

STEM Subject: General Science

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.

President's Council of Advisors on Science and Technology (U.S.), & United States. Executive Office of the President. (2012). *Report to the president, engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. Washington, D.C.: Executive Office of the President, President's Council of Advisors on Science and Technology.

Economic projections point to a need for approximately 1 million more STEM professionals than the U.S. will produce at the current rate over the next decade if the country is to retain its historical preeminence in science and technology. To meet this goal, the United States will need to increase the number of students who receive undergraduate STEM degrees by about 34% annually over current rates. Fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree. Increasing the retention of STEM majors from 40% to 50% would, alone, generate three quarters of the targeted 1 million additional STEM degrees over the next decade. Retaining more students in STEM majors is the lowest-cost, fastest policy option to providing the STEM professionals that the nation needs for economic and societal well-being, and will not require expanding the number or size of introductory courses, which are constrained by space and resources at many colleges and universities.

The reasons students give for abandoning STEM majors point to the retention strategies that are needed. For example, high-performing students frequently cite uninspiring introductory courses as a factor in their choice to switch majors. And low-performing students with a high interest and aptitude in STEM careers often have difficulty with the math required in introductory STEM courses with little help provided by their universities. Moreover, many students, and particularly members of groups underrepresented in STEM fields, cite an unwelcoming atmosphere from faculty in STEM courses as a reason for their departure. Better teaching methods are needed by university faculty to make courses more inspiring, provide more help to students facing mathematical challenges, and to create an atmosphere of a community of STEM learners. Traditional teaching methods have trained many STEM professionals, including most of the current STEM workforce. But a large and growing body of research indicates that STEM education can be substantially improved through a diversification of teaching methods. These data show that evidence-based teaching methods are more effective in reaching all students—especially the “underrepresented majority”—the women and members of minority groups who now constitute approximately 70% of college students while being underrepresented among students who receive undergraduate STEM degrees (approximately 45%). This underrepresented majority is a large potential source of STEM professionals.

Wilson, Z. S., Sylvain, M. R., Sylvain, M. R., Sylvain, M. R., McGuire, S. Y., McGuire, S. Y., McGuire, S. Y., ... Warner, I. M. (January 01, 2012). Hierarchical Mentoring: A Transformative Strategy for Improving Diversity and Retention in Undergraduate STEM Disciplines. *Journal of Science Education and Technology*, 21, 1, 148-156.

In the United States, less than half of the students who enter into science, technology, engineering, and mathematics (STEM) undergraduate curricula as freshmen will actually graduate with a STEM degree. There is even greater disparity in the national STEM graduation rates of students from underrepresented groups with approximately three-fourths of minority students leaving STEM disciplines at the undergraduate level. A host of programs have been

designed and implemented to model best practices in retaining students in STEM disciplines. The Howard Hughes Medical Institute (HHMI) Professors Program at Louisiana State University, under leadership of HHMI Professor Isiah M. Warner, represents one of these programs and reports on a mentoring model that addresses the key factors that impact STEM student attrition at the undergraduate level. By integrating mentoring and strategic academic interventions into a structured research program, an innovative model has been developed to guide STEM undergraduate majors in adopting the metacognitive strategies that allow them to excel in their programs of study, as they learn to appreciate and understand science more completely. Comparisons of the persistence of participants and nonparticipants in STEM curricular, at the host university and with other national universities and colleges, show the impact of the model's salient features on improving STEM retention through graduation for all students, particularly those from underrepresented groups.

Trujillo, G., & Tanner, K. D. (March 01, 2014). Considering the Role of Affect in Learning: Monitoring Students' Self-Efficacy, Sense of Belonging, and Science Identity. *Cbe - Life Sciences Education*, 13, 1, 6-15.

Conceptual learning is a uniquely human behavior that engages all aspects of individuals: cognitive, metacognitive, and affective. The affective domain is key in learning. In this paper, that authors have explored three affective constructs that may be important for understanding biology student learning: self-efficacy--the set of beliefs that one is capable of performing a task; sense of belonging--when one feels a part of a particular group; and science identity--the extent to which a person is recognized or recognizes himself or herself as a "science person." The ideas expressed in this article are intended to help all biology instructors consider the role of affect in biology teaching and learning and to provide starting points for instructors who may wish to collect informal classroom evidence that may give them insights into their students' self-efficacy, sense of belonging, and science identity.

Shapiro, C. A., & Sax, L. J. (March 07, 2012). Major Selection and Persistence for Women in STEM. *New Directions for Institutional Research*, 152, 152, 5-18.

The U.S. federal government identifies many science, technology, engineering, and math (STEM) majors as "areas of national need" that are "crucial to national innovation, competitiveness, and well-being and in which not enough students complete degrees." Underrepresentation of women in STEM in the United States has economic consequences, both individually and nationally. For example, given the ongoing connection between individuals' technological skills and their economic opportunities, women's economic independence may be hindered by underparticipating in the technological industries of the twenty-first century. Further, in light of the national call to action for research in science and technology, women's underrepresentation in STEM signifies a loss of potential talent and innovation that may have an impact on the ability of the United States to remain globally competitive in science and engineering. The technological and scientific professional workforce stands to benefit from diverse perspectives. Creating opportunities for more women to enter and be successful in STEM fields will contribute to diversifying STEM perspectives, ultimately making scientific research more vigorous and

complete. Given that women's underrepresentation in the STEM workforce is largely rooted in their selection of college major, this article summarizes the factors that contribute to women's selection of and persistence in STEM majors. The authors begin with a review of how the educational context shapes women's interest in STEM, and then they move to an overview of the major social and cultural influences beyond the classroom. The article concludes with a discussion of the utility of this information for institutional researchers and how they might further study issues of gender and STEM on their own campuses.

