

STEM Subject: Biology

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Scientific teaching is an intentional approach to teaching by instructors that focuses on the goal of student learning and involves iterative questioning, evidence collection, and innovation. Inspired by the original book on the subject, *Scientific Teaching* (Handelsman et al., 2006), we have chosen to introduce the reader to key terminology in biology education by organizing these terms with respect to the three main tenets of scientific teaching—active learning; assessment; and the related ideas of equity, diversity, and inclusivity—along with a fourth section about tools for moving the ideas of scientific teaching into practice: Active Learning; Engaging Students as Participants in Learning Assessment; Finding Out How Students Are Thinking and Learning Equity, Diversity, and Inclusivity: Creating Fair and Accessible Learning Environments Moving to Practice: Instructional Design, Learning, and Technologies For each of these four sections, there is a brief overview of the topic, followed by a set of commonly encountered terms related to that topic. For each key term, we provide an introductory, descriptive paragraph, which is followed by two references that could be starting points for additional explorations. Whenever possible, these references include accessible review articles written primarily for a scientific audience. No doubt, dozens of additional terms could be added to each section; however, this collection is intended to be a starting point for readers.

Wieman, C. (September 01, 2012). Applying New Research to Improve Science Education. *Issues in Science & Technology*, *29*, 1.)

Insights from several fields on how people learn to become experts can help us to dramatically enhance the effectiveness of science, technology, engineering, and mathematics education. Science, technology, engineering, and mathematics (STEM) education is critical to the U.S. future because of its relevance to the economy and the need for a citizenry able to make wise decisions on issues faced by modern society. Calls for improvement have become increasingly widespread and desperate, and there have been countless national, local, and private programs aimed at improving STEM education, but there continues to be little discernible change in either student achievement or student interest in STEM. Articles and letters in the spring and summer 2012 editions of *Issues* extensively discussed STEM education issues. Largely absent from these discussions, however, is attention to learning. This is unfortunate because there is an extensive body of recent research on how learning is accomplished, with clear implications for what constitutes effective STEM teaching and how that differs from typical current teaching at the K-12 and college levels. Failure to understand this learning- focused perspective is also a root cause of the failures of many reform efforts.

Kober, N. (2015). *Reaching Students: What Research Says about Effective Instruction in Undergraduate Science and Engineering*. National Academies Press. 500 Fifth Street NW, Washington, DC 20001. Tel:

888-624-8373; Tel: 202-334-2000; Fax: 202-334-2793; e-mail: Customer_Service@nap.edu; Web site: <http://www.nap.edu>.

The undergraduate years are a turning point in producing scientifically literate citizens and future scientists and engineers. Evidence from research about how students learn science and engineering shows that teaching strategies that motivate and engage students will improve their learning. So how do students best learn science and engineering? Are there ways of thinking that hinder or help their learning process? Which teaching strategies are most effective in developing their knowledge and skills? And how can practitioners apply these strategies to their own courses or suggest new approaches within their departments or institutions? "Reaching Students" strives to answer these questions. "Reaching Students" presents the best thinking to date on teaching and learning undergraduate science and engineering. Focusing on the disciplines of astronomy, biology, chemistry, engineering, geosciences, and physics, this book is an introduction to strategies to try in your classroom or institution. Concrete examples and case studies illustrate how experienced instructors and leaders have applied evidence-based approaches to address student needs, encouraged the use of effective techniques within a department or an institution, and addressed the challenges that arose along the way. The research-based strategies in "Reaching Students" can be adopted or adapted by instructors and leaders in all types of public or private higher education institutions. They are designed to work in introductory and upper-level courses, small and large classes, lectures and labs, and courses for majors and non-majors. And these approaches are feasible for practitioners of all experience levels who are open to incorporating ideas from research and reflecting on their teaching practices. This book is an essential resource for enriching instruction and better educating students.

Knight, J. K., Wise, S. B., & Southard, K. M. (December 01, 2013). Understanding Clicker Discussions: Student Reasoning and the Impact of Instructional Cues. *Cbe - Life Sciences Education*, 12, 4, 645-654.

Previous research has shown that undergraduate science students learn from peer discussions of in-class clicker questions. However, the features that characterize such discussions are largely un-known, as are the instructional factors that may lead students into productive discussions. To explore these questions, we recorded and transcribed 83 discussions among groups of students discussing 34 different clicker questions in an upper-level developmental biology class. Discussion transcripts were analyzed for features such as making claims, questioning, and explaining reasoning. In addition, transcripts were categorized by the quality of reasoning students used and for performance features, such as percent correct on initial vote, percent correct on revote, and normalized learning change. We found that the majority of student discussions included exchanges of reasoning that used evidence and that many such exchanges resulted in students achieving the correct answer. Students also had discussions in which ideas were exchanged, but the correct answer not achieved. Importantly, instructor prompts that asked students to use reasoning resulted in significantly more discussions containing reasoning connected to evidence than without such prompts. Overall, these results suggest that these upper-level biology students readily employ reasoning in their discussions and are positively influenced by instructor cues.

Hoskinson, A.-M., Caballero, M. D., & Knight, J. K. (2013). How Can We Improve Problem Solving in Undergraduate Biology? Applying Lessons from 30 Years of Physics Education Research. *CBE Life Sciences Education*, 12(2), 153–161. doi:10.1187/cbe.12-09-0149.

If students are to successfully grapple with authentic, complex biological problems as scientists and citizens, they need practice solving such problems during their undergraduate years. Physics education researchers have investigated student problem solving for the past three decades. Although physics and biology problems differ in structure and content, the instructional purposes align closely: explaining patterns and processes in the natural world and making predictions about physical and biological systems. In this paper, we discuss how research-supported approaches developed by physics education researchers can be adopted by biologists to enhance student problem-solving skills. First, we compare the problems that biology students are typically asked to solve with authentic, complex problems. We then describe the development of research-validated physics curricula emphasizing process skills in problem solving. We show that solving authentic, complex biology problems requires many of the same skills that practicing physicists and biologists use in representing problems, seeking relationships, making predictions, and verifying or checking solutions. We assert that acquiring these skills can help biology students become competent problem solvers. Finally, we propose how biology scholars can apply lessons from physics education in their classrooms and inspire new studies in biology education research.

