STEM Topic: Teaching Undergraduate Classes. Best Practices for Effective Teaching

Richardson, J. 2012. Concept inventories: Tools for uncovering STEM students' misconceptions. Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering and Mathematics (STEM) Education. American Association for the Advancement of Science.

> Concept inventories are receiving increased interest from STEM faculty. What are concept inventories, why the interest, and what do I need to know about concept inventories? This chapter answers these questions in the following order. In the first section, you will read a brief history of STEM concept inventory development, which should answer the question, "Why the interest in concept inventories?" In the next two sections, you will read first a short discussion on the theory of assessment as it applies to concept inventories and then a description of how to construct a concept inventory. Together, these two sections should answer the question, "What is a concept inventory?" And finally, you will read how others have used concept inventories and related tools to improve their teaching effectiveness.

Deslauriers, L., Schelew, E., Weiman, C. 2011. Improved learning in a large-enrollment physics class. Science. Vol. 332, 862-865.

> We compared the amounts of learning achieved using two different instructional approaches under controlled conditions. We measured the learning of a specific set of topics and objectives when taught by 3 hours of traditional lecture given by an experienced highly rated instructor and 3 hours of instruction given by a trained but inexperienced instructor using instruction based on research in cognitive psychology and physics education. The comparison was made between two large sections (N = 267 and N = 271) of an introductory undergraduate physics course. We found increased student attendance, higher engagement, and more than twice the learning in the section taught using research-based instruction.

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.

Kalman, C.S. 2011. Enhancing students' conceptual understanding by engaging science text with reflective writing as a hermeneutical circle. Science and Education. Vol. 20, 159-172.

> Students can have great difficulty reading scientific texts and trying to cope with the professor in the classroom. Part of the reason for students' difficulties is that for a student taking a science

> gateway course the language, ontology and epistemology of science are akin to a foreign culture. There is thus an analogy between such a student and an anthropologist spending time among a native group in some remote part of the globe. This brings us naturally to the subject of hermeneutics. It is through language that we attempt to understand an alien culture. The hermeneutical circle involves the interplay between our construct of the unfamiliar with our own outlook that deepens with each pass. It can be argued that for novice students to acquire a full understanding of scientific texts, they also need to pursue a recurrent construction of their comprehension of scientific concepts. In this paper it is shown how an activity, reflective-writing, can enhance students' understanding of concepts in their textbook by getting students to approach text in the manner of a hermeneutical circle. This is illustrated using studies made at three postsecondary institutions.

Kraft, K.J., Srogi, L., Husman, J., Semken, S., Fuhrman, M. 2011. Engaging Students to Learn Through the Affective Domain: A New Framework for Teaching in the Geosciences. Journal of Geoscience Education. Vol. 59, 71-84.

> To motivate student learning, the affective domain—emotion, attitude, and motivation—must be engaged. We propose a model that is specific to the geosciences with theoretical components of motivation and emotion from the field of educational psychology, and a term we are proposing, "connections with Earth" based on research in the fields of environmental education and art education. When all three of these components (motivation, emotion, and connections with Earth) are combined in the classroom, students may experience greater interest in and connection to the content. This interest and connection may lead to greater motivation to learn and value the content. We use our model to evaluate three practices in geoscience education and show that their demonstrated success in achieving student learning lies in the attention to students' affective needs as well as to delivery of content. We propose a future research agenda using currently developed, validated instruments that can measure these motivational and attitudinal shifts to determine what practices work best for our students from both cognitive and affective perspectives. Although this was conducted in both Europe and the United States, the implications of this research may extend across cultures and nationalities. Additional research needs to be conducted to understand these implications.

Marotta, S.M., Hargis, J. 2011. Low-threshold active teaching methods for mathematic instruction. Primus. Vol. 21, 377-392.

> In this article, we present a large list of low-threshold active teaching methods categorized so the instructor can efficiently access and target the deployment of conceptually based lessons. The categories include teaching strategies for lecture on large and small class sizes; student action individually, in pairs, and groups; games; interaction through homework; student questions; role play; student presentations; and brainstorming. Along with a label for each method, we provide a brief summary of meaning, how to implement, and, for many, possible ways to implement in a mathematics course. Many of the methods are an adaptation of the active teaching methods available in books [1–3].

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.

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 (n¼50) interpreted the evolutionary relationships depicted in four such evolutionary diagrams. In Study 2, new students (n¼62) 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.

Lewis, S.E., Shaw, J.L., Freeman, K.A. 2010. Creative exercises in general chemistry: A student-centered assessment. Journal of Science Teaching. Vol. 40. 48-44.

> Creative exercises (CEs) are a form of assessment in which students are given a prompt and asked to write down as many distinct, correct, and relevant facts about the prompt as they can. Students receive credit for each fact that they include that is related to the prompt and distinct from the other facts they list. With CEs, students have an opportunity to demonstrate their knowledge and the opportunity to select the information that they believe is related to the prompt. In addition, CEs encourage students to connect concepts because any relevant information presented can assist them in completing the CEs. This paper describes the use of CEs in a college level chemistry class, including student answers to the CEs and a survey of students' impression of CEs.

McDermott, M.A., Hand, B. 2010. A secondary reanalysis of student perceptions of non-traditional writing tasks over a ten year period. Journal of Research in Science Teaching. Vol. 47, 518-539.

> This study aims to add to the growing research related to the implementation of non-traditional writing tasks in classrooms to encourage science literacy. A secondary reanalysis methodology was employed to review student interviews collected as a part of several individual studies during a ten year research program. This method established an interpretive framework different than the particular frameworks guiding the individual studies. In doing so, a greater ability to generalize findings was sought. Main assertions emerging from the student responses analyzed include recognition of benefits of non-traditional writing, recognition of the need for particular task characteristics to encourage these benefits, and recognition of greater cognitive activity than is present in typical science classroom writing.