Reynolds, J. A., Thaiss, C., Katkin, W., & Thompson, R. J. J. (March 01, 2012). Writing-to-Learn in Undergraduate Science Education: A Community-Based, Conceptually Driven Approach. *Cbe - Life Sciences Education*, 11, 1, 17-25.

Despite substantial evidence that writing can be an effective tool to promote student learning and engagement, writing-to-learn (WTL) practices are still not widely implemented in science, technology, engineering, and mathematics (STEM) disciplines, particularly at research universities. Two major deterrents to progress are the lack of a community of science faculty committed to undertaking and applying the necessary pedagogical research, and the absence of a conceptual framework to systematically guide study designs and integrate findings. To address these issues, we undertook an initiative, supported by the National Science Foundation and sponsored by the Reinvention Center, to build a community of WTL/STEM educators who would undertake a heuristic review of the literature and formulate a conceptual framework. In addition to generating a searchable database of empirically validated and promising WTL practices, our work lays the foundation for multi-university empirical studies of the effectiveness of WTL practices in advancing student learning and engagement. (Contains 3 tables.)

Moss-Racusin, C. A., Dovidio, J. F., Brescoll, V. L., Graham, M. J., & Handelsman, J. (January 01, 2012). Science faculty's subtle gender biases favor male students. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 41, 16474-9.

Despite efforts to recruit and retain more women, a stark gender disparity persists within academic science. Abundant research has demonstrated gender bias in many demographic groups, but has yet to experimentally investigate whether science faculty exhibit a bias against female students that could contribute to the gender disparity in academic science. In a randomized double-blind study (n = 127), science faculty from research-intensive universities rated the application materials of a student who was randomly assigned either a male or female name for a laboratory manager position. Faculty participants rated the male applicant as significantly more competent and hireable than the (identical) female applicant. These participants also selected a higher starting salary and offered more career mentoring to the male applicant. The gender of the faculty participants did not affect responses, such that female and male faculty were equally likely to exhibit bias against the female student. Mediation analyses indicated that the female student was less likely to be hired because she was viewed as less competent. We also assessed faculty participants' preexisting subtle bias against women using a standard instrument and found that preexisting subtle bias against women played a

moderating role, such that subtle bias against women was associated with less support for the female student, but was unrelated to reactions to the male student. These results suggest that interventions addressing faculty gender bias might advance the goal of increasing the participation of women in science.

Menekse, M., Stump, G. S., Krause, S., & Chi, M. T. H. (July 01, 2013). Differentiated Overt Learning Activities for Effective Instruction in Engineering Classrooms. *Journal of Engineering Education*, 102, 3, 346-374.

Similar to other domains, engineering education lacks a framework to classify active learning methods used in classrooms, which makes it difficult to evaluate when and why they are effective for learning.

Purpose/Hypothesis: This study evaluated the effectiveness and applicability of the Differentiated Overt Learning Activities (DOLA) framework, which classifies learning activities as *interactive*, *constructive*, or *active*, for engineering classes. We tested the ICAP hypothesis that student learning is more effective in *interactive* than *constructive* activities, which are more effective than *active* activities, which are more effective than *passive* activities.

Design/Method: We conducted two studies to determine how and to what degree differentiated activities affected student learning outcomes; we measured student knowledge and understanding of materials science and engineering concepts.

Results: Study 1 showed that students scored higher on all postclass quiz questions after participating in interactive and constructive activities than after the active activities. Student scores on more difficult, inference questions suggested that interactive activities provided significantly deeper learning than constructive or active activities. Study 2 showed that student learning, in terms of gain scores, increased systematically from passive to active to constructive to interactive, as predicted by the ICAP hypothesis. All the increases, from condition to condition, were significant.

Conclusions: Our analyses of classroom activities in the engineering domain showed that they fit within the taxonomy of the DOLA framework. The results of the two studies provided evidence to support the predictions of the ICAP hypothesis

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (March 01, 2012). From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses. *Research in Higher Education*, 53, 2, 229-261.

The lack of academic engagement in introductory science courses is considered by some to be a primary reason why students switch out of science majors. This study employed a sequential, explanatory mixed methods approach to provide a richer understanding of the relationship between student engagement and introductory science instruction. Quantitative survey data were drawn from 2,873 students within 73 introductory science, technology, engineering, and mathematics (STEM) courses across 15 colleges and universities, and qualitative data were collected from 41 student focus groups at eight of these institutions. The findings indicate that students tended to be more engaged in courses where the instructor consistently signaled an

openness to student questions and recognizes her/his role in helping students succeed. Likewise, students who reported feeling comfortable asking questions in class, seeking out tutoring, attending supplemental instruction sessions, and collaborating with other students in the course were also more likely to be engaged. Instructional implications for improving students' levels of academic engagement are discussed. (Contains 1 figure and 5 tables.)

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.

Broggt, E. & Draeger, J. D.(2015). Academic Rigor in General Education, Introductory Astronomy Courses for Nonscience Majors. *The Journal of General Education* 64(1), 14-29. Penn State University Press. Retrieved June 2, 2015, from Project MUSE database.

