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Undergraduate Reform in Science Courses:
A Review of the Research Literature

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Abstract

Reform in Undergraduate Science Courses: Themes from the Research Literature

Reports document deficiencies in K-12 and higher education in teaching science. These concerns, expressed in documents beginning with *Nation at Risk* (1983), led to new standards such as *National Science Education Standards – NSES* (1996), *Benchmarks for Science Literacy, Project 2061* (1993), *Shaping the Future* (1996), *Educating Teachers of Science, Mathematics and Technology* (2001), *College Pathways to the Science Education Standards* (2001) and *No Child Left Behind* (2001). The standards provide criteria that can be used to judge whether particular actions will serve the vision of a scientifically literate society. They bring coordination, consistency, and coherence to the improvement of science teaching (National Research Council [NRC], 1996).

Effective K-6 science education reform cannot be separated from standards-based reform in undergraduate science (Lederman & Gess-Newsom, 1999). The literature documents common features of introductory science courses turning off students from taking more science courses or from a major as: lack of relevance, passive student roles, emphasis on competition, and focus on algorithmic problem solving (Tobias, 1990, 1992; Seymour, 1995). To address standards-based reform recommendations, suggestions for effective undergraduate science courses for pre-service teachers include course experiences that involve connections between scientific ideas; provide social, historical, and philosophical context; include meaningful laboratories; teach for inquiry; involve diverse learners; and address important unifying themes (Floden et al., 1995, Lederman

& Gess-Newsome; Sunal et al, 2001). Higher education faculty members are under pressure to create increasingly effective science teaching to achieve congruency with recommendations found in major reports on undergraduate science and pre-service teacher education (Magner, 1992; Sunal & Bland, 2004).

In response to calls for reform and to the perception that reform is needed, higher education faculty members have been reported as attempting to improve the effectiveness of undergraduate science courses (Fedock, Zambo & Cobern, 1996; Barinaga, 1991). The central question addressed by the analysis reported here is “What is the current extent and impact of efforts to offer reform coursework at the undergraduate level, particularly to pre-service teachers?”

To respond to the central question, the related literature from 1999 – 2006 was examined to identify patterns. The literature reviewed from 1999 to the present included 79 articles, books, reports, or position statements. None of the studies could be described as experimental. The most common group in the literature was that of program descriptions and general references aimed at researchers involved in the reform effort (47%, N = 37). Another group included surveys of professors and/or students about their experiences with reform programs and/or courses (10%, N = 8). A small group of studies focused on student achievement of science content knowledge (8%, N = 6). The remainder of the studies, (45%, N = 51) were a mix of case studies, observations, and other measurements of reform classes and the teaching and learning occurring within them.

Of the 79 publications examined, 28 studies were selected for further review based on whether the research was quasi-experimental, and/or used case studies to examine a reform effort in undergraduate science. Each study was then reviewed to identify the type of study, subjects,

measurement instruments utilized, outcome variable, course content (if applicable), and overall results and conclusions. The selected literature was analyzed to identify themes from the patterns (Miles & Huberman, 1994). This analysis yielded twenty themes with no themes representing the preponderance of studies.

Further analysis of the studies yielded two major thematic strands with one relating to faculty and the other to students. The faculty strand was further subdivided into the major themes of collaboration among faculty and the use of inquiry-based teaching in science with undergraduate students. The second theme, students, was initially divided into two strands, works dealing with undergraduate student content achievement and those dealing with science achievement and inquiry-oriented teaching in the classrooms of teachers who had been reform course participants. Each of these strands was further subdivided into sub-themes. The analysis reported below is organized by the two major themes and then by the strands and sub-themes each major theme incorporates.

Faculty

Collaboration

Collaboration and its role in efforts at undergraduate science reform was a central component of seven reports: Ballone-Duran, Czerniak, and Hney (2005); Wainwright, Flick, Morrell, and Schepige (2004); Sunal, MacKinnon, Raubenheimer, and Gardner, (2004), Blackwell (2002); Krockover, Shepardson, Adams, Eichinger, and Nakhleh (2002); Sunal, (2001) and Bland-Hodges (1999). Five sub-themes were identified within the reports: collaborative teams, administrative support, instructional grants, focused reform, and collaborative action research.

A sub-theme found in all of these studies except for Wainwright et al. is that of the use of *collaborative teams*. Course reform is described as most effective when the planning and implementation are shared, often between a small team of faculty. Sunal, et al. (2001) and Bland-Hodges reported on teams of three that include a faculty member from science and one from teacher education, and an administrator. Blackwell reported a meta-ethnography where teams were more broadly conceived as partnerships and included a state education agency, a higher education research institution, one or more teacher education colleges, and one or more school systems. Krockover et al. focused on teams of science faculty as did Ballone-Duran et al. Networks of teams and other faculty members were found effective as supports for an individual team (Sunal, et al. 2001; Bland Hodges). Regardless of the size of the team or how it may be networked, interpersonal skills and a sense of trust were identified as necessary for effective team collaboration (Sunal, et al. 2001; Bland Hodges).

