STEM Subject Chemistry

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.

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 thenecessary 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.)

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.

King, D. (January 01, 2012). New Perspectives on Context-Based Chemistry Education: Using a Dialectical Sociocultural Approach to View Teaching and Learning. *Studies in Science Education, 48,* 1, 51-87

> Context-based chemistry education aims to improve student interest and motivation in chemistry by connecting canonical chemistry concepts with real-world contexts. Implementation of context-based chemistry programmes began 20 years ago in an attempt to make the learning of chemistry meaningful for students. This paper reviews such programmes through empirical studies on six international courses, "ChemCom" (USA), "Salters" (UK), "Industrial Science" (Israel), "Chemie im Kontext" (Germany), "Chemistry in Practice" (The Netherlands) and "PLON" (The Netherlands). These studies are categorised through emergent characteristics of: relevance, interest/attitudes/motivation and deeper understanding. These characteristics can be found to an extent in a number of other curricular initiatives, such as science-technology-society approaches and problem-based learning or project-based science, the latter of which often incorporates an inquiry-based approach to science education. These initiatives in science education are also considered with a focus on the characteristics of these approaches that are emphasised in context-based education. While such curricular studies provide a starting point for discussing context-based approaches in chemistry, to advance our understanding of how students connect canonical science concepts with the real-world context, a new theoretical framework is required. A dialectical sociocultural framework originating in the work of Vygotsky is used as a referent for analysing the complex human interactions that occur in context-based classrooms, providing teachers with recent information about the pedagogical structures and resources that afford students the agency to learn. (Contains 1 table.)

Richards-Babb, M., Drelick, J., Henry, Z., Robertson-Honecker, J. 2011. Online homework, help or hindrance? What students think and how they perform. Research and Teaching. Vol. 40, 81-94.

> To improve students' retention rates in general chemistry, online homework was introduced into our curriculum. Replacing quizzes directly by online homework significantly improved ($p < .0005$) success rates in second-term general chemistry. Attitudinal Likert survey results indicate that the majority of students completed the online homework assignments (90%) and viewed the assignments as worth the effort (83.5%). Students were overwhelming (85.7%) in their recommendation that online homework use should continue. More consistent study habits were reported by 75.6% of students, and students reported using a suite of effective problem-solving approaches for questions marked as incorrect. Our instructors have willingly embraced the use of online homework and point to the incredible amount of time savings for the instructor as reason enough to use online homework.

Bannier, B.J. 2010. Motivating and assisting adult, online chemistry students: A review of the literature. J. Sci Educ Technol. Vol. 19, 215-236.

> While comprehensive texts, articles, and literature reviews presenting research in the singular arenas of motivation, help-seeking, and online science learning are relatively easy to find, syntheses and interactions between these constructs are lacking. Part I of this review addresses this knowledge gap by drawing together key research from the domains of educational psychology and adult education, addressing the constructs of motivation, self-efficacy, adult learning, and help-seeking. Part II of this review extends and applies the motivation and help-

seeking discussion to the emerging and exciting field of online chemistry education. The result is a comprehensive synthesis of the strengths and limitations of the currently existing body of knowledge related to the motivation and help-seeking behaviors of adult, online chemistry students.

Bowen, C. 2010. A Quantitative Literature Review of Cooperative Learning Effects on High School and College Chemistry Achievement. Journal of Chemical Education. Vol. 77, 116.

This paper has two purposes. First, the reader is given an overview on how quantitative literature reviews (meta-analyses) can be conducted to give overall estimates of the quantitative impact an instructional treatment has on a specific student outcome. The second purpose is to illustrate how such a literature review is carried out by examining studies on using cooperative learning to teach chemistry at the high school and college levels. This analysis extends earlier reported work on effects of cooperative learning on achievement in college-level science, mathematics, and engineering and technology (SMET) courses. The analysis shows that while median student performance in a traditional course is at the 50th percentile, the median student performance in a cooperative learning environment is 14 percentile points higher. This paper has two purposes. First, the reader is given an overview on how quantitative literature reviews (meta-analyses) can be conducted to give overall estimates of the quantitative impact an instructional treatment has on a specific student outcome. The second purpose is to illustrate how such a literature review is carried out by examining studies on using cooperative learning to teach chemistry at the high school and college levels. This analysis extends earlier reported work on effects of cooperative learning on achievement in college-level science, mathematics, and engineering and technology (SMET) courses. The analysis shows that while median student performance in a traditional course is at the 50th percentile, the median student performance in a cooperative learning environment is 14 percentile points higher.

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

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

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

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

King, D.B., Joshi, S. 2008. Gender differences in the use and effectiveness of personal response devices. Journal of Science Educational Technology. Vol. 17, 544-552.

The use of personal response devices (or ‘‘clickers’’) in the classroom has increased in recent years. While few quantitative studies on the effectiveness of clickers have been published, it is generally reported that clickers have been well-received by the students who use them. Two separate populations (Winter 2006 and Spring 2006) of engineering students were given clickers to use during a general chemistry class. Clicker use was compared to student grades for each course. During both terms, a higher percentage of female students than male students ‘‘actively participated’’ in the lectures, where active participation as defined as answering more than 75% of the clicker questions over the course of the term. Active male students earned final grades about 10 points higher than non-active male students. Active female students, however, scored only about 5 points higher than non-active female students. Student learning was assessed by comparing performance on exam questions and clicker questions with similar content. Students who answered clicker questions correctly were 11–13% more likely to answer the corresponding exam questions correctly than were students who did not answer the clicker question. In this paper, we demonstrate the effectiveness of clicker use in the classroom and examine gender differences associated with this use.

