EDUCATIONAL RESEARCH ABSTRACTS

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Editor's Note: *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.*

While the teaching topic or instructional strategy will always guide the selection of journal articles presented, there are certain academic journals that typically publish research-based articles or practitioner experiences dealing with math and science teaching from elementary school through university level. If you are unfamiliar with any of the following journals, you may find perusing a recent issue to be a surprising -- and rewarding -- source of teaching and learning ideas.

- *Journal of College Science Teaching*
- *Journal of Research in Science Teaching*
- *Research In Collegiate Mathematics Education*
- *Teaching Children Mathematics*
- *Journal For Research In Mathematics Education*
- *The Mathematics Teacher*
- *The College Mathematics Journal*
- *The American Biology Teacher*
- *Computer Science Education*
- *Journal of Chemical Education*
- *Physics Teacher*
- *Physics Education*

The Journal of Mathematics and Science: Collaborative Explorations Volume 1 No 1 (1997) 91-102

- *American Journal of Physics*
- *Journal of Geological Education*
- *Journal of Geoscience Education*
- *Journal of Science Education and Technology*
- *Teaching PreK-8*

In this first review the focus is on "active learning." Abstracts are presented according to a question examined in the published articles. Hopefully, such a format will trigger your reflections about exemplary math/science teaching 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. Please send your comments and ideas via email to gmbass@facstaff.wm.edu *or by regular mail to The College of William and Mary, P.O. Box 8795, Williamsburg, VA 23185-8795.*

Learning Mathematics And Science Through Active Learning

In recent years national professional organizations have developed new curriculum and teaching standards for mathematics and science education. The National Council of Teachers of Mathematics in 1989 provided specific standards that emphasize active learning. "First, 'knowing' mathematics is 'doing' mathematics. A person gathers, discovers, or creates knowledge in the course of some activity having a purpose....instruction should persistently emphasize 'doing' rather than 'knowing that.'" With respect to student activities, the NCTM standards used two principles to guide their descriptions. "First, activities should grow out of problem situations; and second, learning occurs through active as well as passive involvement with mathematics." Finally, the standards provide specific examples of "active learning" in math. "This constructive, active view of the learning process must be reflected in the way much of mathematics is taught. Thus, instruction should vary and include opportunities for--

- appropriate project work;
- group and individual assignments;
- discussion between teacher and students and among students;
- practice on mathematical methods;
- exposition by the teacher."

The full set of NCTM standards can be found on the World Wide Web at the Eisenhower National Clearinghouse for Mathematics and Science Education (ENC) *http://www.enc.org/reform/journals/ENC2280/nf_280dtoc1.htm*.

The National Science Education Standards published in 1995 also continue this theme of active learning. "Student understanding is actively constructed through individual and social processes." From this key principle specific teaching standards were developed, among them Standard A: "Teachers of science plan an inquiry-based science program for their students." Consistent with the NCTM standards, the National Science Education Standards emphasize that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science." The full text of the National Science Education Standards can be found on the World Wide Web at National Academy Press site *http://www.nap.edu/readingroom/books/nses/html/*

Does the use of active learning strategies enhance K-12 and college students' learning? As more teachers consider utilizing "active learning," it becomes critical to understand the issues involved in such an instructional strategy. What kinds of instructional objectives are best facilitated through active learning? When using active learning with various mathematical and science topics, what factors should a teacher consider? What have been the conclusions of empirical research studies examining active learning in the classroom? The following set of articles provides a representative sample of recent academic writings on the subject of active learning approaches.

- ***How well does active learning work in an introductory college biology course?***

A new two course sequence in introductory biology was developed to emphasize experience-based group learning rather than traditional lectures. This redesigned course required groups of students to work in project groups on topics such as the design of a closed life-support system for long-term space flight or the design of a unicellular organism to colonize a fictitious planet. An independent investigator examined two different groups of students (49 and 40 students respectively) who took these courses. He measured their attitudes and subsequent performance in advanced biology courses over a 15 month period. The authors report that many students would have preferred traditional lectures on traditional biology topics. However, they also acknowledged that this new project approach had increased students' interest in learning more biology and in investigating a wider array of biologically related problems. They also found differences in student preferences for working on projects and working in groups between the two classes of students studied. Follow-up interviews discovered that as biology majors preceded with their education, the value of project-oriented instruction became more evident to them. No differences were found on grades in three advanced biology courses when students who had taken the project biology course were compared to other students who had taken a more traditional introductory biology course. The authors conclude that this project-oriented approach requires a substantial time and effort commitment from both faculty and administrators, but that this investment is necessary if the process of creative scientific problem-solving is to be developed in students.