It should be noted that some team configurations include administrators. Such a configuration recognizes the importance of *administrative support*, a second sub-theme found in four of the studies. Support is integrated into a team when one member is an administrator. Administrators were helpful in garnering collegial support for reform efforts from other faculty. They also supported a reform effort by working with faculty on appropriate scheduling of classes, on setting appropriate class sizes, on providing graduate student assistance when needed, and importantly, in taking the time and effort spent on reform into consideration when making decisions about merit pay increases and tenure and promotion (Sunal et al, 2004, 2001; Krockover et al., 2002; Bland-Hodges, 1999). Hence, these studies support the notion that proactive administrative support is necessary for the planning and implementation of undergraduate science course reform.

Additional support in the form of *instructional grants* is a third sub-theme discussed in two studies. Because of the time and planning required, instructional grants can take several forms including additional graduate assistance, the purchase of new or additional technology, or some faculty release time. Outside instructional grants in the range of \$20,000 - \$30,000 are reported by Bland-Hodges (1999) and Sunal et al (2001). These researchers indicated that internal grants also were a means of initial support for reform efforts closely related to administrative support. They noted that the range of external and internal support should be consistent with the extent and type of reform effort.

As faculty collaborate in reform efforts, *focused reform* is a fourth sub-theme found in four studies. Krockover et al (2002) reported that a focus on one topic of reform at a time such as the use of inquiry, technology, cooperative learning groups, or varied forms of assessment resulted in more progress than did a global approach. Work by Staples (2004) and Sunal et al. (2004) supported this conclusion. These studies noted that an entire course is complex consisting of components including content, instructional strategies, and assessment. The course can aim at deeper understanding of content, greater use of critical thinking skills, and/or a sound understanding of the nature of science. Because of the complexity, collaborative teams may be overwhelmed by taking on too many components at a time. Particularly when reforming an existing course, effective collaborative teams were reported as beginning with one or a few components. These instructors expected to become proficient at using and incorporating these components over several semesters rather than in one semester. As some confidence was gained with new components, additional ones were incorporated. As well as focusing on incremental change when moving into reform of science coursework, Sunal et al. (2001, 2004) further noted

that aligning reform efforts to the goals of the reform rather than attending to the barriers that must be overcome, resulted in a more effective focus.

The fifth and final sub-theme is that of *collaborative action research by faculty teams*. Sunal et al (2001, 2004) report that action research projects enabled faculty teams to address specific problems in implementing reform and to test out solutions. Carrying out action research projects strengthened collegiality and the focus of the reform. Faculty were able to discuss and modify reform elements based on targeted data they collected providing a greater confidence in the effectiveness of the solutions they tested. They saw course improvement as a result of their action research and then were more able and willing to take on another problem and try to solve it. Rather than falling back into traditional instruction because of a problem that has arisen with the reform, their willingness to continue with the reform were enhanced.

Use of Inquiry-Based Teaching in Science with Undergraduate Students

Reform efforts in undergraduate science teaching aim at the incorporation of inquiry-based teaching consistent with the strategies and focus identified in national science standards documents. Eight of the reports analyzed dealt with inquiry-based teaching: Ballone-Duran et al. (2005); Tinoca, Upadhyay & Luft (2005); Weld and Funk (2005); Wainwright et al. (2004); Staples (2004, 2002); Sunal et al. (2004); Krockover et al (2002); and Sunal et al. (2001). Six sub-themes were identified within these reports: cooperative learning groups, modeling, linking concepts to real world examples, assessment, action research on course strategies, and incremental change.

Cooperative learning as a component of undergraduate science course reform is the first sub-theme and was stressed in two reports. Krockover et al. described the Collaborative Action-Based Research (CABR) program that focused on greater implementation of inquiry-based

teaching to emphasize conceptual understanding in undergraduate science courses. Faculty in the CABR science program provided opportunities for their students to engage in cooperative learning experiences. Staples (2004) described the use of cooperative learning experiences among students in a reform undergraduate science class and compared these students with those in a traditional science class. Both studies reported that students in the reform class demonstrated greater scientific literacy. Later, as classroom teachers, these course graduates used more inquiry-oriented teaching in science with their students.

Modeling of inquiry strategies and techniques as another component of science course reform was described in three studies: Krockover et al. (2002); Ballone-Duran, Czerniak, and Huey (2005), and Staples (2002). In the CABR program, Krockover et al. found modeling a component used by science faculty to facilitate inquiry. Scientists collaborating to reform coursework were found to make pedagogical changes such as the use of modeling when collaborating with educators in a study by Ballone-Duran, Czerniak, and Huey. Staples (2002) identified the use of modeling by science faculty as positively impacting the science teaching efficacy of pre-service elementary teachers.

