National Study of Education in Undergraduate Science: 2006-2012 – What Was Learned?

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Abstract

The National Study of Education in Undergraduate Science (NSEUS) was a multi-year, NSF supported research project focused on critical needs in teaching undergraduate science to diverse majors with an emphasis on preparation and long-term development of pre-service K-6 teachers of science. The research question guiding the project was "How do undergraduate entry-level science courses, differing in level of reform, affect student learning outcomes?" The impact of undergraduate standards-based, reformed science courses, as compared to traditional coursework, was the focus. The entry-level courses were analyzed in a professional development impact design model involving a national sample of reformed and comparison undergraduate science courses from a national population of 103 diverse universities. Quantitative and qualitative data were analyzed using comparative and relational studies of the research design model. The NSEUS study answered these questions

- What is an effective reform course?
- What elements are effective in science course reform?
- What is inquiry teaching at the undergraduate level?
- How many reform elements do you have to implement at the undergraduate level to show better than average achievement gain? What PCK is needed for faculty to be effective in undergraduate classes?
- What quality of reform element application is needed at the undergraduate level to show better than average achievement gain?

Conclusions relate to short-term impacts on undergraduate majors in general and long-term effects on matriculated in-service teachers of science and identification of characteristics of faculty instructors and courses producing significant impacts.

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Higher education faculty professional development has received increasing attention over several decades as a means to facilitate improved student achievement. Reforms in entry-level undergraduate science, technology, engineering, and mathematics (STEM) courses impact almost all students in higher education. Today's pre-service elementary teacher candidates also participate in entry-level STEM courses as part of their programs. These courses represent the entire STEM content many students will receive as part of their non-STEM major or teacher certification program in higher education. Such coursework generally includes two or three science courses with a laboratory. The education candidates, in turn, will teach science to their elementary school students, affecting much of children's science education over time. This paper addresses the problem of the extent to which undergraduate entry level science courses affect the science learning outcomes of the students who participate in those courses. Since significant resources and professional development efforts have been undertaken over the past 30 years to enable higher education STEM faculty to reform undergraduate courses, it is important that this problem be investigated (National Commission on Excellence in Education, 1983; National Research Council, [NRC] 1996a; Siebert & McIntosh, 2001, NRC, 2003; National Academy of Sciences, 2007). This study poses a central research question, "What is the impact of undergraduate course reform as measured by the beliefs and actions of higher education faculty on short- and long-term student outcomes?" With this problem and central question in mind, the purposes of this paper are the following.

1) Describe a faculty professional development framework, based on research based practices that was designed and implemented nationally to facilitate change in undergraduate courses in order to enhance the science, mathematics, and technology literacy of pre-service teachers.
2) Examine previous research on faculty professional development and reform in undergraduate science courses and their short- and long-term impacts, including successful reform perspectives.
3) Describe a national research model and methods for conducting a study designed to determine the short- and long-term impacts of level of reform in undergraduate science courses on students, with special emphasis on pre-service teacher education candidates.
4) Summarize findings of a national survey of a population of institutions where STEM reform courses were developed and offered focusing on successful reform perspectives for developing research supported best practice in undergraduate science.
5) Describe several results from a national study designed to determine the relationship between course reform and learning outcomes and the extent of reform that would be needed to measure significantly different learning outcomes.

Background

Over the past several decades, national reports documenting the goals and concerns of the teaching of science, technology, engineering, and mathematics (STEM) courses in higher education began with the report, *Nation at Risk* (1983) which led to a continuing stream of others such as the American Association for the Advancement of Science's (AAAS) *Benchmarks for Science Literacy, Project 2061* (1993), *National Science Education Standards* (NRC, 1996a), *Shaping the Future* (National Science Foundation [NSF], 1996), *Science teaching reconsidered: A handbook* (NRC, 1997), *Educating teachers of science, mathematics, and technology: New practices for the new millennium* (NRC, 2001), *College Pathways to the Science Education Standards* (Siebert & McIntosh, 2001), *No Child Left Behind* (2001), *Evaluating and Improving Undergraduate Teaching in Science, Engineering, and Technology*, (NRC, 2003), and *Rising above the gathering storm: Energizing and employing America for a brighter economic future* (National Academy of Sciences, 2007). These documents set guidelines providing criteria that can be used to judge whether particular reform actions serve the vision of a scientifically literate society.

Traditional, non-reform approaches to teaching undergraduate entry-level science courses do not work effectively with many students, particularly non-science majors. Several past reforms have suggested that faculty and learning in their students at hundreds of universities can be impacted positively (Sundberg & Monaca, 1994). Recognizing that reform is needed, and may be possible, in undergraduate entry-level science courses if all students are to be impacted positively by such coursework, the National Science Foundation identified the goal for higher education reforms as creating an environment where "all students have access to supportive, excellent undergraduate education in STEM and all students learn these subjects by direct experience with the methods and processes of inquiry" (NSF, 1996, p. 1). The NRC later called for reforms addressing the same problem, stressing that "the ultimate goal of undergraduate education should be for individual faculty and departments to improve the academic growth of students" (2003, p. 14).

