

EDUCATIONAL RESEARCH ABSTRACTS

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Editors' Note: As noted in previous issues of the *Journal of Mathematics and Science: Collaborative Explorations*, the purpose of this Educational Research Abstract section is to present current published research on issues relevant to math and science teaching at both the K-12 and college levels. Because educational research articles are published in so many different academic journals, it is a rare public school teacher or college professor who reads all the recent published reports on a particular instructional technique or curricular advancement. Indeed, the uniqueness of various pedagogical strategies has been tacitly acknowledged by the creation of individual journals dedicated to teaching in a specific discipline. Yet many of the insights gained in teaching certain physics concepts, biological principles, or computer science algorithms can have generalizability and value for those teaching in other fields or with different types of students.

In this review, the focus is on "background knowledge." Abstracts are presented according to a question examined in the published articles. Hopefully, such a format will trigger your reflections about the influence of students' entering mathematical and scientific conceptions (and misconceptions,) as well as generate ideas about your own teaching situation. The abstracts presented here are not intended to be exhaustive, but rather a representative sampling of recent journal articles. Please feel free to identify other useful research articles on a particular theme or to suggest future teaching themes to be examined. You may send your comments and ideas via email to gmbass@wm.edu or by regular mail to The College of William and Mary, P. O. Box 8795, Williamsburg, VA 23185-8795.

Students' Background Knowledge in Mathematics and Science Learning

"Why is our sky blue?" How would you explain the color of the sky to a middle-aged painter, a beginning elementary schoolteacher, a teenage musician, or a five-year-old neighbor? The kind of conversation you might have with a colleague in the physics department about "Rayleigh scattering" is likely to be very different from your discussion with any of these other four individuals about sky color.

What scientific concepts do you need to understand in order to answer why our sky is blue? Spectrum? Wavelength? Frequency? Hue? Gas molecules? Dust particles? What does your painter, teacher, musician, or preschooler need to know to understand

your explanation? What do you need to know about their current understanding to help you decide how to “teach” them the scientific answer? How can you help them think about related but more complicated questions, such as: “What does the sky look like on our moon?” “What color could the sky be on other planets?” [For a short presentation on how the atmosphere makes different colors and suggested learner activities, check out the Newton Apple Teacher Guide at <http://www.ktca.org/newtons/9/sky.html>.]

One of the fundamental, learner-centered principles about teaching and learning is that one’s existing knowledge serves as the foundation of all future learning (Alexander & Murphy, 1998, in *How students learn: Reforming schools through learner-centered education* edited by Lambert & McCombs.) This principle contends that new information is filtered through that “old” knowledge, connected to a network of “old” associations, and organized into “old” ways of representing that knowledge. Without first considering a learner’s background knowledge about a topic, a teacher is unlikely to provide the best explanation or experiences to help the learner develop a more complete understanding of the concept.

In science and math, students often enter the classroom with incomplete and faulty conceptions about the very topics they are expected to learn. If students believe green plants get their food from outside sources just as animals do, or that a baseball hit into the outfield must have both an upward and forward force acting on it after it leaves the bat, those students not only have to learn “new” scientific ideas, they have to unlearn “old” common sense ones. Howard Gardner in *The Unschooled Mind* put it this way, “...young adults trained in science continue to exhibit the very same misconceptions and misunderstandings that one encounters in primary school children - the same children whose intuitive facility in language or music or navigating a bicycle produces such awe.”(p.4) Teachers who do not verify their students’ existing knowledge before planning and implementing instruction, risk the same failure as giving identical explanations about blue sky color to a college educated teacher and a five-year-old.

So what must a teacher discover about a student to help that student learn? A wise old teacher was once asked, “What do you need to know before you teach someone?” The teacher paused, smirked inscrutably, and replied, “More than they

know!” Certainly we believe that is true, but a more informed teacher might add “... and more about what they already know!”

The following articles describe specific research studies in which initial student understanding (and misconceptions) are important components. Findings from these recent research studies can indeed inform college professors and K-12 teachers on the best teaching practices for helping their students better understand important mathematical and scientific ideas.