Milner-Bolotin, M., Antimirova, T., Petrov, A. 2010. Clickers beyond the first-year science classroom. Journal of College Science Teaching. Vol. 40, 14-19.

> This case study's primary objective is to describe the implementation of the electronic response system (clickers) in a small (N = 25) second-year physics course at a large public university and to draw attention of the science faculty who teach upper-level science courses to the potential benefits of this pedagogy. This pilot study discusses the impact of the clicker-enhanced pedagogy on students' cognitive and affective outcomes and their attitudes toward using clickers. We also outline challenges faced by the students and the instructors on the way of successful clicker implementation beyond the first year and suggest a few possible ways of addressing them.

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.

Talanquer, V., Pollard, J. 2010. Let's teach how we think instead of what we know. Chem Educ Res. Pract. Vol. 11, 74-83.

> Despite multiple calls for reform, the curriculum for first-year college chemistry at many universities across the world is still mostly fact-based and encyclopedic, built upon a collection of isolated topics, oriented too much towards the perceived needs of chemistry majors, focused too much on abstract concepts and algorithmic problem solving, and detached from the practices, ways of thinking, and applications of both chemistry research and chemistry education research in the 21st century. This paper describes an alternative way of conceptualizing the introductory chemistry curriculum for science and engineering majors by shifting the focus from learning chemistry as a body of knowledge to understanding *chemistry as a way of thinking*. Starting in 2007, we have worked on the development and implementation of a new curriculum intended to: promote deeper conceptual understanding of a minimum core of fundamental ideas instead of superficial coverage of multiple topics; connect core ideas between the course units by following well-defined learning progressions; introduce students to modern ways of thinking and problem-solving in chemistry; and involve students in realistic decision-making and problem-solving activities.

Turpen, C., Finkelstein, N.D., 2010. The construction of different classroom norms during Peer Instruction: Students perceive differences. Physics Education Research 6. 020123.

> This paper summarizes variations in instructors' implementation practices during Peer Instruction _PI_ and shows how these differences in practices shape different norms of classroom interaction. We describe variations in classroom norms along three dimensions of classroom culture that are integral to Peer Instruction, emphasis on: _1_ faculty-student collaboration, _2_ student-student collaboration, and _3_ sense-making vs answer-making. Based on interpretations by an observing researcher, we place three different PI classrooms along a continuum representing a set of possible norms. We then check these interpretations against students' perceptions of these environments from surveys collected at the end of the term. We find significant correspondence between the researchers' interpretations and students' perceptions of Peer Instruction in these environments. We find that variation in faculty practices can set up what students perceive as discernibly different norms. For interested instructors, concrete classroom practices are described that appear to encourage or discourage these norms.

Wieman, C., Perkins, K., Gilbert, S. 2010. Transforming science education at large research universities: A case study in progress. Change. March/April. 7-15.

> We see an emerging culture in which faculty are adopting effective evidence-based teaching methods, collecting data on the results, and coming to see teaching as a rewarding scholarly activity (the SEIs have produced over a dozen research papers on science education). Discussions of teaching in these departments have both increased in frequency and shifted their focus from topical coverage to student learning, pedagogy, and evidence. Here we discuss the model and how it is being implemented, along with some lessons learned and our informal observations of factors that facilitate or inhibit educational innovation.

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 brining 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.

Brickman, P., Gormally, C., Armstrong, N., Hallar, B. 2009. Effects of inquiry-based learning on students' science literacy skills and confidence. International Journal for the Scholarship of Teaching and Learning. Vol. 3, 22.

> Calls for reform in university education have prompted a movement from teacher- to student-centered course design, and included developments such as peer-teaching, problem and inquiry-based learning. In the sciences, inquiry-based learning has been widely promoted to increase literacy and skill development, but there has been little comparison to more traditional curricula**.** In this study, we demonstrated greater improvements in students' science literacy and research skills using inquiry lab instruction. We also found that inquiry students gained self-confidence in scientific abilities, but traditional students' gain was greater –likely indicating that the traditional curriculum promoted over-confidence. Inquiry lab students valued more authentic science exposure but acknowledged that experiencing the complexity and frustrations faced by practicing scientists was challenging, and may explain the widespread reported student resistance to inquiry curricula.

Ghosh, S., Renna, F. 2009.Using electronic response systems in economics classes. Journal of Economic Education. Fall. 354-367.

> College instructors and students participated in a pilot project at the University of Akron to enhance student learning through the use of a common teaching pedagogy, peer instruction. The teaching pedagogy was supported by the use of technology, an electronic personal response system, which recorded student responses. The authors report their experiences in using this technology-enhanced teaching pedagogy and provide another example of an active and collaborative learning tool that instructors can use to move beyond "chalk and talk." Preliminary survey results from students participating in this pilot project are also reported.

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.

Lucas, A., 2009. Using peer instruction and I-clickers to enhance student participation in calculus. PRIMUS. Vol. 19, 219-231.

> In my Calculus classes I encourage my students to actively reflect on course material, to work collaboratively, and to generate diverse solutions to questions. To facilitate this I use peer instruction (PI), a structured questioning process, and i-clickers, a radio frequency classroom response system enabling students to vote anonymously. This article concludes that PI and i-clickers enhance student participation and comprehension. It is important, however, that students write down their reasoning during PI so as not to be led astray by dominant group members.

Mazur, E. 2009. Farewell, lecture? Science. Vol. 232, 50-51.