We discuss a model of academic rigor and apply this to a general education introductory astronomy course. We argue that even without central tenets of professional astronomy—the use of mathematics—the course can still be considered academically rigorous when expectations, goals, assessments, and curriculum are properly aligned.

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.

Anderson, W.A., Banerjee, U., Drennan, C.L., Elgin, C.R., Epstein, L.R., Handelsman, J., Hatfull, G.F., Losick, R., O'Dowd, D.K., Olivers, B.M., Strobel, S.A., Walker, G.C., Warner, I.M. 2011. Changing the culture of science education at research universities. *Science*. Vol. 331, 152-154.

Professors have two primary charges: generate new knowledge and educate students. The reward systems at research universities heavily weight efforts of many professors toward research at the expense of teaching, particularly in disciplines supported extensively by extramural funding (1). Although education and lifelong learning skills are of utmost importance in our rapidly changing, technologically dependent world (2), teaching responsibilities in many STEM (science, technology, engineering, and math) disciplines have long had the derogatory label “teaching load” (3, 4). Some institutions even award professors “teaching release” as an acknowledgment of their research accomplishments and success at raising outside research funds.

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.

Maltese, A.V., Tai, R.H. 2011. Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. Wiley Periodicals, Inc. *Science Education*. 1-31.

As the global economic crisis continues, sustaining the United States' position as a leader in research and development is a top concern of policy makers. Looking to increase the number of students pursuing degrees in STEM (science, technology, engineering, and mathematics), calls for improved mathematics and science education abound. We completed a two-part analysis to assess the school-based factors related to students choosing to complete a major in STEM. The results indicate that the majority of students who concentrate in STEM make that choice during high school, and that choice is related to a growing interest in mathematics and science rather than enrollment or achievement. These results indicate that the current policy focus on advanced-level course taking and achievement as measures to increase the flow of students into STEM may be misguided.

Osborne, J.F., Patterson, A. 2011. Scientific argument and explanation: A necessary distinction? *Science Education*. Vol. 95, 627-638.

In this paper, we argue that there is an emergent confusion in the literature in the use of the terms "argument" and "explanation." Drawing on a range of publications, we point to instances where these terms are either used inappropriately or conflated. We argue that the distinction between these two constructs is, however, important as a lack of clarity of fundamental concepts is problematic for a field. First, a lack of common conception hinders effective communication and, second, it makes defining the nature of the activity we might expect students to engage in more difficult. Drawing on a body of scholarship on argument and explanation, this paper is an attempt to clarify the distinction and to explain why such a distinction might matter.

Ainsworth, H.L., Eaton, S.E. 2010. Formal, non-formal and informal learning in the sciences. Onate Press, Eaton International Consulting, Canada. 48.

This research report investigates the links between formal, non-formal and informal learning and the differences between them. In particular, the report aims to link these notions of learning to sciences and engineering in Canada and the United States. Examples are given for each of these types of learning in different scientific contexts, including basic scientific literacy at one of the scale and professional organizations at the other end of the scale.

Eagan, M.K., Sharkness, J., Hurtado, S., Mosqueda, C.M., Chang, M.J. 2010. Engaging undergraduates in science research: Not just about faculty willingness. <http://heri.ucla.edu/PDFs/pubs/journals/EngagingUndergraduatesinScienceResearchNotJustAboutFacultyWillingness.pdf>

Despite the many benefits of involving undergraduates in research and the growing number of undergraduate research programs, few scholars have investigated the factors that affect faculty members' decisions to involve undergraduates in their research projects. We investigated the individual factors and institutional contexts that predict faculty members' likelihood of engaging undergraduates in their research project(s). Using data from the Higher Education Research Institute's 2007–2008 Faculty Survey, we employ hierarchical generalized linear modeling to analyze data from 4,832 science, technology, engineering, and mathematics (STEM) faculty across 194 institutions to examine how organizational citizenship behavior theory and social exchange theory relate to mentoring students in research. Key findings show that faculty who work in the life sciences and those who receive government funding for their research are more likely to involve undergraduates in their research project(s). In addition, faculty at liberal arts or historically Black colleges are significantly more likely to involve undergraduate students in research. Implications for advancing undergraduate research opportunities are discussed.

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.

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.

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.

Corner, A., Hahn, U. 2009. Evaluating science arguments: Evidence, uncertainty, and argument strength. *Journal of Experimental Psychology: Applied*. Vol. 15, 199-212.

Public debates about socioscientific issues are increasingly prevalent, but the public response to messages about, for example, climate change, does not always seem to match the seriousness of the problem identified by scientists. Is there anything unique about appeals based on scientific evidence—do people evaluate science and nonscience arguments differently? In an attempt to apply a systematic framework to people's evaluation of science arguments, the authors draw on the Bayesian approach to informal argumentation. The Bayesian approach permits questions about how people evaluate science arguments to be posed and comparisons to be made between the evaluation of science and nonscience arguments. In an experiment involving three separate argument evaluation tasks, the authors investigated whether people's evaluations of science and nonscience arguments differed in any meaningful way. Although some differences were observed in the relative strength of science and nonscience arguments, the evaluation of science arguments was determined by the same factors as nonscience arguments. Our results suggest that science communicators wishing to construct a successful appeal can make use of the Bayesian framework to distinguish strong and weak arguments.