Hoskinson, A.-M., Barger, N. N., & Martin, A. P. (July 01, 2014). Keys to a Successful Student-Centered Classroom: Three Recommendations. *Bulletin of the Ecological Society of America*, 95, 3, 281-292.

In this article, we offer three recommendations to increase your chances of success in student-centered courses. For this discussion, we define “success” as (1) students maintaining or increasing achievement on authentic assessments of concepts and skills, and (2) intellectually and emotionally rich experiences for students and instructors alike. Individually, each of us struggled to create successful student-centered courses —despite access to excellent resources like those mentioned above. In response, we formed a community of practice (Wenger 1999) focused on effective student-centered course design for our courses (Table 1). These recommendations emerged from regular (approximately biweekly), sustained discussions among the authors about acknowledging and understanding our failures, and about creating and sharing best practices in college teaching. For each recommendation, we elaborate on what we did and what our students did, and we provide an example of its implementation (Table 2). The present paper provides our best advice for success, grounded in relevant research in teaching in higher education when possible.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (May 12, 2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*.

To test the hypothesis that lecturing maximizes learning and course performance, we metaanalyzed 225 studies that reported data on examination scores or failure rates when comparing student performance in undergraduate science, technology, engineering, and mathematics (STEM) courses under traditional lecturing versus active learning. The effect sizes indicate that on average, student performance on examinations and concept inventories increased by 0.47 SDs under active learning ($n = 158$ studies), and that the odds ratio for failing was 1.95 under traditional lecturing ($n = 67$ studies). These results indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning. Heterogeneity analyses indicated that both results hold across the STEM disciplines, that active learning increases scores on concept inventories more than on course examinations, and that active learning appears effective across all class sizes—although the greatest effects are in small ($n \leq 50$) classes. Trim and fill analyses and fail-safe n calculations suggest that the results are not due to publication bias. The results also appear robust to variation in the methodological rigor of the included studies, based on the quality of controls over student quality and instructor identity. This is the largest and most comprehensive metaanalysis of undergraduate STEM education published to date. The results raise questions about the continued use of traditional lecturing as a control in research studies, and support active learning as the preferred, empirically validated teaching practice in regular classrooms.

Eddy, S. L., & Hogan, K. A. (September 01, 2014). Getting under the Hood: How and for Whom Does Increasing Course Structurework?. *Cbe - Life Sciences Education*, 13, 3, 453-468.

At the college level, the effectiveness of active-learning interventions is typically measured at the broadest scales: the achievement or retention of all students in a course. Coarse-grained measures like these cannot inform instructors about an intervention's relative effectiveness for the different student populations in their classrooms or about the proximate factors responsible for the observed changes in student achievement. In this study, we disaggregate student data by racial/ethnic groups and first-generation status to identify whether a particular intervention--increased course structure--works better for particular populations of students. We also explore possible factors that may mediate the observed changes in student achievement. We found that a "moderate-structure" intervention increased course performance for all student populations, but worked disproportionately well for black students--halving the black-white achievement gap--and first-generation students--closing the achievement gap with continuing-generation students. We also found that students consistently reported completing the assigned readings more frequently, spending more time studying for class, and feeling an increased sense of community in the moderate-structure course. These changes imply that increased course structure improves student achievement at least partially through increasing student use of distributed learning and creating a more interdependent classroom community.

Freeman, S., Haak, D., Wenderoth, M.P. 2011. Increased Course Structure Improves Performance in Introductory Biology. *Life Science Education*. Vol. 10, 175-186.

We tested the hypothesis that highly structured course designs, which implement reading quizzes and/or extensive in-class active-learning activities and weekly practice exams, can lower failure rates in an introductory biology course for majors, compared with low-structure course designs that are based on lecturing and a few high-risk assessments. We controlled for 1) instructor effects by analyzing data from quarters when the same instructor taught the course, 2) exam equivalence with new assessments called the Weighted Bloom's Index and Predicted Exam Score, and 3) student equivalence using a regression-based Predicted Grade. We also tested the hypothesis that points from reading quizzes, clicker questions, and other "practice" assessments in highly structured courses inflate grades and confound comparisons with low-structure course designs. We found no evidence that points from active-learning exercises inflate grades or reduce the impact of exams on final grades. When we controlled for variation in student ability, failure rates were lower in a moderately structured course design and were dramatically lower in a highly structured course design. This result supports the hypothesis that active-learning exercises can make students more skilled learners and help bridge the gap between poorly prepared students and their better-prepared peers.

Haak, D.C., Hillerislambers, J., Pitre, E., Freeman, S. 2011. Increased structure and active learning reduce the achievement gap in introductory biology. *Science*. Vol. 332, 1213-1230.

Science, technology, engineering, and mathematics instructors have been charged with improving the performance and retention of students from diverse backgrounds. To date, programs that close the achievement gap between students from disadvantaged versus nondisadvantaged educational backgrounds have required extensive extramural funding. We show that a highly structured course design, based on daily and weekly practice with problem-solving, data analysis, and other higher-order cognitive skills, improved the performance of all students in a college-level introductory biology class and reduced the achievement gap between disadvantaged and nondisadvantaged students—without increased expenditures. These results support the Carnegie Hall hypothesis: Intensive practice, via active-learning exercises, has a disproportionate benefit for capable but poorly prepared students.

Smith, M.K., Wood, W.B., Krauter, K., Knight, J.K., 2011. Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *Life Science Education*. Vol. 10, 55-63.

Use of in-class concept questions with clickers can transform an instructor-centered "transmissionist" environment to a more learner-centered constructivist classroom. To compare the effectiveness of three different approaches using clickers, pairs of similar questions were used to monitor student understanding in majors' and nonmajors' genetics courses. After answering the first question individually, students participated in peer discussion only, listened to an instructor explanation only, or engaged in peer discussion followed by instructor explanation, before answering a second question individually. Our results show that the combination of peer discussion followed by instructor explanation improved average student

performance substantially when compared with either alone. When gains in learning were analyzed for three ability groups of students (weak, medium, and strong, based on overall clicker performance), all groups benefited most from the combination approach, suggesting that peer discussion and instructor explanation are synergistic in helping students. However, this analysis also revealed that, for the nonmajors, the gains of weak performers using the combination approach were only slightly better than their gains using instructor explanation alone. In contrast, the strong performers in both courses were not helped by the instructor-only approach, emphasizing the importance of peer discussion, even among top-performing students.

