STEM Discipline Mathematics

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.

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, engineer-ing, and mathematics (STEM) courses under traditional lecturing versus active learning. The effect sizes indicate that on average, student performance on examinations and concept inventories in-creased 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 con-cept inventories more than on course examinations, and that ac-tive 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.

Halcrow, C., Iiams, M. 2011. You can build it, but will they come? Primus. Vol. 21, 323-337.

Studies show that more students fail or withdraw from college mathematics courses than any other. To address this concern, the Mathematics Department at the University of North Dakota opened its Mathematics Learning Center (MLC) in the fall of 2000. In this study, the effectiveness of the MLC and the free tutoring offered for students in freshman level mathematics courses was examined.

The quantitative portion of the study examined the difference between course grades in experimental and control sections of four distinct freshman level mathematics courses. Students in the experimental sections were required to attend the Mathematics Learning Center (MLC) for one hour weekly while students in the control sections were simply informed of the availability of tutoring in the MLC. The qualitative portion of the research utilized methodologies of a phenomenological study through in-depth interviews with 13 participants. Three conclusions are offered: 1) Lower level or lower ability students are less likely to attend the MLC and seek help from tutors; 2) Once students got over their fears of engaging with tutors, they found them friendly and helpful, and believed they had greater success because of the tutoring; and 3) A positive correlation existed between time spent in the MLC and course grade for experimental section students.

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

In this article, we present a large list of low-threshold active teaching methods categorized so the instructor can efficiently access and target the deployment of conceptually based lessons. The categories include teaching strategies for lecture on large and small class sizes; student

action individually, in pairs, and groups; games; interaction through homework; student questions; role play; student presentations; and brainstorming. Along with a label for each method, we provide a brief summary of meaning, how to implement, and, for many, possible ways to implement in a mathematics course. Many of the methods are an adaptation of the active teaching methods available in books [1–3].

Esmonde, I. 2009. Ideas and identities: Supporting equity in cooperative mathematics learning. Review of Educational Research. Vol. 79, 1008-1043.

This review considers research related to mathematics education and cooperative learning, and it discusses how teachers might assist students in cooperative groups to provide equitable opportunities to learn. In this context, equity is defined as the fair distribution of opportunities to learn, and the argument is that identity-related processes are just as central to mathematical development as content learning. The link is thus considered between classroom social ecologies, the interactions and positional identities that these social ecologies make available, and student learning. The article closes by considering unresolved questions in the field and proposing directions for future research.

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

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

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

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

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

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

Winter, D. 2007. Infusing mathematics with culture: Teaching technical subjects for social justice. New Directions for Teaching and Learning. Fall. 97-108.

For more than twenty years the undergraduate mathematics teaching community has conducted a deep conversation concerning the pedagogies appropriate for introductory mathematics courses, including college algebra, precalculus, and calculus (Ganter, 2000, 2001). Fueling this ongoing discussion has been the recognition that students' failure to "acquire a deep understanding of the material they are supposed to learn in their [mathematics] courses" (Graesser, Person, and Hu, 2002, p. 33) is still unacceptably common (Bookman and Friedman, 1994; Selden, Mason, and Selden, 1989; Smith, 1998).

This conversation has produced changes in the pedagogy of many mathematics courses (Hurley, Koehn, and Ganter, 1999; Lutzer, Maxwell, and Rodi, 2002), including increased use of cooperative learning and technology to promote learning. Recognizing the value of student interest as a resource for learning (Schiefele and Csikszentmihalyi, 1995), many instructors have highlighted the applicability and usefulness of mathematical techniques for solving problems in the world outside the classroom (see Alper, Fendel, Fraser, and Resek, 1996; De Bock and others, 2003; Forman and Steen, 2000; Pollack, 1978; Walkerdine, 1988). One rationale for integrating social and cultural learning with traditional STEM learning is to use undergraduates' enthusiasm for social and political issues (National Survey of Student Engagement, 2004) as an engine to drive more abstract and conceptual mathematical learning (Carter and Brickhouse, 1989; Nix, Ryan, Manly, and Deci, 1999; Zoller, 1990).

Stigler, J.W., Hiebert, J. 2004. Improving mathematics teaching. Educational Leadership. February. 12-19.

We have been working for 10 years on a research program aimed at answering questions related to the difference in mathematic classrooms around the globe. The TIMSS video studies document typical teaching practices in various countries. These studies employ the video survey, a novel methodology that combines two research traditions: qualitative classroom research and large-scale survey research. The video studies capture close-up pictures of the classroom processes used by national samples of 8th grade mathematics teachers in different countries. These teachers are not necessarily experienced or effective. They are ordinary teachers, teaching lessons that they routinely teach.