Kendall Brown, M., Hershock, C., Finelli, C.J., O'Neal, C. 2009. Teaching for Retention In Science, Engineering, and Math Disciplines: A Guide for Faculty. Center for Research on Learning and Teaching. No. 25. http://www.crlt.umich.edu/publinks/CRLT_no25.pdf

A number of recent national reports have called upon higher education to improve instruction in science, technology, engineering, and mathematics (STEM) as a means of safeguarding U.S. global leadership in these fields (National Academy of Engineering [NAE], 2005; National Academy of Sciences [NAS], 2007b; National Science Board [NSB], 2004). These reports emphasize the importance of preparing a diverse student body for the science and engineering challenges of the twenty-first century. However, statistics indicate that neither the number of students who graduate with STEM¹ degrees, nor the diversity of the graduates is sufficient to meet the needs of a global workforce. Although the overall number of bachelor's degrees awarded annually in the U.S. has risen by nearly 50% over the last twenty years, (NSF, 2008), the proportion of university students achieving bachelor's degrees in STEM fields has declined by

almost 40% (NAS, 2007a). Further, even though women now make up over half of the U.S. undergraduate population (U.S. Census Bureau, 2004), they earned just 21% of the bachelor's degrees awarded in engineering and 25% of bachelor's computer science degrees in 2004 (NSF, 2008).

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.

Willingham, D.T. 2009. Is it true that some people just can't do math? *American Educator*. Winter. 14-15.

How does the mind work – and especially how does it learn? Teachers' instructional decisions are based on a mix of theories learned in teacher education, trial and error, craft knowledge, and gut instinct. Such knowledge often serves us well, but is there anything sturdier to rely on?

Cognitive science is an interdisciplinary field of researchers from psychology, neuroscience, linguistics, philosophy, computer science, and anthropology who seek to understand the mind. In this regular *American Educator* column, we consider findings from this field that are strong and clear enough to merit classroom application.

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.

Lundeberg, M.A. 2008. Case pedagogy in undergraduate STEM: Research we have; Research we need. White Paper, Oct 7. 18.

A promising practice in the STEM undergraduate classroom in the last 15 years is the use of case studies that use realistic or true narratives—that is, stories, to educate (Herreid, 2007). Cases are more than just stories, however; they involve an authentic portrayal of a person(s) in a complex situation(s) constructed for particular pedagogical purposes. Two features are essential: interactions involving explanations, and challenges to student thinking. Interactions involving explanations could occur among student teams, the instructor and a class, among distant colleagues, or students constructing interpretations in a multimedia environment. Cases may challenge students' thinking in many ways, e.g., applying concepts to a real life situation; connecting concepts, sometimes interdisciplinary ideas; examining a situation from multiple perspectives; reflecting on how one approaches or solves a problem; making decisions; designing projects; considering ethical dimensions of situations. Brief vignettes, quick examples, or unedited documents are not cases.

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.

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.

Narum, J.L. 2008. Promising practices in undergraduate STEM education. National Academy of Sciences, commissioned paper, June 30, 2008. http://www7.nationalacademies.org/bose/Narum_CommissionedPaper.pdf

This paper reflects insights and experiences from my work with the Project Kaleidoscope (PKAL) community since the early 1990's. The project that became PKAL began by asking some hard questions about the past, present and future of the undergraduate science learning environment in our country. We began with a group of leaders who brought diverse experiences

and expertise to the table—faculty, deans, and presidents nationally recognized for success in nurturing learning environments that prepared significant numbers of well-qualified science and mathematics undergraduate STEM majors for entry into graduate school.

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.

Sampson, V., Clark, D.B. 2008. Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future direction. Published online 13 March, 2008, in Wiley InterScience (www.interscience.wiley.com).

Theoretical and empirical research on argument and argumentation in science education has intensified over the last two decades. The term "argument" in this review refers to the artifacts that a student or a group of students create when asked to articulate and justify claims or explanations whereas the term "argumentation" refers to the process of constructing these artifacts. The intent of this review is to provide an overview of several analytic frameworks that science educators use to assess and characterize the nature of or quality of scientific arguments in terms of three focal issues: structure, justification, and content. To highlight the foci, affordances, and constraints of these different analytic methods, the review of each framework includes an analysis of a sample argument. The review concludes with a synthesis of the three focal issues and outlines several recommendations for future work. Ultimately, this examination and synthesis of these frameworks in terms of how each conceptualizes argument structure, justification, and content is intended

Trefil, J. 2008. Science education for everyone. Why and What? *Liberal Education*. Spring. 6-12.

The most important use our students will make of whatever science they acquire will be in their future role as citizens.

Zhu, E. 2008. Teaching with clickers. Center for Research on Learning and Teaching. No. 22. 1-8.

Since the 1980s, the use of clickers has proliferated on college campuses. Faculty from various disciplines such as biology, chemistry, history, mathematics, political science, law and psychology have introduced clicker systems into their classrooms. Faculty use clickers for various purposes depending on their course goals and learning objectives. The most common uses of clickers include the following:

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.

Duit, R. 2007. Science education research internationally: Conceptions, research methods, domains of research. *Eurasia Journal of Mathematics, Science & Technology Education*. Vol. 3, 3-15.