Science literacy for all, Kindergarten -16 (K-12), was being stressed by national governmental agencies including NSF and NRC, Kindergarten-12 science standards were developed, the *Benchmarks for Science Literacy, Project 2061* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996a). Effective Kindergarten-12 science education reform cannot be separated from standards-based reform in undergraduate science (Lederman & Gess-Newsom, 1999). Teachers in K-12 appear to be heavily influenced by how the undergraduate science courses they take are taught, and by the science content included in these courses. A renewed emphasis is needed on the learning approaches, organization, breadth, and depth of content found in undergraduate science courses. Undergraduate courses in traditional format and content do not challenge, but instead reinforce, the fragmented nature of students' knowledge and their relative inability to apply that knowledge within the context of teaching (Lederman & Gess-Newsome, 1999, p. 211).

Studies of higher education pre-service and in-service programs often note that the development of the desired integration of subject matter and pedagogy is not accomplished (Smith, 1999). Lederman and Gess-Newsome (1999, p. 209) noted;

> Subject matter structures are largely determined in adults in college science courses and it appears that these courses do not yield coherent and integrated subject matter structures...[and] were not integrated and consistent with the vision of national reforms in science education. [The].. investigation made us aware ...that the nature and validity of instruction in college science courses was absolutely critical.

Teacher education courses and programs can accomplish only so much without the support of a reform climate in undergraduate science courses taken as part of their program by pre-service teacher candidates. University faculty beliefs and actions are responsible for *quality of the learning environment* and of the *content structure and organization* of undergraduate science courses which, in turn, are critical factors in the development of the teachers' pedagogical content knowledge (PCK) and the development of meaningful science learning outcomes among their students. If students come to the university with poor science backgrounds, the undergraduate science courses provided to pre-service teachers are a principle factor in this cyclic process.

The NOVA Faculty Professional Development Model

In response to the needs identified in undergraduate STEM teaching in the mid-1990s, guidelines were developed for a national professional development model for higher education faculty that incorporated research based processes noted in the literature (Peterman, 1993; Weimer & Lenze, 1994; Loucks-Horsley et al., 1998; Sunal et al, 2001; Sunal, 2004a, Zollman, 1997, 2004). The implications of previous research on faculty development in higher education, within the supporting framework of cognitive apprenticeship, provided the guidelines for a more effective model of professional development in higher education. These guidelines were used to develop, implement, and sustain the NASA Opportunities for Visionary Academics (NOVA) model for STEM faculty professional development, 1995-2006. The original authors of the model were experienced researchers in reforming undergraduate STEM courses who were successful in completing externally funded related projects developed and completed over the years 1991-1995.

The NOVA program incorporated specific conditions cited in the research literature as necessary for successful undergraduate course reform, implementation, and institutionalization. These required conditions were;

(1) interaction of faculty between colleges (e.g. Arts and Sciences and Education),
(2) participation in a collaborative team representing differing expertise,
(3) maintenance of a positive college and department climate relating to the reform effort's goals,
(4) maintenance of administrator presence and support in the change process,

(5) initiation by beginning with the reform goals to be accomplished rather than with personnel or contextual barriers,
(6) collaboration via interactions building on effective interpersonal skills and trust,
(7) planning for incremental, rather than initial massive, change, to take place over several years through the sustaining phase of the reform,
(8) ongoing and consistent monitoring and support system for implementation of the reform activities using action research,
(9) sustaining through collaboration in a network of faculty within and outside of the institution (Sunal et al., 2001).

The model's development was the result of STEM researchers focus on reform at three universities, University of Alabama (Michael Freeman, Dennis Sunal, and Kevin Whitaker), Fayetteville State University (Leo Edwards, and Ronald Johnston), and the University of Idaho (Michael Odell). The researchers developed and proposed a program that became the National Aeronautics and Space Administration's (NASA) pre-college preparation program, NOVA (see Figure 1). Beginning in 1995, NOVA annually invited the participation of undergraduate faculty concerned with how universities prepare pre-service teachers. Through NOVA, entry-level reform STEM courses were newly developed or modified and enhanced using existing courses by collaborative teams of faculty in the sciences, mathematics, engineering, and education. The NASA/NOVA Program goals were,

1. Disseminating a national pre-service model based on national standards and benchmarks for mathematics, science, and technology,
2. Utilizing the research and development activities from NASA's strategic enterprises (Earth Science, Aero-Space Technology, Human Exploration and Development of Space, and Space Science),
3. Collaborating across faculties in education and science, mathematics, or engineering to develop innovative approaches to teacher preparation for enhanced student learning,
4. Sustaining the change process through continued professional development and collaboration with networking and mentoring,
5. Stimulating and conducting action research and change.

The NOVA program invited the participation of science, engineering, technology, mathematics, and education faculty who were concerned with how universities prepare new teachers. Using the NASA mission, facilities, and resources, NOVA provided these faculty members with enhanced knowledge and skills to implement change in university STEM courses.