- **How do students’ prior learning affect their study of beginning algebra?**

Algebra is easy, right? Students just need to know that alphabet letters can stand for numbers and that these letters can have operation signs attached to them. Add 3 to x and get $x + 3$. Subtract 12 from y and get $y - 12$. Multiply z by seven and get $7z$. Of course the student better not think that z signifies addition as in $7\frac{1}{2}$ or place value as in 78! In research with over 2,000 Australian students aged 11 to 15, Stacey and MacGregor discovered that students’ interpretation of algebraic symbolism is strongly influenced by their previous experiences. They describe many sources of student misunderstanding that can interfere with their interpretation of beginning algebra. Students may get confused because they have learned to use letters with other meanings, such as abbreviated words or units of measure. Students can indeed confuse the arithmetic operations in composite symbols such as $7\frac{1}{2}$, 78, and VIII. Students may think of the equals sign as “makes” or “gives” and use it to link parts of a calculation. Students can confuse natural language rules for interpreting temporal sequence with the special algebraic “order of operations.” Remember that students arrive in their first algebra course with substantial prior experiences of symbol systems that are not all helpful in comprehending algebraic symbolism. To improve students’ algebra achievement, Stacey and MacGregor urge algebra teachers to recognize the many possible sources of student misunderstanding and explicitly point them out in their own teaching.

K. Stacey and M. MacGregor, "Ideas about Symbolism That Students Bring to Algebra," *The Mathematics Teacher*, **90**(2) (1997) 110-113.

- **How does elementary school children's informal mathematical knowledge about fraction concepts, especially their symbolic representations for fractions, influence their learning?**

Just when young children finally understand the symbolic meaning of whole numbers, teachers introduce them to fractions! Many researchers have predicted that these students' prior knowledge of symbol systems may lead them to overgeneralize or construct inappropriate meanings when presented with fractions. Nancy Mack conducted an intense investigation of four third-graders and three fourth-graders to document how their informal knowledge affected their learning about fractions. She provided six one-to-one, 30 minute instructional sessions for each child during a three week period, and one follow-up session 14 weeks later. Using a combination of clinical interviewing and cooperative problem solving instruction, she posed problems, asked questions, and encouraged the students to think aloud as they solved problems. After each individual session, Mack planned the next lesson based on the student's informal knowledge and misconceptions about fraction symbols and algorithmic procedures. Mack discovered that four students would give one answer to a fraction problem when presented verbally in the context of a real-world situation, and a different answer to a corresponding problem given symbolically. Even after instruction, five students still would interpret the symbol a/b by saying the numerator was the number of wholes and the denominator was the number of parts in each whole. Mack concluded that her sample of students overgeneralized their knowledge of whole numbers to fractions early in the instruction, and overgeneralized their knowledge of fractions to whole numbers at the end of their instruction. She admits this kind of confusion may be unavoidable as elementary students expand their symbolic concepts for fractions. However, she requests that elementary teachers take the time and effort to acknowledge this potential confusion and create instruction to help students make this necessary transition to a more appropriate symbolic representation of fractions.

N. K. Mack, "Confounding Whole-Number and Fraction Concepts When Building On Informal Knowledge," *Journal for Research in Mathematics Education*, **26**(5) (1995) 422-441.

- **How do chemistry students' understanding of "chemical bond" reflect an *alternative conceptual framework* ?**

Given the extensive research literature about the wide range of learners' alternative conceptions about scientific concepts, especially in physics, Keith Taber explores how generalizable this idea is for chemistry. Using 15 pre-university students, he conducted in-depth interviews, recorded student discussions, administered a concept repertory test, and analyzed students' work samples. He discovered that students typically used the octet rule as an explanatory principle for identifying chemical reactions and chemical bonding. The students' octet rule framework included notions that were incorrect, but also perceptions that represented a more limited understanding of chemical bonding. Taber gives numerous examples of how this partial understanding influences students to hold alternative conceptions of chemical bonding. He believes recognizing this will allow a teacher to understand why a student "sees bond type as a dichotomy; believes in ionic molecules; expects bond fission to always be homolytic; considers 'proper bonds' and 'just forces' to be otologically distinct rather than just different in magnitude; and limits the number of possible successive ionizations to the number of valence shell electrons." (p. 606) Acknowledging these kinds of student interpretations permits teachers to identify appropriate demonstrations and counter-examples to challenge the adequacy of their students' alternative thinking.

K. Taber, "An Alternative Conceptual Framework from Chemistry Education," *International Journal of Science Education*, 20(5) (1998) 597-608.

- **How do chemistry majors conceptualize chemical equilibrium and fundamental concepts of thermodynamics?**

Thomas and Schwenz interviewed 16 volunteer chemistry majors to probe their understanding of equilibrium and fundamental thermodynamics concepts. They discovered that students in an advanced undergraduate class for chemistry majors still showed difficulties with key concepts and topics. For example: 88% of the students did not apply the fundamental equation of the first law of thermodynamics to determine how the first law applies to the presented chemical reaction; 94% did not mention the standard change in entropy and enthalpy as factors that determine the values of equilibrium constants; and, 100% of the students failed to mention the value of ΔG is the change in Gibbs energy for the reaction as written when the reaction occurs under conditions of

constant composition of the reaction mixture. Thomas and Schwenz charge teachers to determine the conceptions even of their advanced students and use a variety of active learning/teaching strategies to create the disequilibrium necessary for students to move toward the experts' conceptions.