Disappointing results of international monitoring studies such as TIMSS (Third International Mathematics and Science Study) and PISA (Programme for International Student Assessment) have fuelled another general debate on the need for a sufficient level of scientific literacy and the necessity to improve the quality of science instruction in school. Science education research has played essential roles not only in analyzing the actual state of scientific literacy and the actual practice in schools but also in improving instructional practice and teacher education. A conception of science education research that is relevant for improving school practice and teacher education programs will be presented here. This conception is based on a Model of Educational Reconstruction which holds that science subject matter issues and students’ learning needs and capabilities have to be given equal attention in quality development attempts. Further, research and development activities have to be intimately linked. It is argued that science education research drawing on this framework is an indispensable prerequisite for improving instructional practice and hence for the further advancement of scientific literacy.

Southerland, S.A., Smith, L.K., Sowel, S.P., Kittleson, J.M. 2007. Resisting unlearning: Understanding science education’s response to the United States’s national accountability movement. *Review of Research in Education*. Vol. 31, 45-77.

We argue that the science education reform efforts that began in the mid-1980s represent an attempt to enact second-order change. In contrast, the policy community, via NCLB, simply calls for change without guidelines to support teaching and learning. To comply with NCLB requirements, school districts often take the most expedient and efficient routes rather than support the kinds of teaching and learning environments that support reform-oriented recommendations. For instance, in reaction to the upcoming NCLB inclusion of science, we have seen schools employ after school and weekend tutoring sessions where students who are underperforming are drilled on content. Doing more of what is typically done is akin to a first-order response. In contrast, the science education research community might support a

reformulation of instruction that entails pulling examples of content from students' out-of-school lives or asking them to produce metacognitive maps/journals based on inquiries they have performed. An issue that is particularly frustrating is that the first-order changes associated with policy implementation require substantial time, money, and energy and these requirements shift resources away from the second order changes desired by researchers. Increasing performance on standardized tests.

Wieman, C. 2007. Why not try. A scientific approach to science education. *Change*. September/October. 9-16.

The purpose of science education is no longer simply to train that tiny fraction of the population who will become the next generation of scientists. We need a more scientifically literate populace to address the global challenges that humanity now faces and that only science can explain and possibly mitigate, such as global warming, as well as to make wise decisions, informed by scientific understanding, about issues such as genetic modification. Moreover, the modern economy is largely based on science and technology, and for that economy to thrive and for individuals within it to be successful; we need technically literate citizens with complex problem-solving skills.

In short, we now need to make science education effective and relevant for a large and necessarily more diverse fraction of the population. What do I mean by an effective education in science? I believe a successful science education transforms how students think, so that they can understand and use science like scientists do. (See Figure 1). But is this kind of transformation really possible for a large fraction of the total population?

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.

Tomsho, R. 2006. What's the right formula? Pressure from new tests lead educators to debate how best to teach science. *The Wall Street Journal*. January 19, 2006; page A9.

The debate over how best to teach science, like struggles over English and math instruction, has intensified with the rise of testing. Similar questions are at issue: Should teachers focus on delivering factual basics of knowledge most often gauged by such tests, or encourage students to do more open-ended thinking?

Best, R.M., Rowe, M., Ozuru, Y., McNamara, D.S. 2005. Deep-level comprehension of science texts. The role of the reader and the text. *Top Lang Disorders*. Vol. 25, 65-83.

Many students from elementary school through college encounter difficulty understanding their science textbooks, regardless of whether they have language disorders. This article discusses some of the particular difficulties associated with science text comprehension and possible remedies for facilitating and enhancing comprehension of challenging expository text materials. Specifically, the authors focus on the difficulties associated with generating inferences needed to comprehend science texts. The successful generation of inferences is affected by factors such as students' prior knowledge and reading strategies, and the manner in which science texts are written. Many students lack the necessary prior knowledge and reading strategies to generate inferences and thus comprehend science texts only poorly. Further, science texts are typically "low-cohesion" texts, which means that they require readers to generate many inferences and fill in conceptual gaps. Remedies for overcoming comprehension difficulties include matching texts to students' knowledge level and providing explicit instruction aimed at teaching students to use reading comprehension strategies for comprehension monitoring, paraphrasing, and elaborations. The computer-supported tool iSTART (Interactive Strategy Training for Active Reading and Thinking) is introduced as a technological support to assist students and teachers in the teaching/learning enterprise.

Blickenstaff, J.C. 2005. Women and science careers: leaky pipeline or gender filter? *Gender and Education*. Vol. 17, 369-386.

Women are under-represented in science, technology, engineering and mathematics (STEM) majors and careers in most industrialized countries around the world. This paper explores the broad array of explanations for the absence of women in STEM put forth in the literature of the last 30 years. It is argued that some proposed explanations are without merit and are in fact dangerous, while others do play a part in a complex interaction of factors. It is suggested that the very nature of science may contribute to the removal of women from the 'pipeline'. Recommendations for reform in science education to address this problem are also provided.

DeHaan, R.L. 2005. The impending revolution in undergraduate science education. *Journal of Science Education and Technology*. Vol. 14, 253-270.

There is substantial evidence that scientific teaching in the sciences, i.e. teaching that employs instructional strategies that encourage undergraduates to become actively engaged in their own learning, can produce levels of understanding, retention and transfer of knowledge that are greater than those resulting from traditional lecture/lab classes. But widespread acceptance by university faculty of new pedagogies and curricular materials still lies in the future. In this essay we review recent literature that sheds light on the following questions:

- What has evidence from education research and the cognitive sciences told us about undergraduate instruction and student learning in the sciences?
- What role can undergraduate student research play in a science curriculum?
- What benefits does information technology have to offer?
- What changes are needed in institutions of higher learning to improve science teaching?