Figure 1: Logo used for the National Aeronautics and Space Administration's pre-college preparation program, NOVA

Requests were made for proposals for participation in the NOVA program to faculty at colleges and universities nationwide. Four solicitations were made annually. Participation in NOVA included opportunities for, and commitment to, enhanced knowledge and skills through workshops, exemplary models, grant funding, collaboration, and action research. These were characteristics of continued professional development within and between higher education institutions and NASA resources. The NOVA professional development model was delivered in three phases: (1) *planning and preparation,* involving training, collaboration, and action planning for addressing baseline needs in faculty skills and knowledge enhancement; (2) *development and implementation*, involving initial course change, action research, mentoring, and sharing of expertise; and (3) *continuing development and long-term sustaining activity*, involving action research, networking, monitoring including site visits, and dissemination (Sunal et al., 2004). The NOVA professional development (PD) model included:

1. A collaborative team approach with STEM and Education faculty and administrators in a systemic initiative (collaboration) *Phases 1, 2, 3*
2. Intensive professional development (30 hours) addressing
   a. higher education concerns reflected in the national science standards (learning environment, course structure, pedagogical content knowledge [PCK]) (Siebert & McIntosh, 2001; NRC, 1996; AAAS, 1993)
   b. best practices from research in STEM curriculum, pedagogy, assessment, collaborative learning, and working with student diversity in higher education, (learning environment, PCK) (Backer, 2002; Christopher & Atwood, 2004; Francis, Adams & Noonan, 1998; Krinsky, Anderson & Kidane, 1998; Project Kaleidoscope, 2005; Scharmann, Stalheim-Smith & James, 2004; Slater & Sireci et al, 2003; Sunal, 2004b; Swanson & Bilderback, 1998; Wycoff, 2000)
   c. demonstration course models from research in STEM learning
   d. action research planning and methodology (PCK, collaboration) (Raubenheimer, 2004)
   e. best practices in research and methods in the use of technology to facilitate STEM learning (learning environment, PCK) (Odell et. al. 2004)
   f. strategies for creating course change in the department context (curricular and instructional)
   g. strategies for enhancing grant writing skills (collaboration) *Phase 1*
3. Development of a proposal for course change, that offered funding and resources, that applied the NOVA PD model was reviewed with feedback provided (collaboration) *Phase 1*
4. Development of standards-based reform undergraduate STEM courses in a range of institutions from Bachelor's degree granting through research universities (learning environment, course structure, PCK, collaboration) (Goldston, Clement, & Spears, 2004; Gardner, 2004) *Phases 1, 2*
5. Resources including financial support to implement reform STEM courses on a long-term basis (collaboration) *Phases 1, 2, 3*
6. Continuous mentoring and monitoring of progress including evaluation site visits during development and implementation (collaboration) *Phases 1, 2, 3*

7. Action research conducted by faculty teams that examined student and faculty development (PCK, collaboration) and the sharing of results annually at a national NOVA conference. *Phases 2, 3*
8. Continuous long-term professional development activities based on best practices research over multiple years (PCK, collaboration) Phase *1, 2, 3*
9. Collaboration and sharing of expertise and practices between faculty within an institution and among different institutions (PCK, collaboration). (Sunal, 2002). *Phase 3*

NOVA Phase 1 Professional Development Activities

Each year of the project, NOVA personnel conducted a series of workshops for interdisciplinary teams of college or university faculty. A total of 23 Phase I faculty professional development workshops were conducted (see Figure 2). Each institution's faculty team consisted of three or more members, where one member was required to be from the College/School of Education and the other members from STEM Departments. Approximately ten teams attended each initial NOVA Phase 1 faculty development workshop.

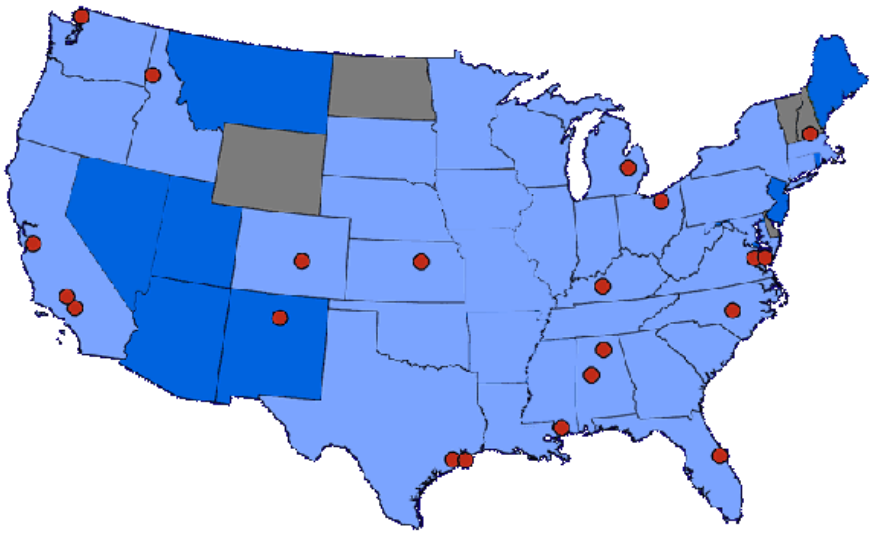

Figure 2: NASA/NOVA National University Phase I Workshop Sties, 1995-2006

During its operation from 1995- 2006, faculty experienced professional development within a national network of institutions. Faculty teams from 240 institutions involving over 550 faculty from 44 states, Washington D.C., Puerto Rico, and the U.S. Virgin Islands attended NOVA workshops during the 12 year period. Proposals from 103 institutions' faculty teams were funded and joined the NOVA Network. The funded teams involved 354 faculty who were involved in developing 167 undergraduate STEM courses at their institutions serving over 15,000 students each year (see Figure 3).