> Discussions of education are generally predicated on the assumption that we know what education is. I hope to convince you otherwise by recounting some of my own experiences. When I started teaching introductory physics to undergraduates at Harvard University, I never asked myself how I would educate my students. I did what my teachers had done—I lectured. I thought that was how one learns. Look around anywhere in the world and you'll find lecture halls filled with students and, at the front, an instructor. This approach to education has not changed since before the Renaissance and the birth of scientific inquiry. Early in my career I

received the first hints that something was wrong with teaching in this manner, but I had ignored it. Sometimes it’s hard to face reality.

Ortiz-Robinson, N.L., Ellington, A.J. 2009. Learner-centered strategies and advanced mathematics: A study of students’ perspectives. Primus. Vol. 19, 463-472.

A number of learner-centered strategies were implemented during a two semester course in real analysis that is traditionally taught in lecture format. We seek to understand the role that these strategies can have in this proof-intensive theoretical mathematics classroom and the perceived benefits by the students. Although learner-centered strategies are a welcome addition in many applied mathematics courses and are known to be successful, the literature indicates that these remain largely absent from more advanced courses [9]. In an effort to correlate student resistance and acceptance of these strategies in different classroom settings we included an applied differential equations course in the study. Student feedback was obtained for two semesters of the real analysis course and compared to the feedback obtained during one semester of the differential equations course.

Schwartz, M.S., Sadler, P.M., Sonnert, G., Tai., R.H. 2009. Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework. Wiley Periodicals, Inc., Science Education. Vol. 93, 798-826.

This study relates the performance of college students in introductory science courses to the amount of content covered in their high school science courses. The sample includes 8310 students in introductory biology, chemistry, or physics courses in 55 randomly chosen U.S. colleges and universities. Students who reported covering at least 1 major topic in depth, for a month or longer, in high school were found to earn higher grades in college science than did students who reported no coverage in depth. Students reporting breadth in their high school course, covering all major topics, did not appear to have any advantage in chemistry or physics and a significant disadvantage in biology. Care was taken to account for significant covariates: socioeconomic variables, English and mathematics proficiency, and rigor of their preparatory high science course. Alternative operationalizations of depth and breadth variables result in very similar findings. We conclude that teachers should use their judgment to reduce coverage in high school science courses and aim for mastery by extending at least 1 topic in depth over an extended period of time.

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.

Willoughby, S.D., Gustafson, E. 2009. Technology talks: clickers and grading incentive in the large lecture hall. American Journal of Physics. Vol. 77, 180-184.

> Two sections of an introductory astronomy class were given different grading incentives for clicker participation for two consecutive semesters. In the high stakes classroom points were awarded only for correct answers, in contrast to the low stakes classroom in which points were awarded simply for participating. Self-formed groups of four students each were recorded in both sections several times during the spring 2007 semester and their conversations were transcribed and categorized into nine topics to analyze the variations between the sections. Performance on clicker questions and tendency to block vote were correlated with class grades and gains for the pre- and post-test scores on the Astronomy Diagnostic Test.

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.

Dancy, M.H., Henderson, C. 2008. Barriers and promises in STEM reform. National Academies. http://www7.nationalacademies.org/bose/Dancy_Henderson_CommissionedPaper.pdf

> It is not enough to simply conduct research and develop high quality teaching materials. High quality research and curriculum development is only valuable if it is actually used. We have been involved in several projects aimed at better understanding why research-based reform has not had as much impact as might be expected given the expenditures of time and money. In the paper that follows, we detail some of our findings and offer recommendations based on these findings. The paper is organized around two large barriers to reform. Barrier 1: STEM change strategies are primarily based on a development and dissemination change model. Barrier 2:

> There is little research effort devoted to the study and improvement of STEM change strategies or models

McConnell, D. 2008. Less talk, more action: Active learning in introductory geoscience courses. McConnell NAS White Paper, October.

> Review of research-supported practices in large, general-education Earth Science classes. Practices focused on conceptual understanding and included a variety of practices from simple multiple choice questions to physical modeling. Analyses of data show that these methods were preferred by students. These processes also improved student retention and increased logical thinking skills (McConnell, 2008).

Mestre, J.P. 2008. Learning Goals in Undergraduate STEM Education and Evidence for Achieving Them. National Academies White Paper. http://www7.nationalacademies.org/BOSE/ Mestre_CommissionedPaper.pdf

> In this white paper I propose a short list of learning goals in undergraduate STEM education and suggest the types of evidence that would indicate whether or not the learning goals are being achieved. Both the learning goals and proposed evidence will be accompanied by arguments and discussions about the relevance of the proposed goals given today's context. I also discuss why certain types of evidence should carry more weight than others, where current gaps in evidence exist, and why the quality of evidence is pivotal in promoting the adoption of promising instructional practices in undergraduate STEM instruction.

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.

Miller, S., Pfund, C., Maidl Pribbenow, C., Handelsman, J. 2008. Scientific teaching practice. Science. Vol. 322, 1329-1331.

> The United States educates and trains outstanding scientists. Doctoral students emerge as rigorous experimentalists and strong analytical thinkers, intellectually prepared for the diverse

employment opportunities that await them. Problems persist, however, in two areas: preparing undergraduate students as scientists and preparing graduate students to teach (1, 2). Both deficiencies can be addressed by implementing programs that train graduate students to teach. Although there have been repeated calls for such programs (1–3), and descriptions of some (4), little work has assessed their impact on the practices and philosophies of the participants.

Park Rogers, M.A., Abell, S.K., 2008. The design, enactment, and experience of inquiry-based instruction in undergraduate science education: A case study. Wiley Periodicals, Inc. Science Education. Vol. 92, 591-607.