P. Thomas and R. Schwenz, "College Physical Chemistry Students' Conceptions of Equilibrium and Fundamental Thermodynamics," *Journal of Research in Science Teaching*, **35**(10) (1998) 1151-1160.

- **How can a teacher assess students' misconceptions using both interviews and multiple-choice tests?**

Most studies of students' misconceptions about science and mathematics have used individual interviews, a time consuming procedure that is usually limited to a relatively few participants. Philip Sadler examined whether a paper and pencil instrument that could be group-administered would provide equally valuable insights into students' alternative conceptions. He constructed a multiple-choice test with 47 items that gave a single correct answer, and several alternative conceptions previously identified through student interviews. For example, "The main reason for its being hotter in summer than in winter is (a) the earth's distance from the sun changes; (b) the sun is higher in the sky; (c) the distance between the northern hemisphere and the sun changes; (d) ocean currents carry warm water north; (e) an increase occurs in 'greenhouse' gases." This instrument was administered to 1,250 eighth through twelfth grade students at the beginning and end of their introductory astronomy courses. Sadler also asked their teachers to predict students' scores on these items at the end of the course. He discovered that his test did indeed diagnose students' conceptions of astronomy and allowed better measurement of students' stagelike progression in conceptual understanding. He also discovered that students of moderate ability would frequently revert to alternative conceptions before returning to the scientifically correct concept. Furthermore, Sadler concluded that the time needed for lasting conceptual change is much longer than teachers believe. (Students in this study only showed one-eighth of the gain in understanding that teachers predicted for their courses!) Based on this research, it appears crucial that test constructors and curriculum developers identify students' alternative conceptions as necessary stepping stones to genuine scientific understanding.

P. Sadler, "Psychometric Models of Student Conceptions in Science: Reconciling Qualitative Studies and Distractor-Driven Assessment Instruments," *Journal of Research in Science Teaching*, **35**(3) (1998) 265-296.

- **What is the relationship between freshmen's prior knowledge, study orientation, and logical thinking ability on their overall performance in a nonmajor's chemistry course?**

Any science professor who teaches nonmajors will almost certainly have experienced a wide range in student performance on course exams and assignments. Previous research on this issue has pointed to students' prior subject matter knowledge, their achievement in science, and their formal reasoning ability as influential factors. BouJaoude and Giuliano chose to examine those factors, and students' approaches to studying, in a large, two-semester, freshman, nonmajor chemistry course (199 students: 114 women and 85 men). In the first semester, they asked the students to complete an Approaches to Studying Inventory (adapted from Entwistle and Ramsden's original instrument), a Test of Logical Thinking (developed by Tobin and Capie), and a demographic questionnaire. Students' grades from their initial hour-long exam in the first-semester and from their second-semester final examination were also obtained. BouJaoude and Giuliano found that prior knowledge was the best predictor of course achievement; that is, students' first-semester, hour-long exam scores were the best predictor of their second-semester final exam performance (accounting for about 25% of the variance). Student scores on the measure of formal reasoning ability, the TOLT, were also statistically significant predictors of students' final exam scores, but this variable only accounted for less than 6% of the variance. They discovered that knowing students' study orientation did allow a significant, but small, improvement in predicting their final exam scores. It appears that students who study using active questioning strategies, relating ideas to other parts of the topic, and expressing intrinsic motivation do better than students who emphasize memorization, rely on teachers to define learning, and prefer extrinsic motivation. However, BouJaoude and Giuliano caution that a balanced study strategy where students memorize key facts, concepts, and generalizations in order to create meaningful relationships among them may indeed be the best approach. They recommend all teachers of nonmajor science students pay close attention to those students' prior knowledge, logical thinking abilities, and methods of studying in order to provide the best instruction to address deficiencies in their entering capabilities.

S. B. BouJaoude and F. J. Giuliano, "Relationships Between Achievement and Selective Variables in a Chemistry Course for Nonmajors," *School Science and Mathematics*, **94**(6) (1994) 296-302.