Figure 3: NOVA network of institutions involved in STEM course reform

The Phase 1 workshops focused on the implementation of science and mathematics standards and benchmarks at the college and university level, the use of innovative pedagogy - active and interactive learning - and authentic assessment, experiences with examples of successful STEM course models, the impact of educational technology facilitating learning, strategies for integrating STEM content, utilization of research on development activities from NASA's strategic enterprises, use of action research in course development as continued professional development, as well as an emphasis on collaboration and diversity. The focus was on enhancing learning for all students in undergraduate STEM courses with a special emphasis on developing a new paradigm for educating future teachers. All workshop participants were mentored during and after the workshop. Faculty teams, in particular, received mentoring concerning implementation planning grant proposal preparation, proposal revision(s), implementation, and institutional barriers. For those institutions that became part of the NOVA Network, additional mentoring took place through site visits by the NOVA management team.

A listing of key action elements of the NOVA professional development model is provided in Figure 4. Upon successful completion of a workshop, a participating team was eligible to submit a proposal for an Implementation Planning Grant of up to $34,000, with at least a 1-to-1 cost-share match. An important element following the Phase I activities was the annual Leadership Development Conference (LDC) at which all the NOVA Network institutions were brought together to receive further professional development, present their projects and research results, and join collaboratively in new Network activities.

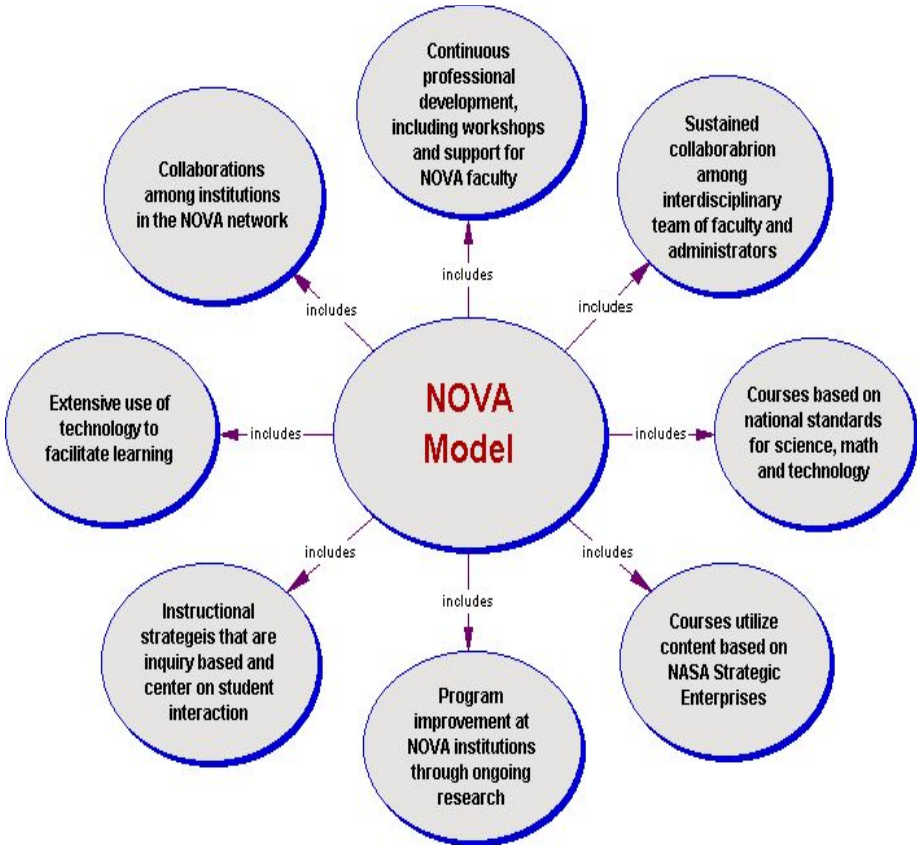

Figure 4: Key action elements of the NOVA professional development model

NOVA Phase 2 Professional Development Activities

A second funding opportunity for NOVA institutions, Phase II Grants, was competitively available for NOVA Network teams, offering the opportunity to propose further development and dissemination of their NOVA projects. Funded institutions developed methods and techniques for replicating the NOVA change model among additional institutions not directly reached by the NOVA workshops. Emphasis was placed on fostering partnerships with community colleges and other educational communities. The research aspect of the Phase II Grants was designed to assess the impact locally, on-site, of the NOVA model. Successful research projects had metrics to include student retention, student achievement and attitudes, innovation sustainability, the extent to which support and collaboration had been maintained, and the overall impact the project had on students, faculty and administrators. Projects also must have produced publishable reports, CD-ROMs, videos, or websites for dissemination.