> The purpose of this study was to understand one case of undergraduate inquiry-based instruction through the words and actions of students and instructors. The data sources included fieldnotes from 16 of 29 classes, two sets of student and instructor interviews (beginning and end of the semester), and a collection of artifacts, such as the laboratory manual, lecture handouts, and the course syllabus. The participants for this study included four faculty instructors and two purposively selected student groups, totaling eight students. We found the instructors' two course goals, (a) teaching students how scientists do science and (b) using an interdisciplinary approach to develop students' content knowledge of the big ideas in science, were consistent with our observations and the students' descriptions of their experience in the course. However, we observed, and the students also noted, an important feature of the course that the instructors did not describe as a course goal was its reliance on the social nature of learning. This telling case demonstrates that inquiry-based instruction is achievable in undergraduate science education. Implications are discussed for college science instructors interested in inquiry teaching.

Pundak, D., Rozner, S. 2008. Empowering engineering college staff to adopt active learning methods. J. of Science Education and Technology. Vol. 17, 1-12.

> There is a growing consensus that traditional instruction in basic science courses, in institutions of higher learning, do not lead to the desired results. Most of the students who complete these courses do not gain deep knowledge about the basic concepts and develop a negative approach to the sciences. In order to deal with this problem, a variety of methods have been proposed and implemented, during the last decade, which focus on the ''active learning'' of the participating students. We found that the methods developed in MIT and NCSU were fruitful and we adopted their approach. Despite research-based evidence of the success of these methods, they are often met by the resistance of the academic staff. This article describes how one institution of higher learning organized itself to introduce significant changes into its introductory science courses, as well as the stages teachers undergo, as they adopt innovative teaching methods. In the article, we adopt the Rogers model of the innovative-decision process, which we used to evaluate the degree of innovation adoption by seven members of the academic staff. An analysis of interview and observation data showed that four factors were identified which influence the degree innovation adoption: (1) teacher readiness to seriously learn the theoretical background of ''active learning''; (2) the development of an appropriate local model, customized to the beliefs of the academic staff; (3) teacher expertise in information technologies, and (4) the teachers_ design of creative solutions to problems that arose during their teaching.

Twigg, C.A. 2008. Math Lectures: An Oxymoron? The National Center for Academic Transformation. http://www.center.rpi.edu/PlanRes/Math%20Lectures%20Editorial.htm. 1-4.

> One of the most enjoyable parts of our work at the National Center for Academic Transformation is that we learn new things all the time. There's nothing like spending most of your time engaging institutions of higher education in changing the way they think about teaching and learning to produce new ways of thinking. Based on eight years of experience in working with a large number of colleges and universities as they seek to improve student learning while reducing instructional costs, we have identified a number of "models" and "principles" to guide the redesign of large-enrollment courses. We have learned that each of our Five Models for Course Redesign can produce improved student learning and reduced instructional costs if it embodies our Five Principles of Successful Course Redesign. Therefore, as part of the application process to both our national and state redesign programs, we have heretofore asked teams to select a redesign model and explain how they will embody the Five Principles within it as the first step in the planning process.

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.

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.

Carlson, C.A. 2007. A simple approach to improving student writing: An example from hydrology. J. of College Science Teaching. 48-54.

> Using the simple approach described in this article, college science instructors can help students become independent thinkers and writers in science. The unique character of this approach is that it shows students how to formulate the questions they need to answer in their writing, as well as how to answer them. Rather than using a cookbook approach, role modeling teaches students that writing is a process and helps them to engage the science.

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.

Connolly, M.R., Bouwma-Gearhart, J.L., Clifford, M.A. 2007. The birth of a notion: The windfalls and pitfalls of tailoring an SoTL-like concept to scientist, mathematicians, and engineers.

> Despite calls for greater agreement in defining the Scholarship of Teaching and Learning (SoTL), terms that resemble SoTL are proliferating. An NSF-sponsored center for teaching and learning coined its own term, teaching-as-research (TAR), believing it would resonate better with research-active scientists, engineers, and mathematicians. To understand whether this was a wise strategy, we interviewed 43 participants from courses that sought to explain and demonstrate TAR. Our study found that participants defined TAR with varying complexity and that disciplinary concepts generally provided "conceptual handles" for making sense of TAR. However, tailoring a term to particular disciplines entails several challenging tradeoffs.

Felder, R.M. 2007. Sermons for grumpy campers. Chemical Engineer Education. Vol. 41, 183-184.

> When you use a proven teaching method that makes students uncomfortable, it's important to let them know why you're doing it. If you can convince them that it's not for your own selfish or lazy purposes but to try to improve their learning and grades, they tend to ramp down their resistance long enough to see the benefits for themselves. I've developed several mini-sermons to help with this process. If any look useful, feel free to appropriate them.

Felder, R.M, Brent, R. 2007. Cooperative Learning. *Active Learning: Models from the Analytical Sciences*, ACS Symposium Series 970, Chapter 4.Washington, DC: American Chemical Society, 2007.

> Cooperative learning is an approach to groupwork that minimizes the occurrence of those unpleasant situations and maximizes the learning and satisfaction that result from working on a high-performance team. A large and rapidly growing body of research confirms the effectiveness of cooperative learning in higher education (*1-4*). Relative to students taught traditionally—i.e., with instructor-centered lectures, individual assignments, and competitive grading—cooperatively taught students tend to exhibit higher academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, deeper understanding of learned material, greater time on task and less disruptive behavior in class, lower levels of anxiety and stress, greater intrinsic motivation to learn and achieve, greater ability to view situations from others' perspectives, more positive and supportive relationships with peers, more positive attitudes toward subject areas, and higher self-esteem. Another nontrivial benefit for instructors is that when assignments are done cooperatively, the number of papers to grade decreases by a factor of three or four.