L. Goodwin, J. E. Miller & R. D. Cheetham, "Teaching freshman to think - does active learning work?", *BioScience*, **41** **(10)**, 719-722, (1991).

- ***How can group activities encourage active learning in an introductory college chemistry course?***

John Frey describes an instructional approach for his introductory chemistry class in which he required teams of two or three students to complete several written assignments throughout the semester. These "homestudy" assignments were developed to encourage both cooperative group behavior and written presentations of the group's ideas. For example, sample questions in the first homestudy assignment included "What is the difference between a theory and a law?" and "What is meant by the term 'metalloid' and which elements are called metaloids?" Sample questions from the second assignment included "Compare kinetic energy and potential energy." and "What is the difference between an ion and a molecule? Give examples of each." Typically, these questions represented topics covered in the textbook, but eliminated from Frey's lectures so that he could cover more complex topics more slowly or allow more in-class discussion and group activities. Anonymous end-of-course student evaluations of these group assignments revealed that 94% of the students found the assignments helpful (either as motivation to read the text, guides for better understanding of broad concepts, or preparation for the course exams). However, 17% of the students felt that working in small groups was a bad idea while 67% expressed positive attitudes to the group work. Frey concludes that the use of homestudy group assignments can be an effective way to cover necessary course topics while at the same time freeing classtime for challenging activities that stimulate more active learning.

J. T. Frey, "Homestudy assignments: An experiment in promoting active learning in introductory chemistry", *Journal of College Science Teaching*, **26** **(4)**, 281-282, (1997).

- ***To what degree does the use of student journals encourage more active learning in a high school physics course?***

In an attempt to stimulate more active rather than passive learning, a high school physics teacher implemented a mandatory journal in his college preparatory physics classes. K. David

Pinkerton calls his approach the Active Mental Processing Journal. It is a very structured, language-rich teaching technique that requires students to make three different journal entries per school day. These three daily entries include (1) class notes with personal embellishments that help them remember and understand key concepts; (2) a physics question related to the class topic, a newspaper article, or other daily event; and (3) an application of a physics concept mentioned in their journal, noting how it is an illustration of that concept. Pinkerton gives the students the last 2 to 4 minutes of each class to write the question and application in their journals. The journals are collected every three weeks and graded according to a specific set of criteria given to students. Pinkerton administered the 29-item Force Concept Inventory (designed by Hestenes, Wells and Swackhamer in 1992) as a pretest and posttest to measure the impact of this journal technique. The pretest-posttest change in the journal-oriented course was from a class mean of 8.3 to a mean of 19.1. Pinkerton's previous year's physics students, who took the course without the journal requirement, had scored a mean of 14.9 on the posttest administration of the Force Concept Inventory. He concludes that the use of this low-cost journal requirement is consistent with other active learning strategies that foster more "interactive engagement" on students' part. Pinkerton recommends teachers use such language-rich teaching techniques to foster active mental processing and help students internalize physics knowledge.

K. D. Pinkerton, "Low-tech solutions, high-tech results", *The Physics Teacher*, **34**, 30-34, (1996).

- ***What active learning techniques may promote independence and responsibility in organic chemistry?***

