

STEM Subject: Earth 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.

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 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 ≤ 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.

Burton, E.P., Mattiati, G.K. 2011. Cognition and Self-Efficacy of Stratigraphy and Geologic Time: Implications for Improving Undergraduate Student Performance in Geological Reasoning. *Journal of Geoscience Education*. Vol. 59, 163-173.

In general, integration of spatial information can be difficult for students. To study students' spatial thinking and their self-efficacy of interpreting stratigraphic columns, we designed an exercise that asks college-level students to interpret problems on the principles of superposition, original horizontality and lateral continuity, and geologic time using text and symbols. The exercise was designed with two goals in mind: to determine the level of student confidence and cognition and to test the effectiveness of this type of exercise in large-enrollment courses. Overall, students performed well on symbolic representations of the columns, but reported low self-efficacy of their interpretations. The opposite occurred with the short-answer questions. Results suggest that these students are more comfortable with verbal questions, but they lack the ability to synthesize complete answers to diverse questions. Students also tended to feel less comfortable with questions where they had to convert text to a symbolic representation. We found this type of assignment to be extremely useful with a large class, as it elicited much information about student learning without taking extensive time to evaluate. Implications for geoscience educators include the need to incorporate techniques to improve the completeness of student responses on problems that require synthesis.

Goldsmith, D.W. 2011. A Case-based Curriculum for Introductory Geology. *Journal of Geoscience Education*. Vol. 59, 119-125.

For the past 5 years I have been teaching my introductory geology class using a case-based method that promotes student engagement and inquiry. This article presents an explanation of how a case-based curriculum differs from a more traditional approach to the material. It also

presents a statistical analysis of several years' worth of student assessment data from both the traditional and case-based curricula. These analyses demonstrate that the case-based method not only improves student learning relative to a traditional curriculum, it also improves students' ability to apply higher-order thinking skills to the study of the earth.

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

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

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

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

Bralower, T.J., Feiss, P.G., Manduca, C.A. 2008. Preparing a new generation to face Earth's future. *Liberal Education*. Spring. 20-25.

As the research interests and the focus of traditional earth scientists are transformed, so too must education in earth system science at colleges and universities across the country change. The required change involved not only the methods we use to teach this new science, but also the essential place of the earth sciences in the panoply of disciplines as traditionally ordered by our academic colleagues. With growing public and political awareness of the significant environmental problems facing the earth in the coming decades, and the realization that issues such as global warming require action on the part of individuals as well as governments, earth system science must establish its place in college curricula to ensure that a new generation of citizens and scientists is prepared to meet future challenges. To earth scientists, all of this is self-evident. But it is not always so within the broader communities of the academy. We hear, for example, that the twenty-first century will be the “Century of Biology.” Earth science courses,

faculty, and departments are often the first casualties of financial exigency and budget insufficiency. Is it possible that in 2050 we will find ourselves wrestling with an earth system we only partially understand as human impacts tip us toward climate, ecosystem, and resource crises of literally life-threatening or apocalyptic dimensions?

We posit that strong research in earth system science and equally strong investments in both teaching the earth sciences and training a new generation of earth system scientists are not optional but essential. The handwriting is on the wall: we have only one earth; we are engaged in a dangerous experiment that involves altering the dynamics of earth systems upon which we are wholly dependent; we do not fully understand how the system works, and we are only beginning to be able to predict our effect on that system.

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

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

Guertin, L.A., Zappe, S.E., Kim, H. 2007. Just-in-Time teaching exercises to engage students in an introductory-level dinosaur course. *J Sci Educ Technol*. Vol. 16, 507-514.

The Just-in-Time Teaching (JiTT) technique allows students to be engaged in course material outside of the classroom by answering web-based questions. The responses are summarized and presented to students in class with a follow-up active learning exercise. College students enrolled in an introductory-level general education geoscience course were surveyed over a two-semester period on their engagement level during lecture and perceived learning of course content. Data show that students are able to reflect on their prior knowledge and construct new knowledge with weekly graded JiTT exercises. Despite increasing and competing pressures outside of the classroom, students reported increased learning and engagement in a course with required weekly assignments.

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

Conceptests are higher-order multiple-choice questions that focus on one key concept of an instructor's major learning goals for a lesson. When coupled with student interaction through peer instruction, conceptests represent a rapid method of formative assessment of student understanding, require minimal changes to the instructional environment and introduce many of the recognized principles of effective teaching that enhance student learning. In this study, instructors from several different institutions developed over 300 conceptests for the

geosciences. These instructors then used this suite of concept questions in a wide range of classroom settings, including large introductory general education Earth Science courses for non-majors at open enrollment institutions, smaller physical geology classes suitable for majors at private colleges, and in introductory geology laboratory settings. Results of pre- and post-class Geoscience Concept Inventory (GCI) testing and qualitative feedback from students and instructors showed that conceptests increased attendance, improved student satisfaction, and enhanced student achievement. Participating instructors found implementation of conceptests into their classes straightforward and required less than 30 minutes of preparation per class. The conceptest question database is available on-line for geoscience instructors.