Felder, R.M. 2007. Why me, Lord? Chemical Engineering Education. Vol. 41, 239-240.

> This is one of several scenarios in the "Crisis Clinic" segment of the teaching workshops Rebecca Brent and I give. After presenting it, I assure the participants that it is not hypothetical—if they haven't seen Charlie in their office yet it's just a matter of time. I first ask them to discuss in small groups their responses to "What should you do," and then I tell them the step-by-step procedure I follow in situations like that. Before I tell you, why don't you take a moment and think about what you would do (or what you did if you've already met Charlie).

Henderson, C., Dancy, M.H. 2007. Barriers to the use of research-based instructional strategies: The dual role of individual and situational characteristics. Physics Education Research. Vol. 3, 020102.

> Many proven research-based instructional strategies have been developed for introductory college-level physics. Significant efforts to disseminate these strategies have focused on convincing individual instructors to give up their traditional practices in favor of particular research-based practices. Yet, evidence suggests that the findings of educational research are, at best, only marginally incorporated into introductory physics courses. In this paper we present partial results of an interview study designed to generate new ideas about why proven strategies are so slow to integrate in mainstream instruction. Specifically we describe the results of openended interviews with five physics instructors who represent likely users of educational research. We found that these instructors have beliefs about teaching and learning that are more compatible with educational research than their self-described instructional practices.

> Instructors often blamed this discrepancy on situational factors that favored traditional instruction. A theoretical model is introduced to explain these findings.

Hrepic, Z., Zollman, D.A., Rebello, N.S. 2007. Comparing students' and experts' understanding fo the content of a lecture. Journal of Science Education and Technology. Vol. 16, 213-225.

> In spite of advances in physics pedagogy, the lecture is by far the most widely used format of instruction. We investigated students' understanding and perceptions of the content delivered during a physics lecture. A group of experts (physics instructors) also participated in the study as a reference for the comparison. During the study, all participants responded to a written conceptual survey on sound propagation. Next, they looked for answers to the survey questions in a videotaped lecture by a nationally known teacher. As they viewed the lecture, they indicated instances, if any, in which the survey questions were answered during the lecture. They also wrote down (and if needed, later explained) the answer, which they perceived was given by the instructor in the video lecture. Students who participated in the study were enrolled in a conceptual physics course and had already covered the topic in class before the study. We discuss and compare students' and experts' responses to the survey questions before and after the lecture.

McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horn, S., Borowski, W., Dick, J., Foos, A., Malone, M., McGrew, H., Greer, L., Heaney, P.J. 2006. Using conceptests to assess and improve student conceptual understanding in introductory geoscience courses. Journal of Geoscience Education. Vol. 54, 61-68.

> Conceptests are higher-order multiple-choice questions that focus on one key concept of an instructor's major learning goals for a lesson. When coupled with student interaction through peer instruction, conceptests represent a rapid method of formative assessment of student understanding, require minimal changes to the instructional environment and introduce many of the recognized principles of effective teaching that enhance student learning. In this study, instructors from several different institutions developed over 300 conceptests for the geosciences. These instructors then used this suite of concept questions in a wide range of classroom settings, including large introductory general education Earth Science courses for non-majors at open enrollment institutions, smaller physical geology classes suitable for majors at private colleges, and in introductory geology laboratory settings. Results of pre- and post-class Geoscience Concept Inventory (GCI) testing and qualitative feedback from students and instructors showed that conceptests increased attendance, improved student satisfaction, and enhanced student achievement. Participating instructors found implementation of conceptests into their classes straightforward and required less than 30 minutes of preparation per class. The conceptest question database is available on-line for geoscience instructors.

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.

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.

Oakley, B.A., Hanna, D.M., Kuzmyn, Z., Felder, R.M. 2007. Best practices involving teamwork in the classroom: Results from a survey of 6435 engineering student respondents. IEEE Transactions on Education. Vol. 50, 266-273.

A teamwork survey was conducted at Oakland University, Rochester, MI, in 533 engineering and computer science courses over a two-year period. Of the 6435 student respondents, 4349 (68%) reported working in teams. Relative to the students who only worked individually, the students who worked in teams were significantly more likely to agree that the course had achieved its stated learning objectives (0 001). Regression analysis showed that roughly one-quarter of the variance in belief about whether the objectives were met could be explained by four factors: 1) student satisfaction with the team experience; 2) the presence of instructor guidance related to teamwork; 3) the presence of slackers on teams; and 4) team size. Pearson product–moment correlations revealed statistically significant associations between agreement that the course objectives had been fulfilled and the use of student teams and between satisfaction with teams and the occurrence of instructor guidance on teamwork skills. These and other results suggest that assigning work to student teams can lead to learning benefits and student satisfaction, provided that the instructor pays attention to how the teams and the assignments are set up.

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.

Beatty, I.D., Gerace, W.J., Leonard, W.J., Dufresne, R.J. 2006. Designing effective questions for classroom response system teaching. American Journal of Physics. Vol. 74, 31-40.

> Classroom response systems can be powerful tools for teaching physics. Their efficacy depends strongly on the quality of the questions. Creating effective questions is difficult and differs from creating exam and homework problems. Each classroom response system question should have an explicit pedagogic purpose consisting of a content goal, a process goal, and a metacognitive goal. Questions can be designed to fulfill their purpose through four complementary mechanisms: directing students' attention, stimulating specific cognitive processes, communicating information to the instructor and students via classroom response system-tabulated answer counts, and facilitating the articulation and confrontation of ideas. We identify several tactics that are useful for designing potent questions and present four "makeovers" to show how these tactics can be used to convert traditional physics questions into more powerful questions for a classroom response system.