Because organic chemistry is often used as a "gatekeeper" course for further professional studies, a professor teaching that course is often faced with students who grudgingly take the course, but question the relevance of the material to their lives and career plans. Marlene Katz wanted to change this perception by designing a course that emphasized greater student ownership, active learning, accountability, and control. She created an organic chemistry course based on a Student-Directed Learning (SDL) philosophy that emphasizes the recognition of student affect and attitudes in learning, the need for support and incentives for struggling students, and the desirability of accessible and relevant course content. Katz reorganized course content around "Big Ideas" such as symbolic language, polarity, reactions, and mechanisms. These central themes were connected to specific skills that were taught in a hierarchy from simple to complex cognitive operations. She also rearranged classes from a traditional lecture to a "reverse Socratic" method where students initiate the teacher-student dialogue through their questions from assigned readings or lab skills. After this initial question/answer session, students choose from a menu of in-class activities aimed at developing the skills connected to the Big Ideas. Often these activities involve group work utilizing peer teaching with the professor being the "coach" who moves among the groups. Student assessment was done through a Mastery Learning strategy where alternative quizzes may be retaken until there are no significant errors in the student's work (thereby stressing the "process" of learning rather than the "performance" of learning.) During the four years she has used this student-directed technique, the average score on the ACS Organic Chemistry Exam has steadily increased to a class mean of 73 (compared to a class mean of 55 over the previous four years of the traditionally taught organic chemistry course.) More importantly, Katz reports the percentage of students scoring below the 50th percentile level has decreased from an average of 41% during the previous four years to less than 9% during the four years of the SDL classes. However, she acknowledges that some of the most valuable classroom innovations may not elicit warm responses from students. During her four years experience she admits to being dismayed at the unwillingness of many students to take over the direction of the class. She also was surprised at the negative responses of some students to their new role. Nevertheless, she concludes that students learning to take responsibility for their own learning can make all her frustrations and challenges worthwhile.

M. Katz, "Teaching organic chemistry via self-directed learning", *Journal of Chemical Education*, **73 (5)**, 440-445, (1996).

- ***How can partnerships between experienced teachers and disciplinary experts improve classroom instruction and student learning?***

Malcolm Wells was a high school physics and chemistry teacher who returned to Arizona State at the age of 49 to initiate doctoral research in physics. He had been a "hands-on" teacher for over two decades ever since his early experience with PSSC and Harvard Project Physics. He embraced a student-centered inquiry approach based on the *learning cycle* of Robert Karplus. Nevertheless, his students' performance on the Halloun and Hestenes Mechanics Diagnostic test was no better than students taught by traditional lecture-lab methods. Through his work at Arizona State, Wells was introduced to David Hestenes's theory of physics instruction with modeling. This modeling approach organizes physics content around a small number of basic models such as the "particle subject of a constant force." Students learn how models in physics are conceptual representations of physical objects and processes. They are introduced to representational tools such as force diagrams and motion maps that are essential for competent modeling and problem solving. The students also receive a detailed analysis of the procedural knowledge necessary for constructing scientific models. Wells adapted Hestenes's ideas into his own teaching by creating a modeling cycle which moves students through all aspects of model development, evaluation, and application in concrete situations. Instead of encouraging the "plug-and-chug" problem solving technique (plugging numbers in equations-and-chugging a little arithmetic), Wells and Hestenes take the position that every physics problem is solved by creating or adapting a known model to the specific problem. Evidence of the effectiveness of the modeling method was examined using the Force Concept Inventory and the Mechanics Baseline test as pretest and posttest measures. Students taught by teachers using traditional instruction were uniformly poor on those measures while students taught by teachers using the modeling method were dramatically better. Wells, Hestenes, and Swackhamer developed five-week summer workshops for introducing their modeling method to physics teachers. They concluded that teacher expertise is the critical factor in improving high school physics. They believe that teacher expertise can only be acquired through lifelong professional development during which the teacher draws on the resources of the physics community - specifically, partnerships between experienced teachers and physicists involved in educational research.

M. Wells, D. Hestenes and G. Swackhamer, "A modeling method for high school physics instruction", *American Journal of Physics*, **63** (7), 606-618, (1995).

- ***What role can physics projects play in helping high school students understand physics?***

In order to encourage her students to realize that "physics is everywhere," Joan Mackin decided to incorporate a more authentic way for her high school students to apply their knowledge. Her strategy was to require students to complete a project where they chose a physics-related topic (such as physics applications in other content areas, physics lessons for middle and elementary school, or student-developed experiments) and also chose the presentation method (such as the format of a poster display, oral talk, model, video tape, or lesson plan and also whether the project was an individual or group effort.) The projects were typically a semester long effort and equivalent to a regular test grade. The projects were judged according to the amount and accuracy of the research used and the quality of the presentation (pertinent information, interest level, and creativity.) Mackin believed these projects allowed students to explore areas of personal interest and also draw on their individual talents to produce the projects. Her evaluation of the success of this approach is that students will share their projects with others and talk about the projects with understanding. Yet she acknowledges that her efforts to teach physics in interesting and effective ways are more guided by intuition, student feedback, and classroom observation than by systematic collection of student learning evidence.

