

STEM Subject: Engineering

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.

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

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.

Felder, R.M. 2011. Hang in there! Dealing with student resistance to learner-centered teaching. *Chemical Engineering Education*. Vol. 45, 131-132.

What can I do about low teaching evaluations from students I teach actively when what they clearly want is much more traditional (passive ride, smooth highway please)? I'm about ready to give up and return to just lecturing, as I am sure students will evaluate my courses higher if I do. Thank you for your time and consideration.

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.

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. 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. 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).

Felder, R.M. 2007. Reaching the second tier: Learning and teaching styles in college science education. <http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Secondtier.html>

In her recent study of college science instruction, Sheila Tobias [19] defines two *tiers* of entering college students, the first consisting of those who go on to earn science degrees and the second those who have the initial intention and the ability to do so but instead switch to nonscientific fields. The number of students in the second category might in fact be enough to prevent the shortfall of American scientists and engineers that has been widely forecast for the coming decade.

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 ($p < 0.001$). 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.

Prince, M.J., Felder, R.M., Brent, R. 2007. Does faculty research improve undergraduate teaching? An analysis of existing and potential synergies. *Journal of Engineering Education*. Vol. 96, 283-294.

Academicians have been arguing for decades about whether or not faculty research supports undergraduate instruction. Those who say it does—a group that includes most administrators and faculty members—cite many ways in which research can enrich teaching, while those on the other side cite numerous studies that have consistently failed to show a measurable linkage between the two activities. This article proposes that the two sides are debating different propositions: whether research can support teaching in principle and whether it has been shown to do so in practice. The article reviews the literature on the current state of the research teaching nexus and then examines three specific strategies for integrating teaching and scholarship: bringing research into the classroom, involving undergraduates in research projects, and broadening the definition of scholarship beyond frontier disciplinary research. Finally, ways are suggested to better realize the potential synergies between faculty research and undergraduate education.

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 responsabili 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.

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.

Felder, R.M., Brent, R. 2005. Understanding student differences. *Journal of Engineering Education*. January. 16.

Students have different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices. The more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students. Three categories of diversity that

have been shown to have important implications for teaching and learning are differences in students' learning styles (characteristic ways of taking in and processing information), approaches to learning (surface, deep and strategic), and intellectual development levels (attitudes about the nature of knowledge and how it should be acquired and evaluated). This article reviews models that have been developed for each of these categories, outlines their pedagogical implications, and suggest areas for further study.

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.

Felder, R.M., Brent, R. 2001. Effective strategies for cooperative learning. *Journal of Cooperation and Collaboration in College Teaching*. Vol. 10, 69-75.

About 15 years ago one of the authors (RF) began to experiment with groupwork in his engineering courses. After making every mistake in the book (which he had not yet read), he recognized that there must be more to getting students to work together effectively than simply putting them in groups and asking them to do something, but he wasn't sure what it was. Then, like so many of his colleagues in engineering, he attended a workshop given by Karl Smith, heard the gospel of cooperative learning according to Johnson *et al.*, and was converted. Things went much better after that, although every course he taught produced additional items on his lists of things that work and things to avoid.

Brent, R., Felder, R., Regan, T., Walser, A., Carlson-Dikes, C., Evans, D., Malave, C., Sanders, K., McGourty, J. 2000. Engineering faculty development: A multicoalition perspective. Paper presented at the Annual Meeting of the American Society for Engineering Education (St. Louis, MO, June 18-21).

This paper addresses the issue of faculty participation in development programs. Participation in faculty development programs has not been part of the culture in engineering education and with the focus on reform, ways are being sought to involve faculty in retraining. At North Carolina State University (NCSU), representatives from the NSF-sponsored Engineering Education Coalition (EEC) decided to use a faculty development model. Details of this model are presented.

Felder, R.M., Silverman, L.K. 1998. Learning and teaching styles in engineering education. *Engineer Education*. Vol. 78, 674-681.

Students learn in many ways— by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. How much a given student learns in a class is governed in part by that student's native ability and prior preparation but also by the compatibility of his or her learning style and the instructor's teaching style.