- **How does reform teaching influence elementary students' learning about fractions?**

"Six people will share three brownies. How much will each person get if each gets a fair share?" An elementary school teacher who values constructivist reform might engage students with this problem in a lesson that builds on their current understanding, that requires them to solve the problem, and that allows the teacher to monitor and expand the mathematics that emerges from the students' efforts. Another teacher who values a procedural approach to problem solving might introduce this fair-share problem by drawing three rectangles on the chalkboard, partitioning each rectangle into two parts, and calling each part "one-half." This teacher would likely expand this approach to other shapes and other number of parts in order to help the students conceptualize the problem in terms of fractions. A third teacher who values student discovery might introduce the problem by providing students with manipulative materials to explore possible solutions in small groups. After discussion with tablemates, the teacher asks students to share their solution and celebrates student work by displaying it on the class bulletin boards. Will students learn fractions equally well in each of these three instructional situations?

Saxe, Gearhart, and Seltzer investigated this question by observing 19, upper elementary teachers and their classrooms, representing both traditional teachers who taught fractions using school-approved textbooks, and reform teachers who taught fractions using constructivist oriented units (*Seeing Fractions* and *My Travels with Gulliver*). Teachers were observed and videotaped during whole-class discussions when teaching fractions. Using the observational field notes and videotapes, the investigators rated teachers on the alignment of their classroom practices with reform principles; specifically, the teachers' level of integrated assessment and their level of conceptual issues integrated with problem-solving procedures. Students were pre-tested to categorize their knowledge of fractions as "with rudimentary understanding" (313 students) or "without rudimentary understanding" (168 students). Students' achievement was measured with a post-test containing both typical textbook fraction problems and more open-ended, non-routine problems associated with reform-oriented curricula. Saxe,

Gearhart, and Seltzer found that, for children with a rudimentary understanding of fractions, alignment of practice with reform principles was a strong predictor of student achievement on the problem solving items. For children without a rudimentary understanding of fractions, alignment with reform practices only predicted student learning when the instructional alignment was above average. No evidence was found that student performance on computational post-test items was influenced by increasing alignment of classroom practices with reform principles.

Saxe, Gearhart, and Seltzer conclude that the learning of fractions involves a complex interaction of students' prior understandings, teachers' classroom practices, and their assessment of students' problem solving and computational abilities.

G. B. Saxe, M. Gearhart, and M. Seltzer, "Relations Between Classroom Practices and Student Learning in the Domain of Fractions," *Cognition and Instruction*, **17**(1) (1999) 1-24.

- **What is the relationship between pre-service teachers' alternative conceptions of science and their science teaching efficacy?**

If elementary education teachers also hold misconceptions and alternative conceptions of science, how prepared will they be to teach their own students? Can these alternative conceptions be identified during their initial teacher preparation so faculty can provide the necessary instruction to remedy this situation? Schoon and Boone surveyed 619 pre-service elementary education teachers in science methods classes at ten U.S. universities. They administered an instrument that identified twelve alternative conceptions of science (constructed by the investigators) and an instrument that measured science teaching efficacy (modeled on Enochs and Rigg's instrument). While there was no overall significant relationship between the number of alternative conceptions held and a pre-service teacher's science teaching self-efficacy, they did discover an interesting pattern. Pre-service teachers who held the following alternative conceptions also showed low self-efficacy scores: "planets can be seen only through telescopes; dinosaurs lived at the same time as cavemen; rusty iron weighs less than the iron that it came from; electricity is used up in appliances; and north is toward the top of a map of Antarctica." They interpret this finding as evidence that pre-service teachers who maintain these

conceptions face a “critical barrier” to a full scientific understanding that would cause them to struggle in science courses, and feel less able to teach science to others.

Schoon and Boone recommend that specially designed, science content courses utilize active teaching methods that relate concepts, avoid excessive lecturing and memorizing, build on students’ previous experiences, and focus on overcoming students’ alternative conceptions.

K. Schoon and W. Boone, "Self-Efficacy and Alternative Conceptions of Science of Pre-service Elementary Teachers," *Science Education*, **82**(5) (1998) 553-568.

- **Where can I get further information on how to teach math and science more effectively?**

A good first step can be found free and easily accessible on the Web (<http://stills.nap.edu/readingroom/books/str/>) in the Science Teaching Reconsidered Handbook. Here, you will find eight chapters produced by the Committee on Undergraduate Science Education for the National Academy Press. Chapter 4 focuses on misconceptions as a barrier to understanding science. Specifically, it addresses the role of misconceptions in the learning process, describes common science misconceptions, and provides methods to identify and break them down. Only when teachers identify their students' misconceptions, provide a forum for students to confront them, and help those students reconstruct and internalize their knowledge based on scientific models, will true conceptual change be accomplished. Without such deliberate teacher efforts, students are unlikely to surrender their previously held beliefs rooted in the power of everyday experience. ■