McConnell, D.A., Steer, D.N., Owens, K.D., Knight, C.C. 2005. How students think: Implications for learning in introductory geoscience courses. *Journal of Geoscience Education*. Vol. 53, 462-470.

Non-major students in introductory geoscience classes exhibit a wide range of intellectual development. Approximately half of these students do not have the skills to understand the abstract scientific concepts traditionally discussed in introductory classes. Many geological concepts will remain unlearned without appropriate activities that build on a foundation of concrete examples. The good news is that these same students can improve their logical thinking skills when they participate in challenging in-class collaborative learning exercises with their more intellectually sophisticated peers. While the exercises themselves are important in promoting the development of higher-order thinking skills, the group interaction also appears to be a significant contributor to the improvement of reasoning.

Caprariis, P.D., Barman, C., Magee, P. 2001. Monitoring the benefits of active learning exercise in introductory survey courses in science: An attempt to improve the education of prospective public school teachers. *The Journal of Scholarship of Teaching and Learning*. Vol. 1, 11.

Introduction of collaborative, active-learning exercises in a traditional lecture-based Environmental Geology course produced measurable changes in student learning. Oral surveys used as part of an assessment strategy suggest that students in the class use material from the exercises in responding to questions long after the subjects were covered in class. In addition, the variance of the grade distribution of the final examination suggests that learning is more uniform across the class than in previous semesters. Implementation of this approach is not limited to small classes; a single instructor can monitor a class of approximately 60 students as they work through the exercise.

Brickhouse, N.W., Dagher, Z.R., Letts, W.J., Shipman, H.L. 2000. Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course. *Journal of Research in Science Teaching*. Vol. 37, 340-362.

Arguments for teaching about the nature of science have been made for several decades. The most recent science education policy documents continue to assert the need for students to understand the nature of science. However, little research actually explores how students develop these understandings in the context of a specific course. We examine the growth in students' understanding about the nature of astronomy in a one-semester college course. In addition to student work collected for 340 students in the course, we also interviewed focus students three times during the course. In this article we briefly describe class data and discuss in detail how five students developed their ideas throughout the course. In particular, we show

the ways in which students respond to instruction with respect to the extent to which they (a) demand and examine evidence used for justifying claims, (b) integrate scientific and religious views, and (c) distinguish between scientific and nonscientific theories.

Trend, R. 1998. An investigation into understanding of geological time among 10- and 11-year-old children. *Int. Jour. Sci Educ.* Vol. 20, 973-988.

This research focused on the understanding of geological time among UK children aged 10 and 11 years. The empirical study, in two stages, involved total of 189 children in activities designed to reveal knowledge and understanding of geological time. The preliminary study with 12 children was designed to identify the most powerful and appropriate techniques to use in the Main Study. It also resulted in some findings concerned with the place of deep time in children's conceptualization of Earth events. The Main Study, with 177 children, involved the sequencing of geological events in three separate but almost identical tasks. Results indicate that children of this age have a general awareness of major events such as the Ice Age and moving continents, but that a clear chronology is almost entirely lacking. Children conceive of events as filling into two distinct time zones: the 'extremely ancient' and the 'less ancient'.

Dove, J.E. 1998. Students' alternative conceptions in Earth science: A review of research and implications for teaching and learning. *Research Papers in Education.* Vol. 13, 183-201.

A considerable amount of information is now available about alternative conceptions in the physical and biological sciences and their implications for teaching and learning. However, a growing number of publications have also appeared which have investigated alternative conceptions about Earth science. Some of these studies have addressed topics taught in geology, geography and science such as conceptions about rocks, earthquakes, volcanoes, the Earth's structure, landforms, weathering and erosion and soil. This paper reviews the literature on these topics, hereto reported across a broad spectrum of papers in science, geological and geographical journals, and presents some new findings. While there are many possible origins for the alternative conceptions identified, it is argued that some of these ideas re founded on various pedagogical practices, such as the imprecise use of language, oversimplification of concepts, use of rote learning, and stereotyping of landforms, as well as on the inadequate use of prerequisite knowledge of students, and the abstract nature of some of the subject matter in Earth science. Moreover, it is suggested that an awareness of, and attention to, these matters would improve teaching and student learning significantly.

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

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