Smith, M.K., Trujillo, C., Su, T.T., 2011. The benefits of using clickers in small-enrollment seminar-style biology courses. *Life Sciences Education*. Vol. 10, 14-17.

Although the use of clickers and peer discussion is becoming common in large-lecture undergraduate biology courses, their use is limited in small-enrollment seminar-style courses. To investigate whether facilitating peer discussion with clickers would add value to a small-enrollment seminar-style course, we evaluated their usefulness in an 11-student Embryology course at the University of Colorado, Boulder. Student performance data, observations of peer discussion, and interviews with students revealed that adding clickers to a small-enrollment course 1) increases the chance students will do the required reading before class, 2) helps the instructor engage all students in the class, and 3) gives students a focused opportunity to share thinking and to learn from their peers.

Catley, K., Novick, L.R., Shade, C.K. 2010. Interpreting evolutionary diagrams: When topology and process conflict. *J of Research in Science Teaching*. Vol. 47, 861-882.

The authors argue that some diagrams in biology textbooks and the popular press presented as depicting evolutionary relationships suggest an inappropriate (anagenic) conception of evolutionary history. The goal of this research was to provide baseline data that begin to document how college students conceptualize the evolutionary relationships depicted in such noncladogenic diagrams and how they think about the underlying evolutionary processes. Study 1 investigated how students (n=450) interpreted the evolutionary relationships depicted in four such evolutionary diagrams. In Study 2, new students (n=62) were asked to interpret what the students in Study 1 meant when they used the terms evolved into/ from and ancestor/descendant of. The results show the interpretations fell broadly into two categories: (a) evolution as an anagenic rather than cladogenic process, and (b) evolution as a teleological (purposedriven) process. These results imply that noncladogenic diagrams are inappropriate for use in evolution education because they lead to the misinterpretation of many evolutionary processes.

Desaulniers Miller, M.C., Montplaisir, L.M., Offerdahl, E.G., Cheng, F.C., Ketterling, G.L. 2010. Comparison of views of the nature of science between natural science and nonscience majors. *Life Sciences Education*. Vol. 9, 45-54.

Science educators have the common goal of helping students develop scientific literacy, including understanding of the nature of science (NOS). University faculties are challenged with the need to develop informed NOS views in several major student subpopulations, including science majors and nonscience majors. Research into NOS views of undergraduates, particularly

science majors, has been limited. In this study, NOS views of undergraduates in introductory environmental science and upper-level animal behavior courses were measured using Likert items and open-ended prompts. Analysis revealed similarities in students' views between the two courses; both populations held a mix of naïve, transitional, and moderately informed views. Comparison of pre- and postcourse mean scores revealed significant changes in NOS views only in select aspects of NOS. Student scores on sections addressing six aspects of NOS were significantly different in most cases, showing notably uninformed views of the distinctions between scientific theories and laws. Evidence-based insight into student NOS views can aid in reforming undergraduate science courses and will add to faculty and researcher understanding of the impressions of science held by undergraduates, helping educators improve scientific literacy in future scientists and diverse college graduates.

Perez, K.E., Strauss, E.A., Downey, N., Galbraith, A., Jeanne, R., Cooper, S. 2010. Does displaying the class results affect student discussion during peer instruction? *Life Sciences Education*. Vol. 9, 133-140.

The use of personal response systems, or clickers, is increasingly common in college classrooms. Although clickers can increase student engagement and discussion, their benefits also can be overstated. A common practice is to ask the class a question, display the responses, allow the students to discuss the question, and then collect the responses a second time. In an introductory biology course, we asked whether showing students the class responses to a question biased their second response. Some sections of the course displayed a bar graph of the student responses and others served as a control group in which discussion occurred without seeing the most common answer chosen by the class. If students saw the bar graph, they were 30% more likely to switch from a less common to the most common response. This trend was more pronounced in true/false questions (38%) than multiple-choice questions (28%). These results suggest that observing the most common response can bias a student's second vote on a question and may be misinterpreted as an increase in performance due to student discussion alone.

Sirum, K.L., Madigan, D. 2010. Assessing how science faculty learning communities promote scientific teaching. *Biochemistry and Molecular Biology Education*. Vol. 38, 193-202.

Although there is a need for continued pedagogical advancement in science undergraduate education, what is needed more urgently is more widespread adaptation of pedagogical practices that research has already shown to promote learning. Those practices include interactive engagement pedagogies such as active learning and inquiry-based learning. The need now is to find ways to integrate and institutionalize these evidence-based strategies for teaching science and to help science faculty learn about and implement them. Scientific Teaching Learning Communities (STLCs) create a culture that values scholarly teaching within science departments, important for bridging the gap between science and education and for improving undergraduate science learning. Evidence for the impact of STLCs on the student-learning environment was obtained through the development and use of the Participant Assessment of Learning Gains survey, an adaptation of the online Student Assessment of Learning Gains survey originally developed by Seymour et al. Data reveal how STLCs are transforming faculty behavior and directly affecting what they do in their science classrooms.

Smith, M.U. 2010. Current status of research in teaching and learning evolution: I. Philosophical/epistemological issues. *Sci & Educ*. Vol. 19, 523-538.

Scholarship that addresses teaching and learning about evolution has rapidly increased in recent years. This review of that scholarship first addresses the philosophical/epistemological issues that impinge on teaching and learning about evolution, including the proper philosophical goals of evolution instruction; the correlational and possibly causal relationships among knowing, understanding, accepting, and believing; and the factors that affect student understanding, acceptance, and/or belief. Second, I summarize the specific epistemological issues involved, including empiricism, naturalism, philosophical vs methodological materialism, science vs religion as non-overlapping magisteria, and science as a way of knowing. Third, the paper critically reviews the strengths and weaknesses of the research tools available to measure the nature of science, epistemological beliefs, and especially the acceptance of evolution. Based on these findings, further research in these areas, especially study of the factors that cause lack of explanatory coherence as well as replications of studies that promise to explain current confusing findings about the interrelationships among student understanding, acceptance, and belief in evolution, are called for. In addition, this review calls for more longitudinal studies to delineate causal connections as well as improved measurement tools.

Smith, M.U. 2010. Current status of research in teaching and learning evolution: II. Pedagogical issues. *Sci & Educ*. Vol. 19, 539-571.