Felder, R.M. 2006. Teaching engineering in the 21st century with a 12th century teaching model: How bright is that? Chemical Engineering Education. Vol. 40, 110-113.

> If you took a stroll down a hall of the University of Bologna in the 12th Century and looked into random doorways, you would have seen professors holding forth in Latin to rooms full of bored-looking students. The professors would be droning on interminably in language few of the students could understand, perhaps occasionally asking questions, getting no responses, and providing the answers themselves. You might see a few students jotting down notes on recycled parchment, a few more sneaking occasional bites of the cold pizza slices concealed in their academic robes, some sleeping, and most just staring vacantly, inwardly cursing the fact that iPods would not become readily available for another 800 years. Toward the end of the lecture, one student would ask "Professore, siamo responábili per tutta questa roba nell'esame?" and that would be the only active student involvement in the class. Eventually the class would be released, and the students would leave grumbling to each other about the 150 pages of reading assigned for the next period and expressing gratitude for the Cliffs Notes version of the text.

Kruckeberg, R. 2006. A Deweyan perspective on science education: Constructivism, experience and why we learn science. Science and Education. Vol. 15, 1-30.

This paper investigates a Deweyan interpretation of constructivism as a means of developing a rationale for teaching science. The paper provides a review of constructivism from recent science education literature, along with some relevant criticisms. The paper then presents an interpretation of Dewey's formulation of the role of knowing and scientific concepts as tools for integrating and transforming experience, based primarily on Experience and Nature and The Quest for Certainty, arguing that a Deweyan version of constructivism improves upon recent cognitivist versions of constructivism, while providing a general justification for why ideas in science are worth teaching and learning.

McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horn, S., Borowski, W., Dick, J., Foos, A., Malone, M., McGrew, H., Greer, L., Heaney, P.J. 2006. Using conceptests to assess and improve student conceptual understanding in introductory geoscience courses. Journal of Geoscience Education. Vol. 54, 61-68.

Conceptests are higher-order multiple-choice questions that focus on one key concept of an instructor's major learning goals for a lesson. When coupled with student interaction through peer instruction, conceptests represent a rapid method of formative assessment of student understanding, require minimal changes to the instructional environment and introduce many of the recognized principles of effective teaching that enhance student learning. In this study, instructors from several different institutions developed over 300 conceptests for the geosciences. These instructors then used this suite of concept questions in a wide range of classroom settings, including large introductory general education Earth Science courses for non-majors at open enrollment institutions, smaller physical geology classes suitable for majors at private colleges, and in introductory geology laboratory settings. Results of pre- and post-class Geoscience Concept Inventory (GCI) testing and qualitative feedback from students and instructors showed that conceptests increased attendance, improved student satisfaction, and enhanced student achievement. Participating instructors found implementation of conceptests into their classes straightforward and required less than 30 minutes of preparation per class. The conceptest question database is available on-line for geoscience instructors.

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

Carlson, P.A., Berry, F.C., Voltmer, D. 2005. Incorporating student peer-review into an introduction to engineering design course. 35th ASEE/IEEE Frontiers in Education Conference, October, Indianapolis, IN.

> We report on a project to improve the teaching of engineering design at the junior level. Peer review of student work is an integral part of collaborative learning and reform-driven engineering education. Yet successfully implementing this pedagogical technique requires significant amounts of instructor and class time. Furthermore, if adequate formative assessment does not emerge from peer review, the experience may devolve into "busy work" in the eyes of the student. Here, we give early results from an NSF-funded study using Calibrated Peer Review (a web-delivered, collaborative learning environment) to enhance learning in engineering design.

Handelsman. J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., Wood, W.B. 2004. Scientific teaching. Science. Vol. 304, 521-523.

> Since publication of the AAAS 1989 report "Science for all Americans" (1), commissions, panels, and working groups have agreed that reform in science education should be founded on "scientific teaching," in which teaching is approached with the same rigor as science at its best (2). Scientific teaching involves active learning strategies to engage students in the process of science and teaching methods that have been systematically tested and shown to reach diverse students (3).

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.

Oakley, B., Felder, R.M., Brent, R., Elhajj, I. 2004. Turning student groups into effective teams. Journal of Student Centered Learning. Vol. 2, 9-35.

> This paper is a guide to the effective design and management of team assignments in a college classroom where little class time is available for instruction on teaming skills. Topics discussed include forming teams, helping them become effective, and using peer ratings to adjust team grades for individual performance. A Frequently Asked Questions section offers suggestions for dealing with several problems that commonly arise with student teams, and forms and handouts are provided to assist in team formation and management.

Schwartz, R.S., Lederman, N.G., Crawford, B.A. 2004. Developing views of Nature of Science in an authentic context: An explicit approach to bridging the gap between Nature of Science and scientific inquiry. Wiley Periodicals, Inc. Science Education. Vol. 88, 610-645.

> Reform efforts emphasize teaching science to promote contemporary views of the nature of science (NOS) and scientific inquiry. Within the framework of situated cognition, the assertion is that engagement in inquiry activities similar to those of scientists provides a learning context conducive to developing knowledge about the methods and activities through which science progresses, and, in turn, to developing desired views of NOS. The inclusion of a scientific inquiry context to teach about NOS has intuitive appeal. Yet, whether the learners are students, teachers, or scientists, the empirical research does *not* generally support the claim that engaging in scientific inquiry alone enhances conceptions of NOS. We studied developments in NOS conceptions during a science research internship course for preservice secondary science teachers. In addition to the research component, the course included seminars and journal assignments. Interns' NOS views were assessed in a pre/post format using the Views of Nature of Science questionnaire, [VNOS-C] and interviews. Results indicate most interns showed substantial developments in NOS knowledge. Three factors were identified as important for NOS developments during the internship: (1) reflection, (2) context, and (3) perspective. Reflective journal writing and seminars had the greatest impact on NOS views. The science research component provided a context for reflection. The interns' role perspective appeared to impact their abilities to effectively reflect. Interns who assumed a reflective stance were more successful in deepening their NOS conceptions. Those who maintained a scientist's identity were less successful in advancing their NOS views through reflection. In light of these results, we discuss the significance and challenges to teaching about NOS within inquiry contexts.