The effort to plan for and then implement linking concepts under study to real world examples is a component of reform teaching discussed by Krockover et al., Wainwright et al., and Staples (2004). The rationale for incorporating such linkages is described as making abstract ideas more concrete and relevant. Highlighting the processes and effects occurring in real-world contexts enables students to more meaningfully understand the key concept operating in such contexts according to these reports. An associated component was the effort to make connections for a concept with other disciplines (Wainwright et al, Staples, 2004). Such connections were

considered as enabling students to see both the more global applications of the concept and to more deeply understand it as they consider its' use in various disciplinary contexts.

Three reports consider assessment: Krockover et al, Ballone-Duran, Czerniak, and Huey, and Staples (2004). Each focuses on the use of diverse assessment strategies. Such strategies de-emphasize but do not exclude traditional multiple choice and short answer quizzes and exams and traditional laboratory reports. Other types of assessment are used to supplement traditional formats such as student journals, projects, presentations, cooperative group tasks, application activities, and student-designed hypotheses and experiments. A variety of formats are thought to be more authentic assessment of inquiry learning. Efforts at authentic assessment typically have more focus on application and use of concepts in contexts that differ from that in which the concept initially was learned. An associated component of a reform course noted in these reports was allowing students to demonstrate their work in a variety of formats. In some instances differing formats for the demonstration of work were used in a single assessment. So, some students might give a presentation, some might demonstrate a process via a computer simulation, and others might set up a panel to discuss specific applications of a concept.

Action research as a means of identifying problems, addressing those problems, and assessing the results of the effort were described in two reports, Sunal et al (2004) and Sunal et al. (2002). Conducting action research was found to be an important element for course change. Action research can be carried out by the instructor or by a collaborative team responsible for a reform course. When doing such research, a small component of the course is investigated. The action research project can address a reform component added to the course. Or, it can recognize a need to enhance an element of the course that is problematic. The instructor or team identifies the problem and examines the literature to determine how it might be addressed. After

implementing a strategy to address it, data are collected and analyzed to determine the effects of the implementation. If such effects are positive, the strategy is retained and another problem is identified as the focus of another action research project. If the effects are not positive, then another strategy is considered and tested. This process uses a data-driven approach to reform.

As instructors and teams work to design and implement course change, the process can be overwhelming if one takes on too many revisions at the same time. Three reports emphasize the need to focus on incremental change, working on one course aspect at a time (Krockover et al., Sunal et al (2004), and Staples (2004). Each notes that successful use of a strategy whether it be cooperative learning groups or the use of student science journals as a form of assessment, will take time to implement and to develop skill in its use. Both the instructor and the students need to learn how to use the strategy and work with it. Action research can support such incremental change as instructors examine the effects of a change and determine whether or not to continue it or to revise it and then further examine its effects (Sunal et al, 2002, 2004).

Student Achievement

Student achievement has been examined at the undergraduate level in relation to science course reform. It has also been examined in terms of the achievement of K-12 students of teachers who themselves participated in one or more reform courses while undergraduates. Among undergraduates participating in reform science courses content achievement has been examined most often. Studies of undergraduates have also examined their science literacy in a broader sense and their pedagogical content knowledge in terms of ability to teach inquiry-oriented science to K-12 students.

Undergraduate science content achievement has been found to correlate positively with participation in courses with greater focus on inquiry-oriented teaching in reports by Francis,

Adams, and Noonan (1998), Hake (1998), Jewett (1998), Hubbard and Abell (2005), Luera and Otto (2005), Weld and Funk (2005), Staples (2004), and Sunal et al. (2004). Francis, Adams, and Noonan report students taking a reform physics course demonstrated a fundamental shift in their conceptual framework, retaining their “Newtonian ideas” of physics over several years. Hake examined another reform physics course and found significantly greater normalized average gains among reform course participants when compared to those among participants in a matched traditional physics course. Hubbard and Abell found more complete physics content understanding among elementary science methods course students who had participated in a reform physics course when compared to those students in their course who had participated in a traditional physics course. Jewett reports on the implementation of web-enhanced features on student achievement in microbiology finding no statistically significant differences when these students are compared to previous students who had taken a traditional microbiology course. While students in the reform microbiology course indicated the web-enhanced course components were useful in learning course material, their achievement was not tested with standardized instrumentation so that any conclusions made are limited. Sunal et al (2004), Staples (2004), and Luera and Otto report significant content achievement among participants in reform coursework in the biological, physical, and earth sciences. With the exception of Jewett, all of these studies report greater science content achievement among undergraduate reform course participants.