Byrnes, J.P. 2003. Factors predicative of mathematics achievement in white, black and Hispanic 12th graders. J. of Educ Psychology. Vol. 95, 316-326.

In this study, a secondary analysis of the National Assessment of Educational Progress was conducted to provide insight into ethnic differences in 12th-grade math achievement. Using the 3 conditions model (3C model) of achievement as a guide, regression analyses showed ethnicity accounted for less than 5% of the variance in math performance once indices of socioeconomic status, exposure to learning opportunities, and motivation were controlled. In contrast, variables central to the 3C model accounted for 45%–50% of the variance. The implications of these results for theories of ethnic differences and for reform efforts are discussed. The findings suggest that schools can do a great deal to close achievement discrepancies among White, Black, and Hispanic students.

Judson, E., Swada, D. 2002. Learning from past and present: Electronic response systems I college lecture halls. Journal of Computers in Mathematics and Science Teaching. Vol. 21, 167-181.

This article reviews literature from the past 33 years particular to the use of electronic response systems in college lecture halls. Electronic response systems, primarily used in science courses have allowed students to provide immediate feedback to multiple-choice questions, and inform the instructor of student understanding. Research from the 1960s and 1970s indicates there is no significant correlation between student academic achievement and a stimulus-response method of using such systems. Recent studies have indicated there is significant student increase of conceptual gains in physics when electronic response systems are used to facilitate feedback in a constructivist-oriented classroom. Students have always favored the use of electronic response systems and attribute such factors as attentiveness and personal understanding to using electronic response systems. Ultimately, this review of literature points to the pedagogical practices of the instructor, not the incorporation of the technology as being key to student comprehension. Electronic response systems are viewed as a tool that holds a promise of facilitating earnest discussion. Recommendations are made that professional development focus on pedagogical practice for instructors considering the use of electronic response system.

Herriott, S.R. 2001. Changes in college algebra. A Position Paper to Stimulate Discussion at the NSF Workshop on Rethinking Precalculus October, Washington, DC

The high rate of students' failure in the college algebra course could be a problem of admissions, placement, curriculum design, or instruction. This paper focuses on the curriculum in light of the needs of the students who tend to enroll in the course. The traditional college algebra curriculum is contrasted with the alternative curricula developed in recent years by textbook authors. Related issues of national and local educational policy are also discussed.

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.

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

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

Novick, L.R., Holyoak, K.J. 1991. Mathematical problem solving by analogy. J. of Experimental Psychology. Vol. 17, 398-415.

We report the results of 2 experiments and a verbal protocol study examining the component processes of solving mathematical word problems by analogy. College students first studied a problem and its solution, which provided a potential source for analogical transfer. Then they attempted to solve several analogous problems. For some problems, subjects received one of a variety of hints designed to reduce or eliminate the difficulty of some of the major processes hypothesized to be involved in analogical transfer. Our studies yielded 4 major findings. First, the process *of mapping xhc* features of the source and target problems and the process *of adapting* the source solution procedure for use in solving the target problem were clearly distinguished: (a) Successful mapping was found to be insufficient for successful transfer and (b) adaptation was found to be a major source of transfer difficulty. Second, we obtained direct evidence that schema induction is a natural consequence of analogical transfer. The schema was found to co-exist with the problems from which it was induced, and both the schema and the individual problems facilitated later transfer. Third, for our multiple-solution problems, the relation between analogical transfer and solution accuracy was mediated by the degree of time pressure exerted for the test problems. Finally, mathematical expertise was a significant predictor of analogical transfer, but general analogical reasoning ability was not. The implications of the results for models of analogical transfer and for instruction were considered.

Lampert, M. 1990. When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. American Educational Research Journal. Vol. 27, 29-63.

> This paper describes a research and development project in teaching designed to examine whether and how it might be possible to bring the practice of knowing mathematics in school closer to what it means to know mathematics within the discipline by deliberately altering the roles and responsibilities of teacher and students in classroom discourse. The project was carried out as a regular feature of lessons in fifth-grade mathematics in a public school. A case of teaching and learning about exponents derived from lessons taught in the project is described and interpreted from mathematical, pedagogical, and sociolinguistic perspectives. To change the meaning of knowing and learning in school, the teacher initiated and supported social interactions appropriate to making mathematical arguments in response to students' conjectures. The activities students engaged in as they asserted and examined hypotheses about the mathematical structures that underlie their solutions to problems are contrasted with the conventional activities that characterize school mathematics.