This is the second of two articles that address recent scholarship about teaching and learning about evolution. This second review seeks to summarize this state of affairs and address the implications of this work for the classroom by addressing four basic questions: (1) What is evolution? What components of the theory are important at the introductory level? (2) Why do students and members of the public at large need to understand evolution? (3) What makes evolution difficult to teach and learn? and (4) What promising instructional approaches have been developed and tested? The paper will also focus on concerns about both the research designs and the measures used in this work. Based on this review, I will then propose a set of pedagogical implications and recommendations for the classroom instructor and call for studies to address specific gaps identified.

Thagard, P., Findlay, S. 2010. Getting to Darwin: Obstacles to accepting evolution by natural selection. *Sci. & Educ*. Vol. 19, 625-636.

Darwin's theory of evolution by natural selection is central to modern biology, but is resisted by many people. This paper discusses the major psychological obstacles to accepting Darwin's theory. Cognitive obstacles to adopting evolution by natural selection include conceptual difficulties, methodological issues, and coherence problems that derive from the intuitiveness of alternative theories. The main emotional obstacles to accepting evolution are its apparent conflict with valued beliefs about God, souls, and morality. We draw on the philosophy of science and on a psychological theory of cognitive and emotional belief revision to make suggestions about what can be done to improve acceptance of Darwinian ideas.

Armbruster, P., Patel, M., Johnson, E., Weiss, M. 2009. Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. *Life Science Education*. Vol. 8, 203-213.

We describe the development and implementation of an instructional design that focused on bringing multiple forms of active learning and student-centered pedagogies to a one-semester,

undergraduate introductory biology course for both majors and non-majors. Our course redesign consisted of three major elements: 1) reordering the presentation of the course content in an attempt to teach specific content within the context of broad conceptual themes, 2) incorporating active and problem-based learning into every lecture, and 3) adopting strategies to create a more student-centered learning environment. Assessment of our instructional design consisted of a student survey and comparison of final exam performance across 3 years – 1 year before our course redesign was implemented (2006) and during two successive years of implementation (2007 and 2008). The course restructuring led to significant improvement of self-reported student engagement and satisfaction and increased academic performance. We discuss the successes and ongoing challenges of our course restructuring and consider issues relevant to institutional change.

Glynn, S.M., Taasoobshirzai, G., Brickman, P. 2009. Science motivation questionnaire: Construct validation with nonscience majors. *Journal of Research in Science Teaching*. Vol. 46, 127-146.

This study examined how 770 nonscience majors, enrolled in a core-curriculum science course, conceptualized their motivation to learn science. The students responded to the Science Motivation Questionnaire, a 30-item Likert-type instrument designed to provide science education researchers and science instructors with information about students' motivation to learn science. The students' scores on the Science Motivation Questionnaire were reliable and related to students' high school preparation in science, GPA in college science courses, and belief in the relevance of science to their careers. An exploratory factor analysis provided evidence of construct validity, revealing that the students conceptualized their motivation to learn science in terms of five dimensions: intrinsic motivation and personal relevance, self-efficacy and assessment anxiety, self-determination, career motivation, and grade motivation. Women and men had different profiles on these dimensions, but equivalent overall motivation to learn science. Essays by all of the students explaining their motivation to learn science and interviews with a sample of the students were used to interpret Science Motivation Questionnaire scores. The findings were viewed in terms of a social-cognitive theory of learning, and directions for future research were discussed.

Kalman, C. 2009. The need to emphasize epistemology in teaching and research. *Sci & Educ*. Vol 18, 325-347.

The views on epistemology by philosophers of science are developed through an historical lens. Enabling students to develop a scientific mindset is complicated by student's views on the Nature of Science. Students need to appreciate the history of science and to contrast different frameworks. In order to do this, students have to be able to follow presentations in class and read their textbooks. Although individual words are understandable, the sentences appear to take the form of an unknown language. The solution utilized in this paper is to get students to approach their reading of their textbooks in the manner of the hermeneutical circle through an activity called Reflective Writing.

Smith, M.K., Wood, W.B., Adams, W.K., Wieman, C., Knight, J.K., Guild, N., Su, T.T. 2009. Why peer discussion improves student performance on in-class concept questions. *Science*. Vol. 323, 122-125.

When students answer an in-class conceptual question individually using clickers, discuss it with their neighbors, and then revote on the same question, the percentage of correct answers

typically increases. This outcome could result from gains in understanding during discussion, or simply from peer influence of knowledgeable students on their neighbors. To distinguish between these alternatives in an undergraduate genetics course, we followed the above exercise with a second, similar (isomorphic) question on the same concept that students answered individually. Our results indicate that peer discussion enhances understanding, even when none of the students in a discussion group originally knows the correct answer.

Tanner, K.D. 2009. Talking to learn: Why biology students should be talking in classrooms and how to make it happen. *Life Sciences Education*. Vol. 8, 89-94.

If instructors in general value Student Talk, why isn't Student Talk a bigger part of undergraduate biology teaching? Below, I consider research evidence that suggests that Student Talk is important in learning, address common challenges that instructors face in getting students talking, and describe some simple teaching strategies that anyone can use tomorrow in their classroom to make Student Talk happen.

Armstrong, N.A., Wallace, C.S., Chang, S.M. 2008. Learning from writing in college biology. *Res Sci Educ*. Vol. 38, 483-499.

This study used both quantitative and qualitative analyses to examine the influence of written arguments on learning in a college level introductory biology class and the types of metacognition employed by students while writing. Comparison of a treatment and control group indicates that the writing assignments used had minimal impact on overall content learning as measured by conventional exams. Subsequent interviews and think-aloud protocols with a subset of students indicated that writing arguments had the potential to foster learning through forward and backward search strategies. However, few of the students took advantage of this opportunity to use metacognitive skills. This study suggests that preparing written arguments is not sufficient, by itself, to have a reliable effect on student learning and is consistent with the view that students must be explicitly taught when and how to use different metacognitive strategies.

Crossgrove, K., Curran, K. 2008. Using clickers in nonmajor- and major-level biology courses: Student opinion, learning, and long-term retention of course material. *Life Sciences Education*. Vol. 7, 146-154.