Case Studies

Three of the case studies considered several themes found in several research studies. In a meta-ethnography, Blackwell (2002) synthesized the reports from nine projects evaluating the impact

of partnerships on teacher education and teacher induction (funded by the Office for Educational Research and Development, U. S. Department of Education), Blackwell (2002) concluded the pre-service teachers participating in the partnership programs were more successful than were pre-service teachers trained by traditional methods. Additionally, the programs offered a mechanism for increased collaboration between higher education institutions and state departments, alleviating a typical barrier to reform; shared vision for teacher development and induction.

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Jeanelle Hodges (Day) (1999) conducted a study to determine factors associated with staff development processes and the creation of innovative science courses by higher education faculty who have participated in a model staff development project. The staff development program was designed for college faculty interested in creating interdisciplinary, constructivist-based science, mathematics, or engineering courses designed for non-majors. The program included workshops on incorporating constructivist pedagogy, alternative assessment, and technology into interdisciplinary courses. Staff development interventions used in the program included grant opportunities, distribution of resource materials, and peer mentoring. University interdisciplinary teams were required to attend the workshops comprised of faculty from the sciences, education, and administration. A purposeful and convenient sample of three university teams were subjects for this qualitative study. Each team had attended a NASA Opportunities for Visionary Academics (NOVA) workshop, received funding for course development, and developed innovative courses.

Five questions were addressed in this study: a) What methods were used by faculty teams in planning the courses? b) What changes occurred in existing science courses? c) What factors affected the team collaboration process? d) What personal characteristics of faculty members were important in successful course development? and e) What barriers existed for faculty in the course development process? Data was collected at each of three sites through individual faculty interviews (N = 11), student focus group interviews (N = 15), and classroom observations. Secondary data included original funding proposals.

The NOVA undergraduate faculty development model had been shown to result in significant changes with preservice teachers. Analysis of data revealed that there were four factors of staff development processes that were most beneficial to effective undergraduate

reform. First, the team collaborative processes were crucial in successful course development. Second, the use of instructional grants to fund course development gave credibility to the faculty involved in course development. Third, the faculty members taking the lead in creating teams actively sought out faculty members in the sciences who had previous experience teaching at the K-12 level or in informal education. In addition, specific college environments were found to have an impact on the success of the innovative course development projects.

Darling-Hammond (2000) also reviewed prior studies. These were case studies with results from the National Assessment of Educational Progress (NAEP) testing program, the 1993-1994 Schools and Staffing Surveys, and data from a 50-state policy survey. From her analysis of the research base, she concluded that it is possible for the effects of well-prepared teachers (those with greater subject knowledge, pedagogical knowledge, and years of teaching experience) on student achievement to be more influential than student background factors including poverty, minority status, and language background. In a related study of successful teacher education programs, Darling-Hammond (2006) described successful teacher education programs at Alverno College, Bank Street College of Education, Trinity University, University of California at Berkeley, University of Southern Maine, University of Virginia and Wheelock College.

The remaining case studies involved in-depth review of a project or a specific course. (

Krockover, Shepardson, Adams, Eichinger, and Nakhleh (2002) reported on a partnership program, *CABR*, among scientists, science educators, master teachers, graduate students, and undergraduate students that resulted in undergraduate science courses which utilized more inquiry-based collaborative teaching pedagogy than previously found in such courses. Part of the process involved an evaluation of the reform courses by employing a case study strategy. Due to

their participation in the *CABR* project, members of the team were “able to (a) implement more inquiry-based teaching that emphasized conceptual understanding; (b) provide opportunities for cooperative learning experiences, (c) use models as an ongoing theme, (d) link concepts and models to real-world situations, (e) provide a more diverse range of assessment strategies, and (f) have students present their understandings in a variety of different forms” (p.274). In addition, by using a collaborative format, graduate and undergraduate students, classroom teachers, scientists, and science educators were able to come together with differing perspectives to reform education. As a result of three case studies conducted by collaborative action-based research teams (each team was tasked with evaluation of the reform courses: Biology for Elementary Teachers, General Chemistry, and Earth Science for Elementary Teachers), the researchers concluded: lasting reform is the result of shared, team responsibility; administrative support is necessary for reform; and focus on a single aspect of the reform course in order to improve and extend the reform effort.

In a case study of an inquiry-based physics course, Hubbard and Abell (2005) compared the beliefs about science teaching in an elementary science methods course between students who were completing or had completed a reform physics course and those students who did not take the course. The case study involved six of the 40 students enrolled in the methods course (two who had not taken the course, two concurrently enrolled, and two who had completed the course.) Primary data sources included a research-designed belief questionnaire administered during the second week of the course and key student written products from the methods course. Additionally, the methods course instructor’s anecdotal records of class discussions were analyzed. As a result of the data analysis, Hubbard and Abell concluded that students completing the inquiry-based physics course expressed a more complete understanding of science teaching

and learning compared to their peers and a greater ability to apply an inquiry approach to their lesson plans.