J. Mackin, "A creative approach to physics teaching", *Physics Education*, **31** **(4)**, 199-202, (1996).

- ***How could problem-based learning be used in a college biology course?***

Problem-based learning (PBL) is an instructional strategy requiring students to examine real-life problems, construct a knowledge base to address the problem, and justify the "best" solution with supporting evidence. Among the major features of PBL are (1) a focus on ill-structured, complex problems; (2) a commitment of several weeks to several months to work on a single problem; (3) the development of an entire curriculum around problems, not just an application of learned concepts; and (4) a change in teachers' roles as "cognitive coaches" guiding student inquiry rather than "knowledge dispensers." To implement PBL in an upper division biology course, Arámbula-Greenfield began by developing a list of problems that were ill-defined, complex, interesting, and required research data to validate a best course of action. For example, one of her problems identified the question of whether there were gender-related factors in the survival rates of patients undergoing treatment for heart attacks. She also determined that her students could access adequate research materials to analyze any of the problems they selected. She had her students work in teams of four or five students investigating one problem each six weeks of the semester. Most of the students' time is spent researching the topic outside of class. Her role was to support their efforts by providing feedback to each team on their research, analysis, and interpretation. In order to assess each student's understanding, Arámbula-Greenfield requires each individual to write a research paper reflecting his or her findings and each team to share their group findings with the rest of the class. Student evaluation of this PBL approach has been uniformly more positive on end of course evaluations than student evaluations in the previous traditional seminar course. Her experience with PBL lead her to conclude that it does not appeal to all students, especially those who prefer more competitive, abstract, and directed learning experiences. She also acknowledges that an instructor may view the new "cognitive coach" role as more challenging than the traditional role of "knowledge dispenser," She admits that students will acquire less breadth of knowledge with PBL which may make PBL inappropriate for some courses.

Because PBL is typically a new experience for students, they may become frustrated in trying to decide the amount of time and effort to be devoted to each problem. Nevertheless, Arámbula-Greenfield believes PBL can be an effective way for learning academic content, practicing independent learning, and applying critical thinking skills.

T. Arámbula-Greenfield, "Implementing Problem-Based Learning in a College Science Class", *Journal of College Science Teaching*, **26 (1)**, 26-30, (1996).

- ***What kinds of simple teaching devices can make active learning practical in the classroom?***

Believing that constructivistic, active learning approaches are necessary for effective student learning is not enough to make teachers change their traditional teaching techniques. These alternative, active learning techniques must also be usable in the everyday classroom. Richard Weisenberg, a college biology professor, proposes a simple yet effective way to allow students to engage in a variety of active learning activities. In his nonmajor biology classes he has been using "post-it notes" as low-tech instructional aids to create a variety of lessons. Teams of two or three students use the "post-it notes" to create concept maps of course concepts. Within the Learning Cycle method of A. E. Lawson (Exploration, Term introduction, and Concept application), Weisenberg has his students use the "post-it notes" for chemical modeling. He also uses them as models for chromosomes and genes and for any multi-step biological process such as glucose metabolism. Since one of the primary goals in the constructivist approach is to identify initial student understanding (or misunderstanding) in order to build new understanding, Weisenberg believes that familiar, concrete objects such as "post-it notes" can make a more visible link between students' existing concepts and new understandings. Using end-of-course evaluation questionnaires in the two courses where he used this technique, Weisenberg found students liked the group work especially the "post-it notes" activities. In a class of elementary education majors, over half commented they would use "post-it notes" in their own lessons when they became teachers.

R.C. Weisenberg, "Appropriate technology for the classroom - Using "post-it notes©" as an active learning tool", *Journal of College Science Teaching*, **26 (5)**, 339-344, (1997).

- ***What kind of inservice program can make hands-on science the predominant mode of instruction in elementary schools?***

