content of a scientific article published in the same issue of *Frontiers*. Each Pathways article includes learning goals for students, teaching goals for faculty, and instructional strategies that actively engage students in the processes of science. The assessments are designed to evaluate students' achievements of the goals, such as understanding the scientific principles and skills discussed in the scientific paper. We designed the Pathways articles to address the challenges of large enrollment courses, confident that scaling down to smaller-size classes is easily accomplished. Panel 1 summarizes the instructional strategies and assessments associated with each article.

Twice since the Pathways series began, we asked the membership of ESA to comment on the articles. In November 2004, a general readership survey about *Frontiers* was conducted, and of those who responded (n = 1559), 81% found the Pathways articles interesting to extremely interesting. Of all the sections/features in *Frontiers*, 15% said the education section was the most useful. In a recent survey via Ecolog (December 2005), we asked the membership more specific questions about the Pathways articles, including how often they were used in courses and how well students achieved the learning goals. Although the sample size was small (n = 14), the majority of respondents used most or some of the articles and reported that their students achieved the associated learning goals.

Based on generally positive responses to the series, we plan to continue the articles with the intent of further advancing the concept of "scientific teaching" (Handelsman *et al.* 2004), where teaching is approached with the same rigor as science. The current collection of Pathways articles are part of the broader collection of course and curricular materials (eg TIEE 2006; BEN 2006) that offer many different models of how to implement active-learning instruction that engages students in the process of science. Missing from the majority of these materials is substantive evidence to back claims that the "new" teaching approaches promote student learning better than "traditional" approaches. Some faculty remain unconvinced of the need for change in instruction because they have not seen adequate assessment data that support this claim. Part of their skepticism is because the methods and arguments presented in education research do not fit their paradigm of scientific research (Dehaan 2005). The challenge is what to do with assessment data about student learning so that it can be rigorously analyzed, disseminated to appropriate audiences, and recognized as part of a scientist's scholarly work.

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To define scholarly work, we will examine a broad range of approaches to conducting "research on scientific teaching". Increasingly, boundaries between disciplines and fields in the sciences are beginning to blur as investigators engage in cross-disciplinary research, framing questions in new ways, using methodologies they did not learn in graduate school, and seeking expertise in new knowledge domains (Sorcinelli *et al.* 2006). Why not consider research on teaching and learning in the disciplines as interdisciplinary research that interconnects biological science and cognitive science?

Although educational research has existed for several decades, the concept of scholarship that focuses on teaching and learning was made visible to scientists in Ernest Boyer's report, Scholarship Reconsidered (1990), which suggested that faculty who design better ways to assist student learning and conduct research on effective teaching are engaged in scholarly work. These ideas led to the Scholarship of Teaching and Learning (SOTL) movement, initiated through the Carnegie Foundation for the Advancement of Teaching and the American Association of Higher Education (Sorcinelli *et al.* 2006). Now scientists (and faculty from other disciplines) and their institutions participate in the national Carnegie network engaged in SOTL that endeavors to subject teaching to critical evaluation, and provides results that are usable by others (www.carnegiefoundation.org/programs/index.asp?key=21).

Further evidence of increased awareness of scientific teaching is seen in the National Science Foundation's investment in the development of a robust research community within the STEM (Science, Technology, Engineering, Mathematics) disciplines. The goal is to conduct rigorous research and assessment to provide the evidence to advance improved STEM education in undergraduate science courses (Ramaley *et al.* 2005). Finally, beginning in 2006, each month, *Science* will publish innovative ideas in science education that "work" (Cech and Kennedy 2005). In all cases, the results from the research need to be translated into practice, so that undergraduate learning and instruction in the sciences improves.

What is research on scientific teaching? In forthcoming articles, we shall explore and define this type of research, using examples based on articles from *Frontiers*. We will examine frameworks that describe the principles of learning that, in effect, become the hypotheses we test. During this process we plan to synthesize the current research available on teaching and learning and identify gaps in knowledge. We will also build an operational definition of research on scientific teaching and provide examples of model studies. Ideally, these articles will help us create a substantive link

Panel 1. Overview of Pathways to Scientific Teaching articles

Date	*Pathways title*	*Review/Research paper*	*Instructional strategies/assessment*
December 2005	Lyme disease: a case about ecosystem services	Kremen and Ostfeld. A call to ecologists: measuring, analyzing, and managing ecosystem services	• Interdisciplinary case study • Analyze data • Design management strategy
November 2005	Problem solving: a foundation for modeling	Ellison *et al.* Loss of foundation species: consequences for the structure and dynamics of forested ecosystems	• Design models • Transfer ecosystem processes in forests to other systems
October 2005	Here today, not gone tomorrow?	Wilcove and Master. How many endangered species are there in the United States?	• Students use web-based data • Faculty analyze assessment data
September 2005	Learning through peer assessment	Gurnell *et al.* Effects of deposited wood on biocomplexity of river corridors	• Peer assessment structure • Group assessment of content • Group assessment of groups
August 2005	Determining confidence: sex and statistics	Willingham. The effects of atrazine and temperature on turtle hatchling size and sex ratios	• Learning cycle • Statistics • Data interpretation
June 2005	Active homework – preparation for active classes	Kappel. Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species	• Active homework • Connect ecological problems with personal choices
May 2005	Collaborative learning – a jigsaw	Fang *et al.* Human-induced long-term changes in the lakes of the Jianghan Plain, Central Yangtze	• Primary research interpretation • Jigsaw – peer interactions • Transfer knowledge
April 2005	Unraveling complexity: building an understanding of Everglades restoration	Sklar *et al.* The ecological–societal underpinnings of Everglades restoration	• JITT (Just in Time Teaching) • Faculty analyze data before class
March 2005	Unleashing problem solvers: from assessment to designing research	Marvier and Van Acker. Can crop transgenes be kept on a leash?	• Use biological principles to analyze problems • Introduce sci–ed research to faculty
December 2004	Ecological controversy: analysis to synthesis	Banks. Divided culture: integrating agriculture and conservation biology	• Group-structured controversy • Integrate concepts
November 2004	Practicing scientific inquiry: what are the rules?	Knapp *et al.* Generality in ecology: testing North American grassland rules in South African savannas	• Build models • Make predictions • Test rules
October 2004	Novel assessments: detecting success in student learning	Callaway and Ridenour. Novel weapons: invasive success and the evolution of increased competitive ability	• Predict, design experiments • Multiple forms of assessment
September 2004	Marine pathology: revealing the ocean's etiology to earthbound students	Harvel *et al.* The rising tide of ocean diseases: unsolved problems and research priorities	• Learning cycle • Construct hypotheses and test based on one disease per group
August 2004	Climate change: confronting student ideas	Beedlow *et al.* Rising atmospheric CO_2 and carbon sequestration in forests	• Learning cycle • Pre-post-tests • Predict effect of increased CO_2

between teaching and research and contribute to the growing knowledge of "what works" in undergraduate science education. Ultimately, the methods used and the quality of evidence reported will help prove that research on scientific teaching is indeed, as Boyer (1990) notes, scholarly.

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