Student response systems (clickers) are viewed positively by students and instructors in numerous studies. Evidence that clickers enhance student learning is more variable. After becoming comfortable with the technology during fall 2005–spring 2006, we compared student opinion and student achievement in two different courses taught with clickers in fall 2006. One course was an introductory biology class for nonmajors, and the other course was a 200 level genetics class for biology majors. Students in both courses had positive opinions of the clickers, although we observed some interesting differences between the two groups of students. Student performance was significantly higher on exam questions covering material taught with clickers, although the differences were more dramatic for the nonmajors biology course than the genetics course. We also compared retention of information 4 mo. after the course ended, and we saw increased retention of material taught with clickers for the nonmajors course, but not for the genetics course. We discuss the implications of our results in light of differences in how the two courses were taught and differences between science majors and nonmajors.

Gunersel, A.B., Simpson, N.J., Aufderheide, K.J., Wang, L. 2008. Effectiveness of calibrated peer review for improving writing and critical thinking skills in biology undergraduate students. *J of the scholarship of Teaching and Learning*, Vol. 8, 25-37.

This study focuses on student development with Calibrated Peer Review (CPR)™, a web-based tool created to promote writing and critical thinking skills. Research questions focus on whether or not students showed improvement in writing and reviewing competency with repeated use of CPR in a senior-level biology course and whether the difference between higher performing and lower performing students decreased over time. Four repeated measures analyses were conducted with different sets of students. Repeated measures analyses indicate that students showed improvement in writing skills and reviewer competency with repeated use of CPR. The difference between higher and lower performing students decreased over time in both writing skills and reviewer competency.

Hermann, R. 2008. Evolution as a controversial issue: a review of instructional approaches. *Sci & Educ*. Vol. 17, 1001-1032.

Although evolution has long been considered a controversial issue, little effort has been made to ensure that instructional approaches address the controversial nature of the issue. A framework for understanding the nature of controversy and some defining characteristics of controversial issues are provided. In light of this framework evolution is evaluated to address the defining characteristics of the issue that make it controversial. The purpose of this exploratory review of evolution instruction is to identify a range of instructional approaches reported in extant literature and to determine the extent to which each approach is commensurate with teaching evolution as a controversial issue.

Martin-Hansen, L.M. 2008. First-year college students' conflict with religion and science. *Science and Education*. Vol. 17, 317-357.

This study took place during a First Year Seminar course where 20 incoming college freshmen studied the central topic of the nature of science within the context of biological evolution. The instructor researched students' understandings in the nature of science as they progressed through the course by examining a variety of qualitative and quantitative data including class writings, pre- and post-test selected items from the VOSTS (Views on Science- Technology- Society), and interviews. The intended outcomes of the course were to reduce the number of student misconceptions in the nature of science and to ease student apprehension when learning about evolution. Data were analyzed to determine whether students were moving toward a more generally accepted idea of the nature of science or toward another type of misconception.

Morse, D., Jutras, F. 2008. Implementing concept-based learning in a large undergraduate classroom. *Life Sciences Education*. Vol 7, 243-253.

An experiment explicitly introducing learning strategies to a large, first-year undergraduate cell biology course was undertaken to see whether awareness and use of strategies had a measurable impact on student performance. The construction of concept maps was selected as the strategy to be introduced because of an inherent coherence with a course structured by

concepts. Data were collected over three different semesters of an introductory cell biology course, all teaching similar course material with the same professor and all evaluated using similar examinations. The first group, used as a control, did not construct concept maps, the second group constructed individual concept maps, and the third group first constructed individual maps then validated their maps in small teams to provide peer feedback about the individual maps. Assessment of the experiment involved student performance on the final exam, anonymous polls of student perceptions, failure rate, and retention of information at the start of the following year. The main conclusion drawn is that concept maps without feedback have no significant effect on student performance, whereas concept maps with feedback produced a measurable increase in student problem-solving performance and a decrease in failure rates.

Wood, William. 2008. Teaching concepts versus facts in developmental biology. *Life Science Education*. Vol 7, 10-16.

In our teaching of undergraduate life sciences courses, we are admonished to place more emphasis on concepts over facts, conceptual understanding over memorization of details. But understanding the biology of development requires extensive knowledge of facts as well as concepts, and sometimes it seems hard to distinguish which is which.

Allen, D., Tanner, K. 2007. Putting the horse back in front of the cart: Using visions and decisions about high-quality learning experiences to drive course design. *Life Science Education*. Vol. 6, 85-89.

Another, more systematic approach to designing significant learning experiences, often referred to as the “backward design process,” has been popularized by Wiggins and McTighe (1998) and is included as a central feature of Fink’s model for integrated course design (Fink, 2003). The process is referred to as backward because it starts with a vision of the desired results. The design process then works backward to develop the instruction. The design choices that constitute the beginning of the process in the common model of course design (described above in the Chris and Pat scenarios) would be made toward the end of the backward design process and would not drive the curriculum. How you teach might become as important as what you teach.

Armstrong, N., Chang, S.M., Brickman, M. 2007. Cooperative learning in industrial-sized biology classes. *Life Sciences Education*. Vol. 6, 169-171.

This study examined the impact of cooperative learning activities on student achievement and attitudes in large-enrollment (~250) introductory biology classes. We found that students taught using a cooperative learning approach showed greater improvement in their knowledge of course material compared with students taught using a traditional lecture format. In addition, students viewed cooperative learning activities highly favorably. These findings suggest that encouraging students to work in small groups and improving feedback between the instructor and the students can help to improve student outcomes even in very large classes. These results should be viewed cautiously, however, until this experiment can be replicated with additional faculty. Strategies for potentially improving the impact of cooperative learning on student achievement in large courses are discussed.

Barber, M., Njus, D. 2007. Clicker evolution: Seeking intelligent design. *Life Sciences Education*. Vol. 6, 1-8.

Two years after the first low-cost radio-frequency audience response system using clickers was introduced for college classrooms, at least six different systems are on the market. Their features and user-friendliness are evolving rapidly, driven by competition and improving technology. The proliferation of different systems is putting pressure on universities to standardize or otherwise limit the number of different clickers a student is expected to acquire. To facilitate that choice, the strengths and weaknesses of six systems (eInstruction Classroom Performance System, Qwizdom, TurningPoint, Interwrite PRS, iClicker, and H-ITT) are compared, and the factors that should be considered in making a selection are discussed. In our opinion, the selection of a clicker system should be driven by the faculty, although students and the relevant teaching and technology support units of the university must also participate in the dialogue. Given the pace of development, it is also wise to reconsider the choice of a clicker system at regular intervals.