Professional development programs for improving the quality of teaching science have generally focused on developing teachers' knowledge of science and creating more positive attitudes toward science. Observations in schools have often found that many teachers support the active learning goals of science education but have difficulty implementing those practices in their classroom. Therefore, an inservice program was developed to engage teachers in scientific inquiry rather than hear persuasive lectures on the importance of hands-on science. Over one academic year, twenty-eight elementary teachers were trained to be "mentor teachers" in the use of hands-on science investigations. During the subsequent summer these mentor teachers created 72 hands-on science lessons, each one identified for a specific K-5 grade level. Three Saturday workshops (a total of 20 hours) were held at each elementary school in the district led by these mentor teachers. At each of the workshops teachers worked in small groups on a variety of hands-on investigations appropriate for their own students. To evaluate the effectiveness of these mentor/colleague workshops, a teacher questionnaire was administered prior to the first workshop participation and as a posttest upon completion of the final workshop. Only the data from those teachers who had attended all twenty hours of the workshops were analyzed (Unfortunately only 48% of the 200 teachers who participated in the project met this criterion.) The analysis of the workshop evaluation questionnaire revealed a significant positive change in these teachers' attitudes toward teaching science and in their self-reported understanding of science. However, the teachers who attended the workshops did not significantly increase their classroom time for teaching science (teachers' average was about 145 minutes per week). They did indicate a change in the type of science instruction they used - more student hands-on investigations (from an average of 23 minutes per week to 54 minutes per week.) Because this district was only in the third year of implementing the hands-on workshops, no attempt was made to examine student science achievement as the ultimate outcome measure. Nevertheless, Shapley and Luttrell are encouraged that the mentor/colleague inservice approach reduced elementary teachers' anxiety toward science and increased their willingness to use active learning strategies with their students.

K.S. Shapely and H.D. Luttrell, "Effectiveness of mentor training of elementary colleague teachers", *Journal of Elementary Science Education*, **4 (2)**, 1-12, (1992).

- ***How can elementary and middle school teachers learn to teach chemistry with hands-on activities?***

Davis and George agree that teacher experience, teacher attitudes, and available materials can be a major barrier to implementing active learning in elementary and middle schools. They recognize that many K-8 teachers want to use hands-on activities with their students, but lack the academic training in specific science disciplines. They also believe that teachers overwhelmingly prefer to learn about new ideas and techniques from colleagues. Based on these premises, Davis and George designed a professional development program to prepare selected teachers to utilize hands-on activities to teach simple chemistry, to provide inservice workshops for their colleagues, and to serve as resource persons within their school districts. Teachers participated in an initial three-week summer workshop, a three-day session during the next February, and a three week workshop during the subsequent summer. During May of that subsequent academic year the teachers returned for a one day final evaluation of the project. Using the Shrigley and Johnson Science Attitude Scale as a pretest-posttest measure, these researchers found a strong positive improvement in the teachers' attitudes toward science. Using an 85-item chemistry content test they developed as a pretest-posttest measure, they found the teachers went from a mean of 52 to a mean of 62 during the two year project. An independent project evaluator added that "from the teachers' subjective perspectives, the methods and activities taught in this program, substantially improved young students' involvement in, knowledge of, and enthusiasm for science." However, no attempt was made to assess the students' knowledge of chemistry before and after changes in teachers' instructional activities. Davis and George conclude that programs such as theirs can indeed lead to a cadre of experienced teachers becoming inservice science specialists even though their initial college experiences lacked such a science emphasis.

S. A. Davis and A. George, "Chemistry for children: A program in precollege chemistry for elementary and middle school teachers", *Journal of Chemistry Education*, **74** **(1)**, 59-61, (1997).

- ***What can be the long term impact of a hands-on science workshop for middle school teachers?***

Consistent with a constructivist philosophy that hands-on science is the best foundation for developing middle school students' scientific interest and understanding, Hadfield and Lillibridge offered a one-week summer workshop emphasizing scientific process skills. Pretest-posttest data on the forty teachers who attended the workshop revealed significant improvements in knowledge of science concepts and in science teaching confidence. Visits to the teachers' classroom during the following academic year indicated they were using workshop materials and had disseminated these hands-on activities among their colleagues. A follow-up questionnaire was mailed to all forty teachers two years after the initial workshop to determine the lasting effects of that inservice experience. The return rate was 82.5% of the initial forty teachers. The vast majority of these respondents (88.5%) reported they spent either more time or equal time teaching science as they had the previous year. Nearly two-thirds of the responding teachers (64%) also indicated they thought their students enjoyed science more this school year than the previous year. Hadfield and Lillibridge conclude that the lasting effects of the hands-on science workshops, at least over the first two years, are a result of five key elements: (1) an introductory session on the importance of science education; (2) teacher construction of materials and guided practice; (3) teacher dissemination of activities; (4) administrative support; and (5) follow-up visits to their schools.

O. D. Hadfield and F. Lillibridge, "Can a hands-on, middle grades science workshop have staying power?", *The Clearing House*, **66 (4)**, 213-217, (1993). ■