Inquiry-Based Pedagogy

Central to the reform effort is the effort to increase the use of student-centered pedagogy in undergraduate science courses. Judson and Sawada (2001) sought to determine the impact of the *Arizona Collaborative for Excellent in the Preparation of Teachers (ACEPT)*. Eighty-six classroom observations of middle and high school teachers with one to three years of teaching experience were evaluated using the Reformed Teacher Observation Protocol (RTOP). Of these teachers, 53 had taken at least one ACEPT course and 33 were non-ACEPT teachers. Observations were both announced and unannounced. Analysis showed no significant difference between the two types of observations. The seven evaluators were not aware of the institution which the pre-service teacher had attended (i.e. which institutions participated in ACEPT and which did not). Based on average RTOP scores, teachers taking courses designed using the tenets of the ACEPT program showed a significantly higher level of reformed instruction than non-ACEPT teachers ($p < 0.05$). In addition, teachers who had taken two or more ACEPT courses were found to have a higher mean RTOP score than teachers with only one ACEPT course. While both ACEPT-influenced and non-ACEPT teachers showed increasing mean RTOP scores with years of experience, this increase was only found to be statistically significant for the ACEPT-influenced teachers (among the subsections of the RTOP, $p = 0.005 - 0.042$).

In another study of the ACEPT program, Lawson et al. (2002) evaluated the effect of summer workshops on teachers' use of reformed teaching methods as well as the effects of these

teaching methods on student achievement in undergraduate science and mathematics courses. Evaluative data were collected for five courses (two from Physics, two from Biology, and one from Mathematics). Three of which were designed specifically for pre-service teachers. In addition, one course was designed specifically to teach pre-service biology teachers about reformed methods of teaching by using those reformed methods. Teaching practices were evaluated in all courses except the biology teaching methods course, using the RTOP. Student achievement was measured in each course with a different unnamed pre- and post-test, depending on the subject being taught. Students who participated in a course on mechanics were evaluated with the Force Concept Inventory (FCI). For each course with RTOP data, the data from experimental sections were compared to data from at least one control section. In all four courses with RTOP data, instructors' mean RTOP scores strongly correlated with normalized student gains ($r = 0.88, p < 0.05$; $r = .92, p < 0.001$; $r = 0.70, p < 0.05$; $r = 0.97, p < 0.01$). In addition, Lawson et al presented preliminary data on the effectiveness of new teachers who had recently graduated. These data showed that first-year teachers who enrolled in one or more ACEPT-influenced undergraduate science or math courses had a significantly higher ($p = 0.05$) mean RTOP score of 48 ($N = 20$) than first year teachers who had not participated in an ACEPT course of 40 ($N = 8$). Researchers found similar data for second- and third-year teachers (mean RTOP score of 62 vs. 45, $p < 0.05$).

In similar research, Adamson et al (2003) evaluated the effects the ACEPT *Program* on in-service junior and senior high school teachers' instruction practices, as well as the subsequent effects on these teachers' students as the result of taking college science courses designed with the ACEPT guidelines. Twenty-eight in-service teachers (14 ACEPT-influenced and 14 non-ACEPT-influenced) were observed using the RTOP. In addition, the achievement of students (n

= 1116) from a subset of 15 high school biology classes was measured using the Biology Attitude Skills and Knowledge Survey (BASKS) during the last three weeks of the academic year. School SES (percentage of students receiving subsidized lunch), years of teaching experience, and “Regular” vs. “Honors” designations of biology classes were used as covariates. RTOP scores were found to be significantly higher for ACEPT-influenced teachers than for non-ACEPT-influenced teachers ($F_{2,26} = 3.44$, $p < 0.05$ for all teachers; $F_{2,13} = 3.68$, $p < 0.05$ for biology teachers). Achievement scores of students with ACEPT-influenced teachers were also significantly higher than were those of students with non-ACEPT influenced teachers ($F_{2,13} = 6.23$, $p = 0.01$). Results of all three studies indicated that program participants were more likely to use reform-based instructional techniques than were their counterparts who did not participate in the professional development. Additionally, results from the research of Judson and Sawada (2001) indicated student achievement was higher when the teacher had taken courses designed with the ACEPT design protocols as did Lawson, et al (2002) who reported achievement of pre-service elementary teachers in undergraduate science courses. The research base reveals the attitudes of pre-service and in-service teachers toward science and science education impacts the use of reform pedagogy in the K-12 classroom and K-12 student achievement.

Kim Staples (2002) investigated the differential effects of experiences in non-traditional and traditional undergraduate science courses on the science teaching and learning of undergraduate elementary education majors, elementary classroom teachers, and students. The non-traditional course focused on assisting teachers in demonstrate knowledge through inquiry investigations, critical analysis, and synthesis of the science discipline.