MacArthur, J.R., Jones, L.L. 2008. A review of literature reports of clickers applicable to college chemistry classrooms. Chemistry Education Research and Practice. Vol. 9, 187-195.

The use of clickers (also referred to as Audience Paced Feedback, Classroom Communication Systems, Personal Response Systems, Electronic Voting Systems, Student Response Systems, Audience Response Systems, voting-machines, and zappers) has grown in college chemistry classrooms within the last decade. This review summarizes the pedagogic applications of research on clickers as well as insights from their practical use. Fifty-six publications reporting on the use of clickers in college-level science classrooms are categorized as practical application or research studies, and reviewed. Publications on the practical use of clickers suggest that students have a positive attitude towards the technology and that many benefits and few drawbacks are associated with its use. Research studies show that the use of clickers results in measurable increases in student learning in some cases and inconclusive results in other cases. In every published report of student improvement with the use of clickers, the course included student collaboration of some form.

Woelk, K. 2008. Optimizing the use of personal response devices (clickers) in large-enrollment introductory courses. Journal of Chemical Education. Vol. 85, 1400-1406.

While many studies are still in progress, especially those seeking to quantify learning outcomes, clicker systems have already been permanently installed in numerous college and university classrooms, particularly for use in large-enrollment first- and second-year science courses. Evidently, instructors are encouraged by their own or their colleagues' evaluation of the technology so that they are willing to try or stick with this new way of interacting with students in the classroom. As the devices, hardware, and software have become less expensive, high school instructors are also experimenting with clickers.3 Teaching research studies *(2, 3)* and personal anecdotes, many of which are presented on Web pages, praise the successful contribution of clickers for enhancing the students' engagement in large-enrollment courses *(4)* and the positive impact clickers may have on final course grades *(5)*. A closer look at these studies indicates that the use of clickers particularly helps students with low grades to maintain or regain their interest in the subject matter. A recent literature review article is available *(6)* focusing on reports of clickers in educational settings.

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. Reaching the second tier: Learning and teching 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.

Bunce, D.M., VandenPlas, J.R., Havanki, K.L. 2006.Comparing the effectiveness on student achievement of a student reponse system versus online WebCT quizzes. Journal of Chemical Education. Vol. 83, 488-494.

The use of computers to gather student responses is not new to science education. Use of electronic response systems, especially in large lectures, dates back to the 1960s *(3).* Research on the effectiveness of this approach has been limited to its influence on increased rates of passing the course *(4).* More work is needed to test the effectiveness of computers and ConcepTests on student achievement. It is this question that led to the incorporation of the Student Response System (SRS) into a second-semester nursing course. SRS is a Web based questioning system *(5)* designed to assist instructors in receiving and analyzing student responses to questions posed in lecture or recitation. In this study, the electronic student response system, SRS, was used primarily as a means of delivering electronic ConcepTests for students working in pairs.

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

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

Zusho, A., Pintrich, P.R. 2003. Skill and will: The role of motivation and cognition in the learning of college chemistry. Int. Jour. Science Education. Vol. 25, 1081-1094.

> This study investigated how students' level of motivation and use of specific cognitive and self-regulatory strategies changed over time, and how these motivational and cognitive components in turn predicted students' course performance in chemistry. Participants were 458 students enrolled in introductory college chemistry classes. Participants' motivation and strategy use were assessed at three time points over the course of one semester using self-report instruments. Results showed an overall decline in students' motivational levels over time. There was also a decline in students' use of rehearsal and elaboration strategies over time; students' use of organizational and self-regulatory strategies increased over time. These trends, however, were found to vary by students' achievement levels. In terms of the relations of motivation and cognition to achievement, the motivational components of self-efficacy and task value were found to be the best predictors of final course performance even after controlling for prior achievement.

Coll, R.K., Treagust, D.F. 2001. Learners' mental models of chemical bonding. Research in Science Education. Vol. 31, 357-382.

> The research reported in this inquiry consisted of a study involving two each of Year-12, undergraduate and postgraduate Australian students. The learners' mental models for chemical bonding were elicited using semi-structured interviews comprising a three-phase interview protocol. Each learner was presented with samples of metallic, ionic and covalent substances, and asked to describe the bonding in the substance. Second, they were shown prompts in the form of Interviews-About-Events (IAE) focus cards depicting events that involved the use of models of chemical bonding. Finally, each was shown prompts in the form of focus cards derived from curriculum material that showed ways in which the bonding in specific metallic, ionic and covalent substances had been depicted. Students' responses revealed that learners across all three academic levels refer simple, realistic mental models for chemical bonding.

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

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

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

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

House, J.D. 1994. Student motivation and achievement in college chemistry. Int'l J. of Instructional Media. Vol. 21, 1-6.

> The initial assessment of learner characteristics is an important component of instructional design models; however, limited attention has been given to the importance of students' initial motivation. The purpose of this study was to investigate the relationship between students' achievement expectancies and academic self-concept and their subsequent achievement in college chemistry. There were three main findings from this study. First, several specific learner characteristics were significant predictors of achievement. Second, students' achievement expectancies and academic self-concept were more significant predictors of performance than

were students' prior achievement and their prior instructional experience. Finally, prior achievement was the only variable to significantly enter the regression equation for predicting students' earning the highest grade possible vs. earning lower grades. These findings suggest that students' academic self-concept and achievement expectancies are significant predictors of overall grade performance in chemistry while prior achievement was the only significant predictor of high grade performance.