We conclude that widespread promotion and adoption of the elements of scientific teaching by university science departments could have profound effects in promoting a scientifically literate society and a reinvigorated research enterprise.

Kennedy, G.E., Cutts, Q.I. 2005. The association between students' use of an electronic voting system and their learning outcomes. *Journal of Computer Assisted Learning*. Vol. 21, 260-268.

This paper reports on the use of an electronic voting system (EVS) in a first-year computing science subject. Previous investigations suggest that students' use of an EVS would be positively associated with their learning outcomes. However, no research has established this relationship empirically. This study sought to establish whether there was an association between students' use of an EVS over one semester and their performance in the subject's assessment tasks. The results from two stages of analysis are broadly consistent in showing a positive association between EVS usage and learning outcomes for students who are, relative to their class, more correct in their EVS responses. Potential explanations for this finding are discussed as well as modifications and future directions of this program of research.

Ramaley, J.A., Olds, B.M., Earle, J. 2005. Becoming a learning organization: New directions in science education research at the National Science Foundation. *Journal of Science Education and Technology*. Vol. 14, 173-190.

The Education and Human Resources (EHR) Directorate at the National Science Foundation has been examining its role in supporting the development of new approaches to science, technology, engineering and mathematics (STEM) education. This article explores what it means to be scientifically literate, what it takes to become a learning organization, how the EHR Directorate is working towards becoming such an organization through rigorous selfstudy, and how EHR can best manage its large portfolio of awards that support investigations in STEM education to enhance their collective value to researchers, policymakers and educators. Several elements of the self-study process are described, and the implications for the Directorate as well as for the field of researchers in science education are explored.

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).

Miller, J.D. 2004. Public understanding of, and attitudes toward, scientific research: what we know and what we need to know. Sage Publications, *Public Understanding Science*. Vol. 13, 273-294.

Over the last four decades, a substantial body of national survey material has been collected in the US concerning the public understanding of science and technology. Using this body of research, this analysis outlines the major trends from 1957 to 1999 and discusses their

implications for public understanding of, and attitudes toward, scientific research. The analysis found that although the rate of civic scientific literacy in the US is only now approaching 20 percent, there is a strong and continuing public belief in the value of scientific research for economic prosperity and for the quality of life. Even though there are some continuing reservations about the pace of change engendered by science and technology and the relationship between science and faith, the public consistently reconciles these differing perceptions in favor of science.

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.

Bell, R.L., Lederman, N.G. 2003. Understandings of the Nature of Science and decision making on science and technology based issues. *Science Education*. Vol. 87, 352-377.

The purpose of this investigation was to explicate the role of the nature of science in decision making on science and technology based issues and to delineate factors and reasoning

associated with these types of decisions. Twenty-one volunteer participants purposively selected from the faculty of geographically diverse universities completed an open-ended questionnaire and follow-up interview designed to assess their decision making on science and technology based issues. Participants were subsequently placed in one of two groups based upon their divergent views of the nature of science as assessed by a second open-ended questionnaire and follow-up interview. Profiles of each group's decision making were then constructed, based on participants' previous responses to the decision making questionnaire and follow-up interviews. Finally, the two groups' decisions, decision influencing factors, and decision making strategies were compared. No differences were found between the decisions of the two groups, despite their disparate views of the nature of science. Participants in both groups based their decisions primarily on personal values, morals/ethics, and social concerns. While all participants considered scientific evidence in their decision making, most did not require absolute "proof," even though many participants held absolute conceptions of the nature of science. Overall, the nature of science did not figure prominently in either group's decisions. These findings contrast with basic assumptions of current science education reform efforts and call for a re-examination of the goals of nature of science instruction. Developing better decision making skills—even on science and technology based issues—may involve other factors, including more value-based instruction and attention to intellectual/moral development.

Duit, R., Treagust, D.F. 2003. Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*. Vol. 25, 671-688.

In this review, we discuss (1) how the notion of conceptual change has developed over the past three decades, (2) giving rise to alternative approaches for analysing conceptual change, (3) leading towards a multiperspective view of science learning and instruction that (4) can be used to examine scientific literacy and (5) lead to a powerful framework for improving science teaching and learning.

Fox, M.A., Hackerman, N. Editors, National Research Council. 2003. *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*. Free Executive Summary. <http://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.

Gess-Newsome, J., Southerland, S.A., Johnston, A., Woodbury, S. 2003. Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research*. Vol. 40, 731-770.

The Teacher-Centered Systemic Reform model (TCSR) recognizes teaching context, teacher characteristics, teacher thinking, and their interactions as influential factors in attempts to implement classroom reform. Using the TCSR model, teachers' personal practical theories, and conceptual change as a framework, the authors of this article studied three college science faculty members as they designed and implemented an integrated, inquiry based science course. The documentation and analysis of context, instructors' knowledge and beliefs, and teaching episodes allowed the authors to identify and study the interaction of factors, including grant support, that shape reform attempts. The results suggest that grant-supported mitigation of structural barriers is a necessary but insufficient precursor to change and that personal practical theories are the most powerful influence on instructional practice. The findings highlight the critical role of pedagogical and contextual dissatisfaction in creating a context for fundamental change.