The research study included a sample of 264 participants from a single university that represented undergraduate education majors, college science instructors, elementary classroom

teachers, and elementary classroom students. Short term and long term learning outcomes of undergraduate education majors and classroom teachers were evaluated for the effect of experiences in a nontraditional college science course. Quantitative and qualitative data were collected through questionnaires, standardized tests, surveys, oral and written interviews, and observations of undergraduate and elementary science lessons. A triangulation of the data results revealed that modeling, active engagement, project-based activities, and cooperative learning positively affected undergraduate education majors' science teaching efficacy, science content mastery, and elementary teacher performance in science classroom instruction. Standardized test scores revealed higher achievement in science among elementary students in classrooms of teachers experienced in a nontraditional science course than students of teachers experienced only in traditional learning environments. The results of this study support the call for reform in college science teaching. The standards based context in which science content was delivered resulted in the development of scientific literacy among education majors, elementary teachers, and students in elementary classrooms.

The change in the pedagogical techniques and beliefs of university science professors emerges from the research as well. In a case study, Wainwright, et al (2004) reported on the utilization of inquiry-based pedagogy in science content courses taught by twelve faculty fellows at five higher education institutions in Oregon. All twelve-faculty members had participated in summer institutes of the Oregon Collaborative for Excellence in the Preparation of Teachers (OCEPT) that modeled reform-based practices and fostered reflection on current issues in science, mathematics, and technological literacy for K-16 teaching. The faculty fellows were observed at least three times with the *OCEPT-Teacher Observation Protocol (O-TOP)*. Following observations, each faculty member was individually interviewed in order to validate

observational data and to add an in-depth description of the instructor's perspective. Six of the faculty fellows were from the science disciplines and six were from mathematics. Results indicated all faculty fellows used inquiry-based techniques; OTOP provides a profile of instruction, not an overall rating of inquiry pedagogy. Science faculty tended to make more interconnections with other disciplines while mathematics faculty was more likely to promote student discourse and collaboration in small groups.

In a mixed method design, Ballone-Duran, Czerniak, and Haney (2005), examined the change in beliefs and practices of teaching and learning of scientists as a result of their participation in the Toledo Area Partners in Education Support Teachers as Resources for Improving Elementary Science (TAPESTRIES) project. In the TAPESTRIES project, science faculty participated in professional development and collaborated with science educators and K-6 teachers. The study summarized results from interviews of the scientists and student surveys of the scientists' classrooms with the *Classroom Learning Environment Survey (CLES)* (Taylor, Fraser, and White, 1994). The scientists reported the courses in undergraduate science did not adequately prepare pre-service elementary teachers. Some scientists indicated elementary science students should take additional science courses and other scientists indicated undergraduate courses in science should be restructured to better meet the needs of pre-service elementary teachers. Four themes emerged from the interviews: (a) pre-service teachers must have positive dispositions toward teaching and learning; (b) scientists made pedagogical and curricular changes as a result of collaborating with educators; (c) scientists began to think reflectively about their own teaching and learning; and (d) new collaborative projects emerged between scientists and educators as a result of the program. Additionally, the scientist expressed a greater understanding of the complexity of the reform process and indicated that they knew there must

be more reform in undergraduate science. Results from administration of the *CLES* instrument to the students of 11 scientists involved in the study from the two universities ($N = 260$) indicated the scientists were beginning to incorporate reform-based changes in their courses as a result of the program. Ballone-Duran, Czerniak, and Haney delineated the following implications of the research: (a) faculty professional development facilitates change in higher education; (b) it takes time to plan, develop, and implement change; (c) personal belief systems are a barrier to reform; (d) support is necessary to implement change; and (e) collaboration is required for reform in teacher education.

Surveys

In related survey research, Staples (2004) compared student perceptions in a reform course ($n = 55$) with a traditional science course ($n = 192$). Quantitative and qualitative data was collected through surveys, and oral and written interviews measuring undergraduate students' preference of learning environment for science content, science learning, and teaching. Undergraduate education majors were also given pre- and post-test *CLES* surveys. Students reported teaching techniques that helped them make connections between science concepts and the real world assisted in understanding the concepts.

One of the difficulties with the reform process is the development and validation of instrumentation designed to measure programmatic success. McGinnis, Kramer, Shama, Graeber, Parker, and Watanabe, (2002) described the development and validity of the *Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science* survey designed for the Maryland Collaborative for Teacher Preparation (MCTP), a statewide, standards-based