NOVA Phase 3 Professional Development Activities

The NOVA program further connected local Network activities with NASA's strategic plan and its field centers via a funding program. The overall goal of this program was to create and maintain a NOVA presence at all NASA centers and to infuse

cutting edge NASA data into innovative higher education courses. To ensure the widest possible participation by NOVA Network institutions in this program, participants integrated technology to facilitate learning and well as developing blended and fully online interactive learning activities on websites designed for their NOVA reformed courses. Technology focused on the use of web technology and the use of NASA web products in education. The NOVA technology initiative encouraged the introduction of technologies into college courses and sought to effect change in the manner in which content courses were taught to pre-service teachers.

Meaningful integration of technology was an integral part of NOVA and of web-based learning. The electronic design of an environment for learning is quite different from a design for giving out information. Incorporating technology in a "meaningful way" utilized a number of strategies; the use of electronic asynchronous interactions in the form of "whole class idea containers", where the student's view is presented to the class, small "study group" discussion spaces, private journal spaces, and synchronous "live chat" sessions, allowed students the opportunity to examine their ideas, comments, and reflections, in varying degrees of "safe" environments. The use of technology promoted integration of content knowledge with reflective assignments, while at the same time maintaining a reasonable faculty time involvement, with the goal of offering a significant enhancement to the learning structure.

NOVA Program Evaluation

Initial comparisons of small samples of courses in pilot studies found positive results for the use of the NOVA professional development model indicating it met the specific conditions identified above for successful course reform (Bland-Day, 1999; Staples, 2002; Sunal et al., 2002, 2003b, 2003c). These preliminary studies found increased undergraduate student achievement, long-term change in efficacy in science teaching, positive attitudes toward science, and more effective use of research based science teaching practice among pre-service elementary teachers after they graduated. These preliminary studies found long-term impacts increased as students gained additional experiences in coursework and in classroom teaching rather than declining over time. The NOVA Model design fostered the formation of diverse partnerships and networks that provided for institution and faculty collaboration on a wide range of research and educational endeavors including reforms compatible with new teacher certification. The NOVA program provided a means for faculty and students to exchange and have access to exemplary reform course models, materials, activities, as well as updated NASA research and information. The program also fostered numerous proposals and awarded grants extending the reforms developed under the original NOVA activities.

The NOVA model defined undergraduate standards-based reform STEM courses as classrooms consisting of multiple levels of communication and multiple contexts for communication (Sunal et al., 2004). Teachers and students bring individual frames of reference to the classroom environment and these perspectives shape the ways in which individuals construct meaning from classroom interactions (Morine-Dershimer & Kent, 1999). The following NOVA reform course characteristics resulted from this definition:

- emphasis on facilitating all students' learning of STEM
- use of pedagogy engaging students' prior knowledge
- use of structured inquiry pedagogy with active and extended student participation as a regular part of the instruction
- refocusing of the role of the instructor who works to become a reflective practitioner using action research
- use of integrated multiple learning formats not only separated lecture and lab
- refocusing of STEM content on a few key ideas covered in depth
- use of interdisciplinary approaches in course content
- use of student group reflection and learning activities focused on interactive and collaborative learning through shared responsibility
- emphasis on evidence-based learning, using relevant and real data reflecting the way science is done
- use of diverse technology in most course activities to facilitate learning
- focusing on performance assessment forming the greater part of course assessment (DeBoer, 2004; Heppert & French, 2004; Mason & Gilbert, 2004)

Other studies reporting results of faculty development and course reform projects supported the NOVA model reforms (Gabel, 2004; McCormick, & MacKinnon, 2004; Jordan, Elmore & Sundberg, 2004; Sunal et al., 2001; Sunal et al., 2003; Waggoner et al., 2004). Evaluation and research results reported by these studies supported the key elements of the NOVA model.

Review and Synthesis of the Research Literature on Reform in Undergraduate Science

An extensive review was conducted of numerous sources and items on research and reform in undergraduate science teaching published from 1999-2008. Two major strands relating to undergraduate course reform were determined: a faculty strand and a student achievement strand. Within those strands, specific themes were identified. The research literature review indicated that reform efforts are needed in undergraduate science courses serving pre-service elementary teacher candidates, that undergraduate science faculty have benefited from professional development on teaching, and that support exists for specific types of reform.

Following the literature review, an extended analysis and synthesis was made of 23 studies meeting stricter standards of research criteria. The analysis and synthesis was guided by the research question, *"What criteria can be used to identify the level of implementation of reform in an undergraduate science course?"* The original literature review was an initial means of determining criteria with which to examine and identify the level of implementation of reform and of determining data collection procedures and instruments that may hold promise in a national study.