Brainard, J. 2007. The tough road to better science teaching. *The Chronicle of a Higher Education*. August 3, 2007. <http://chronicle.com/weekly/v53/i48/48a01601.htm>

One might expect California State University at Fullerton, with a history of preparing elementary- and secondary-school teachers, to embrace new but proven methods of instruction. Still, when its biology department began a project a decade ago to overhaul the undergraduate curriculum, the effort bogged down quickly.

Most of the professors wanted to consolidate the department's eight required courses, which they felt covered too much content in too little depth. But they argued endlessly about how that should be done. After two fruitless years of faculty meetings, the department called in a professional facilitator, who helped the participants reach agreement on where to trim and how to incorporate teaching methods proven to develop students' critical-thinking skills and performance.

Caldwell, J.E. 2007. Clickers in the large classroom: Current research and best-practice tips. *Live Science Education*. Vol. 6, 9-21.

Audience response systems (ARS) or clickers, as they are commonly called, offer a management tool for engaging students in the large classroom. Basic elements of the technology are discussed. These systems have been used in a variety of fields and at all levels of education. Typical goals of RS questions are discussed, as well as methods of compensating for the reduction in lecture time that typically results from their use. Examples of ARS use occur throughout the literature and often detail positive attitudes from both students and instructors, although exceptions do exist. When used in classes, ARS clickers typically have either a benign or positive effect on student performance on exams, depending on the method and extent of their use, and create a more positive and active atmosphere in the large classroom. These systems are especially valuable as a means of introducing and monitoring peer learning methods in the large lecture classroom. So that the reader may use clickers effectively in his or her own classroom, a set of guidelines for writing good questions and a list of best-practice tips have been culled from the literature and experienced users.

Colbert, J.T., Olson, J.K., Clough, M.P. 2007. Using the web to encourage student-generated questions in large-format introductory biology classes. *Life Sciences Education*. Vol. 6, 42-48.

Students rarely ask questions related to course content in large-format introductory classes. The use of a Web-based forum devoted to student-generated questions was explored in a second semester introductory biology course. Approximately 80% of the enrolled students asked at least one question about course content during each of three semesters during which this approach was implemented. About 95% of the students who posted questions reported reading the instructor's response to their questions. Although doing so did not contribute to their grade in the course, approximately 75% of the students reported reading questions posted by other students in the class. Approximately 60% of the students reported that the Web-based question asking activity contributed to their learning of biology.

Garin-Doxas, K., Klymkowsky, M., Elrod, S. 2007. Building, using, and maximizing the impact of concept inventories in the biological sciences: Report on a National Science Foundation-sponsored conference on the construction of concept inventories in the biological sciences. *Life Science Education*. Vol. 6, 277-282.

The meeting "Conceptual Assessment in the Biological Sciences" was held March 3-4, 2007, in Boulder, Colorado. Sponsored by the National Science Foundation was hosted by University of Colorado, Boulder's Biology Concept Inventory Team, the meeting drew together 21 participants from 13 institutions, all of whom had received National Science Foundation funding for biology education. Topics of interest included Introductory Biology, Genetics, Evolution, Ecology and the Nature of Science. The goal of the meeting was to organize and leverage current efforts to develop concept inventories for each of these topics. These diagnostic tools are inspired by the success of the Force Concept Inventory, developed by the community of physics educators to identify student misconceptions about Newtonian mechanics. By working together, participants hope to lessen the risk that groups might develop competing rather than complementary inventories.

McDaniel, C.N., Lister, B.C., Hanna, M.H., Roy, H. 2007. Increased learning observed in redesigned introductory biology course that employed web-enhanced, interactive pedagogy. *Life Sciences Education*. Vol. 6, 243-249.

Our Introduction to Biology course (BIOL 1010) changed in 2004 from a standard instructor centered, lecture-homework-exam format to a student-centered format that used Web-enhanced, interactive pedagogy. To measure and compare conceptual learning gains in the traditional course in fall 2003 with a section of the interactive course in fall 2004, we created concept inventories for both evolution and ecology. Both classes were taught by the same instructor who had taught BIOL 1010 since 1976, and each had a similar student composition with comparable biological knowledge. A significant increase in learning gain was observed with the Web enhanced, interactive pedagogy in evolution (traditional, 0.10; interactive, 0.19; $p = 0.024$) and ecology (traditional, 0.05; interactive, 0.14; $p = 0.000009$) when assessment was made unannounced and for no credit in the last week of classes. These results strengthen the case for augmenting or replacing instructor-centered teaching with Web-enhanced, interactive, student centered teaching. When assessment was made using the final exam in the interactive course, for credit and after studying, significantly greater learning gains were made in evolution

(95%, 0.37, $p = 0.0001$) and ecology (143%, 0.34, $p = 0.000003$) when compared with learning gains measured without credit or study in the last week of classes.

Nehm, R. H., Schonfeld, I.S. 2007. Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools? *J Sci Teacher Ed.* Vol 18, 699-723.

This study investigated whether or not an increase in secondary science teacher knowledge about evolution and the nature of science gained from completing a graduate-level evolution course was associated with greater preference for the teaching of evolution in schools. Forty-four precertified secondary biology teachers participated in a 14-week intervention designed to address documented misconceptions identified by a precourse instrument. The course produced statistically significant gains in teacher knowledge of evolution and the nature of science and a significant decrease in misconceptions about evolution and natural selection. Nevertheless, teachers' postcourse preference positions remained unchanged; the majority of science teachers still preferred that antievolutionary ideas be taught in school.

Nelson, C.E. 2007. Teaching evolution effectively: A central dilemma and alternative strategies. *McGill Journal of Education.* Vol. 42, 265-285.

We will continue to have a public that is scientifically illiterate until we find ways to get faculty in post-secondary science classes to use effective pedagogical approaches. In this article, I present three scientifically and pedagogically valid strategies for helping students evaluate their initial understandings of evolution and to compare those understandings with more scientifically valid formulations. Adoption of such strategies in post-secondary teaching is central to more adequate preparation of future scientists, opinion leaders, and secondary school teachers.

Preszler, R.W., Dawe, A., Shuster, C.B., Shuster, M. 2007. Assessment of the effects of student response systems on student learning and attitudes over a broad range of biology courses. *Life Science Education.* Vol. 6, 29-41.