Halpern, D.F., Hakel, M.D. 2003, Applying the science of learning to the university and beyond: Teaching for long-term retention and transfer. *Change*. July/August. 6.

Most of the general public knows that we also "do research" and committee work [in addition to teaching]. But they believe that these other parts of the professor's job are secondary to teaching. Those outside academia further assume that because we are college faculty, we actually have a reasonable understanding of how people learn and that we apply this knowledge in our teaching.

Kelly, G.J., Bazerman, C. 2003. How students argue scientific claims: A rhetorical-semantic analysis. *Applied Linguistics*. Vol. 24, 28-55.

This paper investigates ways students engage in scientific reasoning practices through the formulation of written argument. Through textual analysis of university students' scientific writing we examined how general theoretical claims are tied to specific data in constructing evidence. The student writers attended a writing-intensive university oceanography course that required them to write a technical paper drawing from multiple interactive geological data sets concerning plate tectonics. Two papers, chosen as exemplary by the course instructor, were analysed in three ways: First, genre analysis was applied to identify the rhetorical moves used by the authors to complete the academic task. Second, a previously developed model of epistemic generality was used to uncover the relationships of theoretical assertions and empirical data. Third, an analysis of lexical cohesion mapped the recurrence and relationships of topics throughout the student papers. These analyses identified ways that the students engaged with the genre (as defined within the activity system of the course): the successful student authors were shown to adjust the epistemic level of their claims to accomplish different rhetorical goals, build theoretical arguments upon site specific data, method, introduce key concepts that served as anchors for subsequent conceptual development, and tie multiple strands of empirical data to central constructs through aggregating sentences. Educational applications are discussed.

Norris, S.P., Phillips, L.M., Korpan, C.A. 2003. University students' interpretation of media reports of science and its relationship to background knowledge, interest, and reading difficulty. *Public Understanding Science*. Vol. 12, 123-145.

Three hundred and eight first and second year university students were asked to read five media reports that described recent scientific research and findings. We instructed the students to interpret and make judgments about the certainty, status, and role of statements identified in the reports, and to assess how much knowledge they had about the general topics of the reports, their interest in the general topics, and their difficulty reading each report. Students' performance on the interpretive tasks mirrored in major detail the performance of a group of high school students studied previously. The university students displayed a certainty bias in their responses to questions regarding truth status, confused cause and correlation, and had difficulty distinguishing explanations of phenomena from the phenomena themselves. The university students' self-assessments of their knowledge, interests, and reading difficulty were able to explain virtually none of the variance in their interpretive performance. In general, the university students had an inflated view of their ability to understand the five media reports. Implications for the development of scientific literacy are discussed.

Fairweather, J.S., Beach, A.L. 2002. Variations in faculty work at research universities: Implications for state and institutional policy. *The Review of Higher Education*. Vol. 26, 97-115.

In the 21st century, the mantra of state higher education policymakers has changed from "how much money should we spend?" toward "do these dollars make a difference?" The impetus for this shift is the desire to improve college teaching and student learning. The Ohio mandate (Cage, 1995), for example, requires faculty members in all four-year public universities to increase the amount of time they spend on teaching by 10%. The Tennessee and South Carolina performance funding initiatives (Banta, 1986; Carnevale, Johnson, & Edwards, 1998) tie all (South Carolina) or part (Tennessee) of state funding to public four-year colleges and universities meeting state policy goals, especially improved student learning.

Kardash, C.M., Wallace, M.L. 2001. The perceptions of science classes survey: What undergraduate science reform efforts really need to address. *Journal of Educational Psychology*. Vol. 93, 199-210.

Nine-hundred twenty two undergraduates completed an 80-item survey that assessed their perceptions of undergraduate science classes. Factor analysis of the items yielded 6 factors: (1) Pedagogical Strategies, (2) Faculty Interest in Teaching, (3) Student Interest and Perceived Competence in Science, (4) Passive Learning, (5) Grades as Feedback, and (6) Laboratory Experiences. Women differed significantly from men on the Pedagogical Strategies, Passive Learning, Grades as Feedback, and Laboratory Experiences factors. Correlational analyses and evidence from distinct groups supported the survey's construct validity. Students reported room for improvement of the science faculty's pedagogical practices. From the students' perspective, how information is taught appears to be at least as much of a concern as what information is taught.

Roth, W.M., Lee, S. 2002. Scientific literacy as a collective praxis. *Public Understanding Science*. Vol. 11, 33-56.

In this article, we conceive of scientific literacy as a property of collective activity rather than individual minds. We think of knowing and learning science as situated in and distributed across social and material aspects of a setting. To support the proposed conception, we provide several detailed cases from our three-year multi-site ethnographic study of science in one community, featuring different types of citizens who walk a creek, interact during an environment-oriented open-house event, discuss water problems, collect data, and have different conceptions of human-environment relations. The case studies show that collectively, much more advanced forms of scientific literacy are produced than any individual including scientists could produce. Creating opportunities for scientific literacy to emerge from collective activity, irrespective of whether one or more participants know some basic scientific facts, presents challenges to science educators very different from teaching basic facts and skills to individuals.

Shavelson, R.J., Towne, L. Editors, National Research Council. 2002. Scientific research in education. Free Executive Summary. <http://www.nap.edu/catalog/10236.html>.