The synthesis further identified criteria that can be used to determine if a characteristic found in a course can be considered as a reform component. The first criterion is universality: all reform courses include this component. The second criterion is uniqueness: change, or enhancement, in student outcomes would not result if the component were not present. The third criterion is validity: the presence of this variable is measurable in short- and long-term student science performance. The detailed research paper can be read in its entirety at the NSEUS web site as Background Research paper No. 2 *What Do We Know About Undergraduate Science Course Reform? Synthesizing Themes*. (Sunal et. al., 2008a)

Using the literature review as the basis, criteria were developed that could be used to identify the level of implementation of reform in an undergraduate STEM course. Reform course criteria identified in the review of the research literature included the following factors;

- emphasis on facilitating all students' learning of science
- use of pedagogy engaging students' prior knowledge
- use of structured inquiry pedagogy with active and extended student participation as a regular part of the instruction
- refocusing of the role of the instructor who works to become a reflective practitioner using action research
- use of integrated multiple learning formats including more than separated lecture and laboratory approaches
- refocusing of science content on a few key ideas covered in depth
- use of interdisciplinary approaches in course content
- interaction of faculty between colleges (e.g. Arts and Sciences and Education) regarding teaching and learning
- use of student group reflection and learning activities focused on interactive and collaborative learning through shared responsibility
- emphasis on evidence-based learning, using relevant and real data reflecting the way science is done
- use of diverse technology in most course activities to facilitate learning
- focus on performance assessment forming the greater part of course assessment
- faculty participation in a collaborative team representing differing expertise and collaborative interactions, building on effective interpersonal skills and trust,
- a positive college and department climate relating to the reform effort's goals,
- administrator presence and support in the change process,
- beginning with the reform goals to be accomplished rather than with personnel or contextual barriers,
- planning for incremental rather than initial massive change,
- ongoing and consistent monitoring of the reform activities using action research, and
- sustaining through collaboration in a network of faculty within and outside of the institution

Necessary criteria for an undergraduate science course to claim that it is a reform course based on the national science standards are being explored as a result of the review of literature and a national survey of the NSEUS institutions. The criteria should be: (1) universal across all science disciplines; (2) unique in that change/enhancement in student outcomes would not result if it were not present; and (3) relevant and valid in that the presence of this variable is measurable in short- and long-term student science performance. Factors causing change are being considered as a component of the criteria. These factors are of two kinds: individual and situational (Henderson and Dancy, 2007).

Individual factors are those that impact moving from traditional practice to reformed practice. These factors are specific to the individual instructor and include prerequisite knowledge, skills, and beliefs. Other individual factors may exist.

Situational factors include: student resistance to change, the time structure, expectations for content coverage, a lack of instructor time, departmental norms, a lack of resources, promotion and tenure and merit pay concerns, a lack of a core of supporters such as a team of colleagues, and the grading system. Other situational factors may exist.

National Study of Education in Undergraduate Science (NSEUS): Research Model

The goal of the National Study of Education in Undergraduate Science (NSEUS), funded by NSF, is to determine the feasibility of creating reforms in undergraduate science in order to provide an alternative to existing teaching and learning in undergraduate courses. The major elements of this study included (1) a *literature review* of research on previous undergraduate science reform, (2) a *national survey* of faculty and courses at institutions involved in a professional development program aimed at undergraduate reform program, (3) a *pilot study* determining the feasibility, or proof of concept, of the procedures and instruments for gathering data, and (4) a *national study* of a sample from a population of institutions involved in a long-term professional development program and reform of one or more undergraduate courses with the intention of improving student outcomes.

The research model for the NSEUS study links faculty beliefs, perceptions, experiences, and actions to the professional knowledge of the course instructor, including pedagogical content knowledge and abilities in planning, implementing, and conducting meaningful learning in an undergraduate science course. A course's learning environment, content structure and organization, as well as the instructor's demonstrated pedagogical content knowledge and beliefs about student learning, are experienced by students. Students use these experiences to construct their perceptions and values concerning the overall character and nature of the course. As a result of these cumulative experiences, in a general sense, student learning short-term outcomes including perceptions, beliefs, and achievement can be predicted. Long-term outcomes also may be predicted from short-term outcomes. These long-term outcomes can evolve from short-term predispositions established during a course, for example, toward openness to

considering the extent of evidence available to support a hypothesis, or the obverse, a lack of willingness to search for additional evidence. Long-term outcomes may include perceptual understandings such as a conception of the nature of science as evidence based which is learned, or a conception of the nature of science as a set of final form statements, assumed to have support, which are to be memorized. Another long-term outcome may be pedagogical content knowledge (PCK) that is demonstrated in specific ways as a means to represent knowledge for learning by the student. The model suggests, then, that pre-service teacher candidates' predispositions, perceptual understandings, and PCK as demonstrated in their own in-service teaching of science, will show such long-term outcomes (see Figure 5).