With the advent of wireless technology, new tools are available that are intended to enhance students' learning and attitudes. To assess the effectiveness of wireless student response systems in the biology curriculum at New Mexico State University, a combined study of student attitudes and performance was undertaken. A survey of students in six biology courses showed that strong majorities of students had favorable overall impressions of the use of student response systems and also thought that the technology improved their interest in the course, attendance, and understanding of course content. Students in lower-division courses had more strongly positive overall impressions than did students in upper-division courses. To assess the effects of the response systems on student learning, the number of in-class questions was varied within each course throughout the semester. Students' performance was compared on exam questions derived from lectures with low, medium, or high numbers of in-class questions. Increased use of the response systems in lecture had a positive influence on students' performance on exam questions across all six biology courses. Students not only have favorable opinions about the use of student response systems, increased use of these systems increases student learning.

Quitadamo, I.J., Kurtz, M.J. 2007. Learning to improve: Using writing to increase critical thinking performance in general education biology. *Life Sciences Education*. Vol. 6, 140-154.

Increasingly, national stakeholders express concern that U.S. college graduates cannot adequately solve problems and think critically. As a set of cognitive abilities, critical thinking skills provide students with tangible academic, personal, and professional benefits that may ultimately address these concerns. As an instructional method, writing has long been perceived as a way to improve critical thinking. In the current study, the researchers compared critical thinking performance of students who experienced a laboratory writing treatment with those who experienced traditional quiz-based laboratory in a general education biology course. The effects of writing were determined within the context of multiple covariables. Results indicated that the writing group significantly improved critical thinking skills whereas the nonwriting group did not. Specifically, analysis and inference skills increased significantly in the writing group but not the nonwriting group. Writing students also showed greater gains in evaluation skills; however, these were not significant. In addition to writing, prior critical thinking skill and instructor significantly affected critical thinking performance, whereas other covariables such as gender, ethnicity, and age were not significant. With improved critical thinking skill, general education biology students will be better prepared to solve problems as engaged and productive citizens.

Rath, K.A., Peterfreund, A.R., Xenos, S.P., Bayliss, F., Carnal, N. 2007. Supplemental instruction in introductory biology I: Enhancing the performance and retention of underrepresented minority students. *Life Sciences Education*. Vol. 6, 203-216.

Supplemental instruction classes have been shown in many studies to enhance performance in the supported courses and even to improve graduation rates. Generally, there has been little evidence of a differential impact on students from different ethnic/racial backgrounds. At San Francisco State University, however, supplemental instruction in the Introductory Biology I class is associated with even more dramatic gains among students from underrepresented minority populations than the gains found among their peers. These gains do not seem to be the product of better students availing themselves of supplemental instruction or other outside factors. The Introductory Biology I class consists of a team-taught lecture component, taught in a large lecture classroom, and a laboratory component where students participate in smaller lab sections. Students are expected to master an understanding of basic concepts, content, and vocabulary in biology as well as gain laboratory investigation skills and experience applying scientific methodology. In this context, supplemental instruction classes are cooperative learning environments where students participate in learning activities that complement the course material, focusing on student misconceptions and difficulties, construction of a scaffolded knowledge base, applications involving problem solving, and articulation of constructs with peers.

Scott, E.C. 2007. What's wrong with the "teach the controversy" slogan? *McGill Journal of Education*. Vol. 42, 307-317.

Teachers are often exhorted by creationists to "teach the controversy." Although such encouragement sounds on the surface like a proposal for critical thinking instruction, the history of the creationist movement in North America belies this claim. Rather than teach students to analyze and evaluate actual scientific controversies, the intent of "teach the controversy"

exhortations is to have teachers instruct students that evolution is weak or unsubstantiated science that students should not take seriously. Such instruction in alleged “evidence against evolution,” or “critical analysis of evolution” would seriously mis-educate students, and should be resisted by teachers and administrators.

El-Rady, J. 2006. To click or not to click: That is the question. *Innovate, Journal of Online Education*. Vol. 2, 18.

It is not unusual in higher education these days to have classes with large enrollment. Indeed at the University of South Florida ([USF](#)) (enrollment 41,000), large classes are the norm. In the eight years during which I have been an instructor in the [Biology Department](#) at USF, my mid-level and lower-level classes have had enrollments ranging from 100-300 students. This large class size generates a few problems, especially in terms of engaging students in active learning. While a well-designed traditional lecture can be very effective, students can engage more directly with the material when they actively take part in their learning instead of simply passively receiving information. Another problem in large enrollment courses is low attendance, especially by students taking a non-major course.

Allen, D., Tanner, K. 2005. Infusing active learning into the large-enrollment biology class: Seven strategies, from the simple to the complex. *Cell Biology Education*. Vol. 4, 262-268.

Science educators are urged (National Research Council [NRC], 1997, 2003; National Science Foundation, 1996) to adopt active-learning strategies and other alternatives to uninterrupted lecture to model the methods and mindsets at the heart of scientific inquiry, and to provide opportunities for students to connect abstract ideas to their real-world applications and acquire useful skills, and in doing so gain knowledge that persists beyond the course experience in which it was acquired. While these and other calls for reform dangle the carrot of promised cognitive gains before us (Bransford et al., 1999), the process of translating their message into the realities of practice in given classroom contexts remains a challenge of considerable magnitude. Perhaps because the inquiry-oriented methods that offer the most promise (Edgerton, 2001; Smith, K.A., et al., 2005) were often developed in small-class settings, the gap between promise and practice can seem almost impossible to close in the large-enrollment class environment that still predominates in the introductory course offerings of many colleges and universities. The conditions that led to creation of the large-enrollment class, particularly in research universities, are still with us (Edgerton, 2001) and are not likely to change in the foreseeable future. Thus, although the environment of a large class is not an easy one in which to thrive—either for the instructors who teach them (Carbone and Greenberg, 1998) or for the students who take them (Seymour and Hewitt, 1997; Tobias, 1990)—it is most probably here to stay.

Tanner, K., Allen, D. 2005. Approaches to biology teaching and learning: Understanding the wrong answers – teaching toward conceptual change. *Cell Biology Education*. Vol. 4, 112-117.