Fox, M.A., Hackerman, N. Editors, National Research Council. 2003. Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics. Free Executive Summary. ttp://www.nap.edu/catalog/10024.html.

> Economic, academic, and social forces are causing undergraduate schools to start a fresh examination of teaching effectiveness. Administrators face the complex task of developing equitable, predictable ways to evaluate, encourage, and reward good teaching in science, math, engineering, and technology. Evaluating, and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics offers a vision for systematic evaluation of teaching practices and academic programs, with recommendations to the various stakeholders in higher education about how to achieve change. What is good undergraduate teaching? This book discusses how to evaluate undergraduate teaching of science, mathematics, engineering, and technology and what characterizes effective teaching in these fields. Why has it been difficult for colleges and universities to address the question of teaching effectiveness? The committee explores the implications of differences between the research and teaching cultures-and how practices in rewarding researchers could be transferred to the teaching enterprise. How should administrators approach the evaluation of individual faculty members? And how should evaluation results be used? The committee discusses methodologies, offers practical guidelines, and points out pitfalls. Evaluating, and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics provides a blueprint for institutions ready to build effective evaluation programs for teaching in science fields.

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.

Seymour, E. 2002. Tracking the Processes of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology. Science Education. Vol. 85, 79-105.

> This paper describes some features in the changing landscape of activities intended to improve both quality and access in science, mathematics, engineering, and technology (SMET) undergraduate education. Observations are offered from the viewpoint afforded by my work—broadly over the last 10 years—both as a researcher, and as an evaluator for projects related to the improvement of undergraduate SMET education. Over that period, I have watched the landscape change—some issues, at first prominent, have diminished in importance; some are emergent; and yet others lie on the horizon. I have also observed that actions in pursuit of various reform goals reflect a variety of theories about how change can be accomplished that are not necessarily complementary. This short history of shifts in the focus of our efforts, and in our beliefs about how they may be achieved, is offered as a framework for discussion of these nationwide endeavors and as an aid in considering next steps.

Hall, S.R., Waitz, I., Brodeur, D.R., Soderholm, D.H., Nsr, R. 2002. Adoption of active learning in a lecture-based engineering class. 32nd ASEE/IEEE Frontiers in Education Conference. November, Boston MA.

> Three years ago, the Department of Aeronautics and Astronautics at MIT expanded its repertoire of active learning strategies and assessment tools with the introduction of muddiest-point-in-the-lecture cards, electronic response systems, concept tests, peer coaching, course web pages, and web-based course evaluations. This paper focuses on the change process of integrating these active learning strategies into a traditional lecture-based multidisciplinary course, called Unified Engineering. The description of the evolution of active learning in Unified Engineering is intended to underscore the motivation and incentives required for bringing about the change, and the support needed for sustaining and disseminating active learning approaches among the instructors.

Sunal, D.W., Hodges, J., Sunal, C.S., Whitaker, K.W., Freeman, L.M., Edwards, L., Johnston, R.A., Odell, M. 2001. Teaching science in higher education: Faculty professional development and barriers to changes. School of Science and Mathematics. Vol. 101, 245-257.

> The focus of this research was to better understand the change processes necessary for university science teaching reform to be successful. The professional development processes involved faculty cognitive perceptions of learning, teaching skills, and pedagogical knowledge, as well as faculty culture in teaching science courses. A series of faculty development programs were conducted at nine U.S. locations to explore, develop strategies, and implement changes in science classrooms. A review of research and these professional development experiences

provided a base to carry out research activities related to understanding change in science faculty. Faculty participants in the program from 30 institutions were selected to be involved in the study. Ethnographic and case study approaches were used to collect and analyze data. Many faculty members encountered in this study had conceptions of the change process that inhibited successful action. These research efforts provide a predictive model for assisting faculty change and help determine which faculty professional development efforts may be successful in overcoming barriers to change in undergraduate science classrooms.

Taconis, R., Ferguson-Hessler, M.G.M., Broekkamp, H. 2001., Teaching science problem solving: An overview of experimental work. Journal of Research in Science Teaching. Vol. 38, 442-468.

> The traditional approach to teaching science problem solving is having the students work individually on a large number of problems. This approach has long been overtaken by research suggesting and testing other methods, which are expected to be more effective. To get an overview of the characteristics of good and innovative problem-solving teaching strategies, we performed an analysis of a number of articles published between 1985 and 1995 in high-standard international journals, describing experimental research into the effectiveness of a wide variety of teaching strategies for science problem solving. To characterize the teaching strategies found, we used a model of the capacities needed for effective science problem solving, composed of a knowledge base and a skills base. The relations between the cognitive capacities required by the experimental or control treatments and those of the model were specified and used as independent variables. Other independent variables were learning conditions such as feedback and group work. As a dependent variable we used standardized learning effects. We identified 22 articles describing 40 experiments that met the standards we deemed necessary for a meta-analysis. These experiments were analyzed both with quantitative (correlational) methods and with a systematic qualitative method. A few of the independent variables were found to characterize effective strategies for teaching science problem solving. Effective treatments all gave attention to the structure and function (the schemata) of the knowledge base, whereas attention to knowledge of strategy and the practice of problem solving turned out to have little effect. As for learning conditions, both providing the learners with guidelines and criteria they can use in judging their own problem-solving process and products, and providing immediate feedback to them were found to be important prerequisites for the acquisition of problem-solving skills. Group work did not lead to positive effects unless combined with other variables, such as guidelines and feedback.