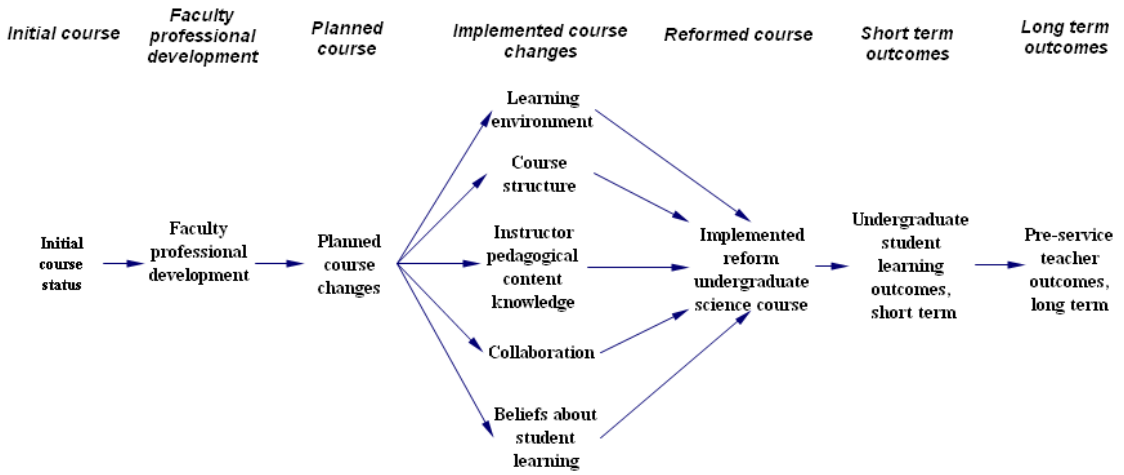

Figure 5: Undergraduate science course impact research model

Other factors play a role in this model and can lead to alternative hypotheses. These include the history and tradition of the teaching occurring in the science departments at an institution, student backgrounds and motivations in courses (e.g. student's academic major), and the nature and prevalence of teaching and learning science in the region's elementary schools. To address these factors, and because such factors are context-specific, comparison courses were selected for the study from the same institution, in most cases from a similar or the same science department. As a means of further addressing such factors, the study utilized random and stratified selection of participant courses and students from the population of institutions.

The population involved 103 institutions at which undergraduate reform courses were taught as a result of participation in the NASA/NOVA professional development program (Freeman, Sunal, Whitaker, & Odell, 2005). From this population, 20 higher education institutions were selected. At these institutions, one NOVA reform course (experimental course) was matched with one undergraduate science course not associated with the NOVA program (comparison course), totaling 40 courses serving about 2500 students. Data were collected from course faculty, current students, and past student participants who had graduated and were elementary classroom teachers. Additional data

were collected on the learning environment found in the undergraduate courses at the college or university and in the Kindergarten-grade 6 classrooms of teachers who were graduates of the selected courses.

One overall research question and the sub-questions link the NSEUS Undergraduate Science Course Impact Research Model, outlined in Figure 5.

Problem: *Do efforts in changing undergraduate science courses based on the key issues in national reports of education make a difference in student learning outcomes?*

Central Research Question: *How do undergraduate entry-level science courses, differing in level of reform, affect student learning outcomes*?

Sub-questions:

- *Does faculty professional development change undergraduate science faculty teaching practice?*
- *How do science teaching/learning course characteristics differ between courses?*
- *How do these differences relate to the learning outcomes of undergraduate students?*
- *How do the differing levels of course reform relate to the short term learning outcomes of undergraduate students and long term outcomes for graduated in-service K-6 teachers in their own school classrooms?*

To investigate the problem of the study, its central question, and sub-questions, NSEUS was conceptualized as developing from several primary study components sequenced so that earlier parts informed later parts. The seven sequenced NSEUS study components were;

1. Review of the NASA/NOVA faculty development program, 1995-2006
2. Review and synthesis of the research literature on reform in undergraduate science
3. Development of the National Study of Education in Undergraduate Science (NSEUS) research model
4. Survey of the population of institutions involved in a program reforming undergraduate science, 2006-2007
5. Pilot study of a small sample of courses selected from the population of institutions conducted to determine the efficacy of the procedure and instruments planned for gathering data in a large scale national study.
6. *Described in other papers:* National study of a sample of institutions involved in a program of reforms in education in undergraduate science, 2007-2012
7. Sponsor national dissemination research conferences and publications on undergraduate science teaching – 2011-2012

This study report focuses on discussion of the first five items.

NSEUS Survey of Population of Institutions Involved in a Program Reforming Undergraduate Science

An important step in the process of implementing the national study was to conduct a national survey of the population of institutions whose faculty participated in a NASA/NOVA professional development program that led to reforms in undergraduate entry level STEM courses (Sunal, Sunal, Mason, Zollman, Sundberg, & Lardy, 2008b, 2008d, 2008e, 2008f). The purpose of the NSEUS national survey was to describe the population of institutions, faculty, and courses. The description was used to determine variables related to reform activities, the implementation process, and the learning environment including the content structure and organization (curriculum) and pedagogy used in the courses. This survey data also was intended to describe the sustained impact of reforms conducted in undergraduate STEM courses over the previous 11 years. Survey data were collected from the population in the spring of 2007.