Underpinning science education reform movements in the last 20 years—at all levels and within all disciplines—is an explicit shift in the goals of science teaching from students simply creating a knowledge base of scientific facts to students developing deeper understandings of major concepts within a scientific discipline. For example, what use is a detailed working knowledge of the chemical reactions of the Krebs cycle without a deeper understanding of the relationship between these chemical reactions of cellular respiration and an organism’s need to harvest

energy from food? This emphasis on conceptual understanding in science education reform has guided the development of standards and permeates all major science education reform policy documents (American Association for the Advancement of Science, 1989, 1993, 2001; National Research Council, 1996). However, this transition to teaching toward deep conceptual understanding often sounds deceptively simple, when in reality it presents a host of significant challenges both in theory and in practice. Most importantly, few if any students come to the subject of biology in college, high school, or even middle-school classrooms without significant prior knowledge of the subject. It is no surprise, then, that students can never be considered blank slates, beginning with zero knowledge, awaiting the receipt of current scientific understanding. Yet, there is often little time invested by instructors in finding out in depth what students already know and, more specifically, what they do not know, what they are confused about, and how their preconceptions about the world do or do not fit with new information they are attempting to learn. In this feature, we explore key ideas associated with teaching for understanding, including the notion of conceptual change, the pivotal role of alternative conceptions, and practical implications these ideas have for teachers of science at all levels in designing learning experiences for students.

Cavallo, A.M.L., Rozman, M., Blickenstaff, J., Walker, N. 2004. Learning, reasoning, motivation, and epistemological beliefs. Differing approaches in college science courses. *The Journal of College Science Teaching*. Dec2003-Jan2004, 18-24.

This study explored college students' learning approaches, reasoning abilities, motivational goals, and beliefs about the nature of science relative to science concept understanding and course achievement. We examined these variables within different science subjects, content sophistication, and course contexts. Results revealed unique relationships among these learning variables and students' understanding and achievement.

Lodish, H.F., Rodriguez, R.K. 2004. Points of view: Lectures: Can't learn with them, can't learn without them. *Cell Biology Education*. Vol. 3, 202-211.

How to decide on the format for an undergraduate course in cell biology—a "standard" combination of lectures and recitations sections, or something else? The answer depends on many factors, including the numbers, abilities, and course backgrounds of the students and, perhaps most importantly, the purpose of the course. Thus, to explain why we feel that our junior-senior level cell biology course, taught with a combination of lectures, teaching assistant (TA)-led recitation sections, and extensive problem sets, works extraordinarily well for the vast majority of Massachusetts Institute of Technology (MIT) students and accomplishes its intended purposes, we need to describe several aspects of the MIT undergraduate curriculum and also what we expect the students to learn in the course.

Moore, R. 2004. Helping students succeed in introductory science courses. *Journal of College Science Teaching*. Vol. 33, 14-17.

I measured the reliability of introductory biology students' claims regarding lecture attendance, help session attendance, and reading assignment compliance. In all areas, students' reported behaviors were different than their actual behaviors. Also, penalties for excessive absences did not substantially improve either attendance or academic performance. These data indicate that students' self-reports of these course-related behaviors are unreliable and that penalties for

absenteeism are ineffective for improving attendance and grades. Strategies for enhancing students' success in introductory science classes are also discussed.

Sundberg, M. 2003. Strategies to help students change naïve alternative conceptions about evolution and natural selection. NCSE Reports. Vol. 23, No 2.

The purpose of my ongoing research in biological education is to identify and describe teaching strategies that are effective against such entrenched beliefs and that will promote a more sophisticated understanding of basic concepts. In this paper, I summarize the results of my most successful interventions to address (1) major concepts related to evolutionary theory and (2) concepts related to the nature of science.

Kugler, C., 2002 Darwin's Theory, Mendel's Laws: Labels & the teaching of science. The American Biology Teacher. Vol. 64, 341-351.

We call Mendelian concepts "laws," but Darwinian concepts a "theory." Why? Both provide explanations of diverse observations in nature. Both have elements that are universal in biology. Both provide a fundamental basis to our understanding of modern biology. Nevertheless, we give them labels that can greatly affect our students' perceptions of their validity. This difference in labeling of Darwinian and Mendelian concepts led me to study biology textbooks in order to find out how biologists define and apply the terms law and theory. I soon found it necessary to study the use of hypothesis and principle as well.

Murphy, T.M., Cross, V. 2002. Should students get the instructor's lecture notes? Journal of Biological Education. Vol. 36, 72-76.

Providing copies of an instructor's lecture notes before lectures is enthusiastically approved of by university students in introductory biology classes. Surprisingly, students who use the notes tend to perform less well on exams than students who avoid using the notes. However, there is no evidence that using the notes is harmful to learning; rather, those students who choose not to use the notes enter the course with better preparation or knowledge than the class as a whole. Pre-circulated notes may improve the clarity of lectures and encourage advance preparation by students – a learning discipline possibly as valuable as organizing and reviewing one's own notes.

Robertson, L.J. 2000. Twelve tips for using a computerized interactive audience response system. Medical Teacher. Vol. 22, 237-240.

The role of the lecture in medical education has recently been called into question. Adults learn more effectively through active learning therefore where is the place for the traditional lecture? This paper describes the use of a computerized audience response system to transform large group teaching sessions into active learning experiences, thereby securing a future for the lecture format. We pass on our tips, gleaned from our varied experiences using the system, for the successful design and running of such interactive sessions.

Ebert-May, D., Brewer, C., Allred, S. 1997. Innovation in large lectures: Teaching for active learning. BioScience, Vol. 47, 601-607.

Although the two cases we describe use different strategies for changing instruction, they are based on the same goal-teaching to involve active learning by all students. The NAU case describes an experiment that tested the relative effectiveness of inquiry-based instruction. The UM case illustrates how such teaching strategies can be easily incorporated into the largest lecture courses.

Groccia, J.E., Miller, J.E. 1996. Collegiality in the classroom: the use of peer learning assistants in cooperative learning in introductory biology. *Innovative Higher Education*. Vol. 21, 87-100.

Experienced undergraduate students served as Peer Learning Assistants (PLAs) to facilitate group process and dynamics in cooperative learning groups. The use of this model in large classes (150 students) resulted in statistically significant improvements in group performance and satisfaction with the group experience. PLAs defused conflict in groups which were, by their cognitively diverse nature, conflict-prone. Student attitudes about their PLAs and PLA attitudes about the experience were positive. Faculty productivity was substantially enhanced because group dynamics problems rarely landed in the faculty office.