Anderson, J.R., Reder, L.M., Simon, H.A. 2000. Applications and misapplications of cognitive psychology to mathematics education.

> There is a frequent misperception that the move from behaviorism to cognitivism implied an abandonment of the possibilities of decomposing knowledge into its elements for purposes of study and decontextualizing these elements for purposes of instruction. We show that cognitivism does not imply outright rejection of decomposition and decontextualization. We critically analyze two movements which are based in part on this rejection--situated learning and constructivism. Situated learning commonly advocates practices that lead to overly specific learning outcomes while constructivism advocates very inefficient learning and assessment procedures. The modern information processing approach in cognitive psychology would recommend careful analysis of the goals of instruction and thorough empirical study of the efficacy of instructional approaches.

Abd-El-Khalick, F., Bell, R.L., Lederman, N.G. 1998. The nature of science and instructional practice: Making the unnatural natural. John Wiley & Sons, Inc. Science Education. Vol. 82, 417-436.

> The purpose of this study was to delineate the factors that mediate the translation of preservice teachers' conceptions of the nature of science (NOS) into instructional planning and classroom practice. Fourteen preservice secondary science teachers participated in the study. Prior to their student teaching, participants responded to an open-ended questionnaire designed to assess their conceptions of the NOS. Analysis of the questionnaires was postponed until after the completion of student teaching to avoid biasing the collection and/or analysis of other data sources. Throughout student teaching, participants' daily lesson plans, classroom videotapes, and portfolios, and supervisors' weekly clinical observation notes were collated. These data were searched for explicit references to the NOS. Following student teaching, participants were individually interviewed to validate their responses to the open-ended questionnaire and to identify the factors or constraints that mediate the translation of their conceptions of the NOS into their classroom teaching. Participants were found to possess adequate understandings of several important aspects of the NOS including the empirical and tentative nature of science, the distinction between observation and inference, and the role of subjectivity and creativity in science. Many claimed to have taught the NOS through science-based activities. However, data analyses revealed that explicit references to the NOS were rare in their planning and instruction. Participants articulated several factors for this lack of attention to the NOS. These included viewing the NOS as less significant than other instructional outcomes, preoccupation with classroom management and routine chores, discomfort with their own understandings of the NOS, the lack of resources and experience for teaching the NOS, cooperating teachers' imposed restraints, and the lack of planning time. In addition to these volunteered constraints, the data revealed others related to an intricate interaction between participants' perspectives on the NOS, pedagogy, and instructional outcomes.

Wright, J.C., Millar, S.B., Kosciuk, S.A., Penberthy, D.L., Williams, P.H., Wampold, B.E. 1998. A novel strategy for assessing the effects of curriculum reform on student competence. Journal of Chemical Education. Vol. 75. 986-993.

> In this paper, we describe a new assessment strategy that was designed to determine whether such changes in student skills are observable by independent and unbiased observers. The methods were developed by representatives of the University of Wisconsin Chemistry faculty to assess reform success in ways that they would believe. The strategy is applicable to course comparisons that are often found in curriculum reform projects where the project design does not allow the controlled course settings that are sought for educational research. Two sections of a large analytical chemistry course for first-year undergraduates were assessed. One section was taught using methods that focused on lectures that carefully led the student to mastery of the course material using methods that encouraged student questions and participation. The other section was taught using cooperative learning methods that emphasized group work and self-discovery (*12*). These sections are labeled responsive lecturing (RL) and structured active learning (SAL). The SAL approach had been developed in 1992 and refined during the subsequent spring semesters. Unbiased external evaluation judged that both sections represented best practice for each method.

Webster, T.J., Hooper, L. 1998. Supplemental instruction for introductory chemistry courses. Journal of Chemical Education. Vol. 75, 328-332.

> The lack of conceptual understanding of chemistry principles mentioned above has been vastly researched, yielding positive results when direct team learning methods were introduced into the chemistry lecture (*2–5, 9, 10*). Our approach was to utilize the same team learning methods but not to disrupt the lecture format. In this study, the lecture, recitation, and laboratory structure were maintained, but one additional review opportunity was offered to the students: Supplemental Instruction (SI). SI is an interactive program developed in 1979 by Deanna Martin at the University of Missouri–Kansas City, with the goal of helping students achieve mastery of course content while they develop and integrate effective learning and study skill strategies (Martin, D. C. *Supplemental Instruction Training Manual*, unpublished results). Here, SI was utilized as an interactive learning approach to combat the features of traditional algorithmic chemistry teaching techniques, with the hope of increasing the conceptual knowledge and retention rate of introductory chemistry students. By increasing students' conceptual knowledge and thus interest in the class, a reduction in attrition should follow. The limited available literature on this topic illustrates that SI has been successfully implemented into university general chemistry courses (*10, 11*).

Felder, R.M., Brent, R. 1996. Navigating the bumpy road to student-centered instruction. College Teaching. Vol. 44. 43-51.

> Student-centered instruction is a broad teaching approach that includes substituting active learning for lectures, holding students responsible for their learning, and using self-paced and/or cooperative (teambased) learning. Other ways to center our teaching on students include assigning open-ended problems and those requiring critical or creative thinking, reflective writing exercises, and involving students in simulations and role-plays. When properly used, this approach enhances motivation to learn, retention of knowledge, depth of understanding, and appreciation of the subject being taught (Bon-well and Eisen 1991; Johnson, Johnson, and Smith 1991a,b; McKeachie 1994; Meyers and Jones 1993).