project. This research compared teachers participating in the MCTP program with their counterparts in terms of attitudes and beliefs about science and mathematics before and after taking a reform-based course. The longitudinal study was conducted over a 2.5-year period. Factor analysis of the results indicated the first 32 items of the questionnaire should be split into 5 factors. These sections of the instrument were verified by factor analysis: “beliefs about mathematics and science ($\alpha = .76$), attitudes toward mathematics and science ($\alpha = .81$), beliefs about teaching mathematics and science ($\alpha = .69$), attitudes toward using technology to teach mathematics and science ($\alpha = .80$), and attitudes toward teaching mathematics and science ($\alpha = .60$).” (p. 714) The pilot instrument was administered to 200 students in the fall of 1994 and 210 students enrolled in MCTP courses in the spring of 1995. After the pilot administration, the original 51-item questionnaire was adapted to the 37-item instrument included in the report. As a result of analyzing the data of the survey instrument, the researchers recommended using surveys that were related either to science or to mathematics. The research revealed no statistical difference between pre/post administrations of the survey of teachers taking MCTP courses. There was a statistically significant difference between the pre/post survey results of teachers who did not take the MCTP courses; after taking traditional science courses, the attitudes of teachers toward science, mathematics, and technology decreased. When the survey was administered to teachers in the MCTP program after 2.5 years, however, there was a positive significant difference.

In a follow-up study, McGinnis, et al (2003) reported that when MCTP pre-service teachers surveys were compared to surveys of non-MCTP students (33 content and pedagogy courses distributed statewide, $N = 486$), in general, MCTP students started with attitudes and beliefs more in line with program goals than did non-MCTP students, and the gap between the

two groups widened by the end of the course. In addition, that gap widened in some cases because MCTP students advanced beyond non-MCTP, but in other cases it widened because non-MCTP students' scores actually declined between the beginning and end of the course. Researchers also found that MCTP candidates' attitudes and beliefs changed favorably over time as they participated in the program (from Fall 1995 to Fall 1997), and that this change was significant ($p < 0.001$). From surveys administered over a three-year period ($N = 68$), researchers found that MCTP graduates differed significantly ($p < 0.05$) from a national sample of surveys ($N = 478$) on beliefs about the nature and teaching of science. "Specifically, they were less likely to believe: that science is a primarily formal way of representing the real world; that science is primarily a practical and structured guide for addressing real situations; that a liking for and understanding of students are essential for teaching science; that it is important for teachers to give students prescriptive and sequential directions for science experiments; and, that students see a science task as the same task when it is represented in two different ways. However, they were more likely to believe that if students get into debates in class about ideas or procedures covering the sciences, it can harm their learning" (p.21-22).

In a similar study on pre-service teacher attitudes toward science, Le and Krapfl (2002) investigated the impact of an inquiry-based elementary science minor program of 25 semester hours on pedagogical content knowledge. Semi-structured personal interviews with nine program graduates in their 2nd - 6th year of teaching were analyzed qualitatively. Surveys were sent to program graduates ($N = 34$). Respondents reported: (a) positive feelings about the experience and belief that the experience made a difference in how they currently teach science, (b) expressed concern about their ability to meet the requirements of special needs students, constraints of time, money, and materials, classroom management, and the reality of required

curriculum in using inquiry-based teaching methodology, (c) articulated a positive self-efficacy to teach science, (d) expressed feelings of teaching “differently” from many of their peers, and (e) described typical barriers (lack of materials, lack of planning time, etc) that they had to overcome to use inquiry-based teaching methodology. Lee and Krapfl concluded that the program achieved its goals, but noted a classroom management component should be added and that the current component dealing with special needs students should be extended.

Sunal, et. al. (2001) conducted research to better understand the change processes necessary for university science teaching reform to be successful. An ethnographic and case study approach was used to determine the effects of the faculty development model. A stratified random selection process for institutions was used based on time in a staff development program, type of institution and geographical distribution. 30 institutions were selected from among NASA Opportunities for Visionary Academics (NOVA) institutions that participated in the staff development program. Data was gathered on faculty attitude, knowledge, faculty efficacy, course planning, and classroom action. Quantitative and qualitative data gathering instruments included surveys, questionnaires, and interviews. The study concluded that specific conditions were necessary for successful innovative course implementation and institutionalization to take place. They were;

- interaction of faculty between colleges in reform teams,(i.e. Arts and Sciences or Engineering and Education), correlates strongly with successful course change.
- collegial and administrative support is critical in successful change for most of the faculty. The greater the change attempted, the greater the need for support.
- change begins with the goal to be accomplished, not with the personal or contextual barriers to be overcome.

- collaborative work starts with building effective interpersonal skills and trust with others having a similar goal facilitate change.
- planning for incremental change is a successful staff development process.
- Conducting action research is an important element for most faculty in creating successful change. This requires a questioning of your common sense, everyday knowledge about teaching and learning.
- joining and being active in a network of faculty within or outside an institution who regularly collaborate and disseminate results of change in teaching is a critical factor in sustaining action leading to success.