There is long-standing debate among scholars, policy makers, and others about the nature and value of scientific research in education and the extent to which it has produced the kind of cumulative knowledge expected of scientific endeavors. Most recently, this skepticism led to proposed legislation that defines what constitutes rigorous scientific methods for conducting education research.

That proposal, coupled with rising enthusiasm for evidence-based education policy and practice, led to this National Research Council study to examine and clarify the nature of scientific inquiry in education and how the federal government can best foster and support it. Specifically, the charge to the committee was to “. . . review and synthesize recent literature on the science and practice of scientific educational research and consider how to support high quality science in a federal education research agency.” We did not attempt to evaluate the quality of bodies of existing research, of existing researchers in the field, or of the existing federal research function because that would have constituted a monumental challenge and we judged it to be beyond the scope of our charge. Instead, we adopted a forward-looking approach that draws on lessons from history and identifies the roles of various stakeholders (e.g., researchers, policy makers, practitioners) in fulfilling a vision for the future of education research.

Seymour, E. 2001. Tracking the processes of change in US undergraduate education in Science, Mathematics, Engineering and Technology. *Science Education*. Vol. 86, 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.

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.

Zimmerman, C., Bisanz, G.L., Bisanz, J., Klein, J.S., Klein, P. 2001. Science at the supermarket: a comparison of what appears in the popular press, experts' advice to readers, and what students want to know. Institute of Physics Publishing, Public Understanding Science. Vol. 10, 37-58.

The popular print media constitute a major source of new information about scientific research for the public and for members of the scientific community outside their areas of expertise. Despite the potential importance of media reports to scientific literacy and public awareness of science, little is known about the content of these articles. We sampled the popular print media (e.g., publications such as those sold at a convenience store or supermarket) and found that the majority of articles about scientific research were in the form of news briefs. We analyzed and compared (a) the content of these news briefs, (b) advice given by experts about how to read media reports about science critically, and (c) university students' requests for information as they evaluated brief reports about research. Some marked discrepancies were found. For example, much of the information that experts advised readers to attend to or that students spontaneously requested for conceptualizing scientific literacy, as well as for changing science journalism and science education in ways that can enable readers to become effective consumers of scientific information.

Musheno, B.V., Lawson, A.E. 1999. Effects of learning cycle and traditional text on comprehension of science concepts by students at differing reasoning levels. *Journal of Research in Science Teaching*. Vol. 36, 23-37.

Research has found the learning cycle to be effective for science instruction in hands-on laboratories and interactive discussions. Can the learning cycle, in which examples precede the introduction of new terms, also be applied effectively to science text? A total of 123 high school students from two suburban schools were tested for reasoning ability, then randomly assigned to read either a learning cycle or traditional text passage. Immediate and delayed posttests provided concept comprehension scores that were analyzed by type of text passage and by reasoning level. Students who read the learning cycle passage earned higher scores on concept comprehension questions than those who read the traditional passage, at all reasoning levels. This result supports the hypothesis that reading comprehension and scientific inquiry involve similar information-processing strategies and confirms the prediction that science text presented in the learning cycle format is more comprehensible for readers at all reasoning levels.

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.

McComas, W.F. 1998. The principle elements of the Nature of Science: dispelling the myths. *Adapted from the chapter in W. F. McComas (ed.) The Nature of Science in Science Education*, 53-70. © 1998 Kluwer Academic Publishers, Netherlands

The "myths of science" discussed here are commonly included in science textbooks, in classroom discourse and in the minds of adult Americans. These fifteen issues, described here as "myths of science," do not represent all of the important issues that teachers should consider when designing instruction relative to the nature of science, but may serve as starting points for evaluating current instructional foci while enhancing future curriculum design. Misconceptions about science are most likely due to the lack of philosophy of science content in teacher education programs and the failure of such programs to provide real science research experiences for preservice teachers while another source of the problem may be the generally shallow treatment of the nature of science in the textbooks to which teachers might turn for guidance. Some of these myths, such as the idea that there is a scientific method, are most likely caused by the explicit inclusion of faulty ideas in textbooks while others, such as lack of knowledge of the social construction of scientific knowledge, are the result of omissions in texts.

Trigwell, K., Prosser, M., Taylor, P. 1994. Qualitative differences in approaches to teaching first year university science. *Higher Education*. Vol. 27, 75-84.

Abstract. Changing lecturers' teaching strategies to improve learning in higher education may mean first having to address the intentions associated with those strategies. The study reported in this paper used a phenomenographic approach to explore the intentions associated with the teaching strategies of first year physical science lecturers. Approaches found ranged from those involving information transmission to those where the intention was to develop learning through conceptual change, but in all approaches, logical relations were found between intention and strategy. The implications for attempts to improve teaching through developing strategies are discussed.

Matthews, M.R. 1993. Constructivism and science education: some epistemological problems. *Journal of Science and Technology*. Vol. 2, 359-371.

The paper outlines the significant influence of constructivism in contemporary science and mathematics education and emphasizes the central role that epistemology plays in constructivist theory and practice. It is claimed that constructivism is basically a variant of old-style empiricist epistemology, which had its origins in Aristotle's individualist and sense-based theory of knowledge. There are well-known problems with empiricism from which constructivism appears unable to dissociate itself.

Johnstone, A.H. 1991. Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*. Vol. 7, 75-83

The difficulties of learning science are related to the nature of science itself and to the methods by which science is customarily taught without regard to what is known about children's learning. An information processing model is proposed to guide thinking and research in this area.