Weld and Funk (2005) described similar results in a study of an inquiry-based biology course specifically designed for elementary education majors and modeled on the *National Science Education Standards* (NRC, 1996.) The study involved research into students (N = 61) self-perceived effectiveness as a teacher of biology. The four specific attitude factors tested in this study were: subjects' self-perceived change in command of biology subject matter; biology curriculum development competence; biology education pedagogical skill, and change in self-perceived effectiveness as a biology teacher. Data were collected pre- and post-course for all subjects using a survey of attitudes and self-perceived effectiveness as a teacher of biology. In addition, 10% of all enrollees participated in semi-structured telephone interviews immediately following pre- and post-testing, and data were supported by informal observations. Gains were found in pre-service teacher efficacy in teaching biology due to self-reported gains in pedagogical content knowledge. In addition, interviews revealed an increased interest in taking more science courses as a result of taking the reform biology course.

Achievement

One central goal in the position statements of leaders in science, mathematics, engineering, and technology is increased student achievement. There is a paucity of substantive research on the achievement of students involved in reform courses. Therefore, additional research should focus on achievement. In particular, future studies should be at least quasi-experimental in design, preferably experimental. In terms of research in student achievement in the studies reviewed, two studies of participants in reform courses in physics found that students taking reform courses had higher gains in conceptions of mechanics. Hake (1998) compared the effects of reformed versus traditional teaching practices on high school, college, and university students' conceptions of mechanics. The Force Concept Inventory (FCI) was administered pre- and post-course for 6542 students in 62 introductory physics courses. Students who participated in reformed courses ($N = 4458$) were found to have significantly greater normalized average gains (0.48 ± 0.14) than those who participated in traditional courses ($N = 2084$) (0.23 ± 0.04). In a similar longitudinal study, Francis et al. (1998) set out to determine whether gains in students' Force Concept Inventory (FCI) scores seen immediately after taking a reformed physics class would remain up to four years after completing the course. That is, "Do students retain their 'Newtonian ideas' of the world years after finishing a reformed physics course?" The researchers concluded from this data that to a large extent, the students retained their "Newtonian ideas" of physics over the several years following instruction, supporting a fundamental shift in students' conceptual framework as a result of the course.

Other research supports the hypothesis that pre-service teachers taking reform courses have higher achievement in undergraduate science courses. Luera and Otto (2005) described the

impact of a series of undergraduate science courses utilizing inquiry-based pedagogy in life, physical, and earth-planetary sciences and a capstone course requiring pre-service elementary teachers to engage in deep exploration of one of the big ideas in science. They compared content knowledge between students who completed the reform inquiry-based science courses and those who completed the previous traditional series of courses. A least squared difference (LSD) t test with an alpha value of .05 showed that students who completed two inquiry content courses ($M = 43.67$) scored significantly higher in overall content knowledge than students who completed zero ($M = 40.34$) or one inquiry course ($M = 40.44$). Results of the *Science Teaching Efficacy Behavior Instrument Version B, STEBI B*, (Enochs & Riggs, 1990) indicated that at least one inquiry-based content course was required to see a change in efficacy: three inquiry courses ($M = 56.65$, $n = 21$), two inquiry courses ($M = 54.27$), one inquiry course ($M = 53.26$) [$n = 145$ for students completing one and two inquiry courses] and students who completed zero inquiry courses ($M = 51.80$, $n = 119$).

While Lawson, et al (2002) and Adamson, et al (2003) concluded reform courses positively impact achievement among K-12 students and undergraduate students in science courses, the research conducted by Le, et al (2006) indicated that how achievement is assessed is problematic in evaluation of reform. Typically, multiple choice assessments are used rather than alternative assessment. Le, et al (2006) reported on *Mosaic II*, a longitudinal study called of the impact of reform in mathematics and science education on student achievement. Students in five cohorts (3 mathematics and 2 science) from three districts which had recently concluded participation in the Local Systemic Change Program, were followed for three years to measure student achievement over long exposure to reform education. Student age varied from grades 3-8 and achievement was measured using the mathematics or science component of the Stanford

Achievement Test Series, Ninth Edition (SAT-9) for all cohorts, as well as the open-ended version of the SAT-9 for a sub-sample of three cohorts. In addition, each year all participating teachers completed a survey, filled out classroom logs, and responded to a set of vignette-based questions about instructional practices. In selected years, classroom observations and interviews were conducted with a subset of teachers. The research indicated little impact on student achievement as measured by multiple choice tests, but positive achievement when other measures were used such as open response tests. Positive relationships tended to become stronger with sustained exposure to reform teaching. The researchers concluded that the way in which achievement is measured might have a large effect on the observed relationship between reform-oriented instruction and achievement. Additionally, the research revealed that teacher competency and efficacy might have impacted success with reform-based pedagogy. Teachers reported that, despite the training they received, they believed that reform-oriented practices were likely to be less effective than traditional practices for promoting high scores on state accountability tests.

In summary, the research base supports the use of inquiry-based instruction to increase student achievement in science in K-12 classroom and undergraduate students. Analysis of the studies cited indicates pre-service teachers were more likely to use inquiry-based instruction following reform based science courses and the process of reform positively impacted the use of reform pedagogy in undergraduate science courses.

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