Characteristics of the NASA/NOVA Population of Institutions

National survey data were collected during the first year of the National Study of Education in Undergraduate Science Project on the population of institutions who participated in the NASA/NOVA program. A total of 103 institutions were involved in the NASA/NOVA Program receiving ongoing professional development, funding, and additional resources beyond the initial workshop phase of the program. The national survey found that the population was represented by a diverse set of institutions (see Figure 6). The 103 institutions surveyed ranged from tribal colleges to doctoral/research universities-extensive (R-I) using the Carnegie (1994) classification. Most institutions (52%) participating in the survey were Master's degree granting, with 47% MA-I and 5% MA-II institutions. The representation of Bachelor's degree granting institutions (21%) included BA-GEN (14%), BA-LA (6%) and BA-SPECI (1%) classifications. Doctoral granting universities (26%) were represented by DR-EXT (16%) and DR-INT (10%). Community colleges in the AA classification represented 1% of the population.

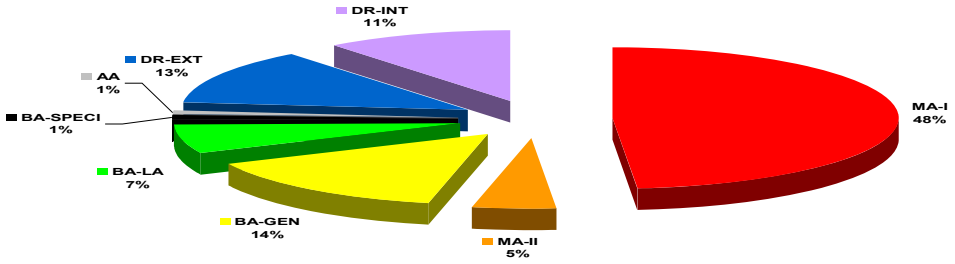

Figure 6: Carnegie Classification of NSEUS Institution Population

Characteristics of the NASA/NOVA Reformed Undergraduate STEM Courses at the Time of the Survey

Within the national population, a total of 185 STEM reform courses were developed under the NASA/NOVA Program continued to be offered at the time of the NSEUS survey. These courses were still being offered at 72 (70%) of the 103 institutions in the population (see Table 1). The developed reforms continued to be sustained in courses offered and in format of the course. The original NOVA reform course was no longer offered at 31 (30%) of the institutions at the time of the survey. At the 31 institutions 39 courses, 21% of the total originally funded, were no longer being offered. The earliest and latest reforms and course offerings occurred between three and 11 years before the national survey. The average course implementation occurred eight years before the survey was completed.

At many institutions, NASA/NOVA reformed courses influenced other faculty teaching other courses at the institution, as instructional practices were changed. In addition to the reform courses created as a result of the NOVA professional development program, courses (n = 118) were created at institutions as a direct result of the impact made by the original reform process on campus (see Table 1). Faculty creating these additional courses had not received NASA/NOVA professional development or grant funding. The NOVA trained team instead acted as facilitators with peer faculty who expressed interest in the results of original reforms. Physics faculty at an Ohio institution, for example, created a reformed introductory PHY 101 (physics) course after seeing the results of student experiences with the introductory biology (BIO 101) course. These new courses have been referred to as NOVA-like courses (or NOVA course clones) with some developed in the same science department and others in different science departments. The NOVA-like courses represent an impact 64% greater than the original 185 courses developed in the professional development program at the time of the survey in 2007. Forty nine (48%) of the 103 institutions reported at least one NOVA-like course with many developing more than one of these courses (see Figure 7).

Table 1
Institutions Offering Reform Courses Created under the NASA/NOVA Program

Course Status	Institutions	Number of Reform Courses	Institutions Offering NOVA-Like Courses not Developed Under NOVA Program but Influenced by NOVA Campus Activity (Number of Courses)
Reform courses still offered	72	146	41 (104)
Reform courses no longer offered	31	39	8 (14)
Total	103	185	49 (118)

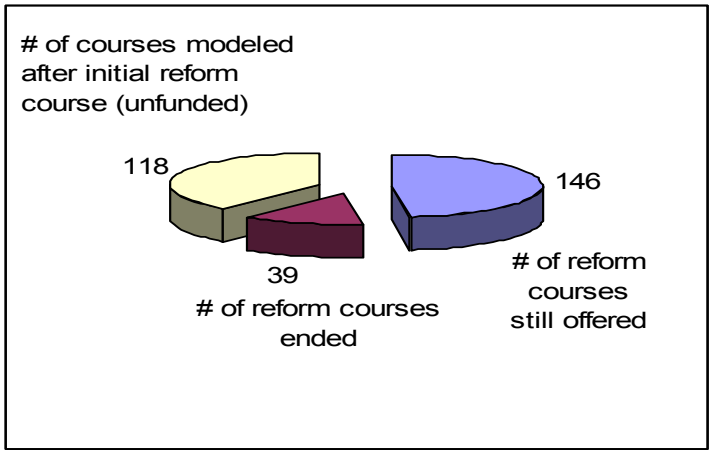

Figure 7: Reform courses at study population of higher education institutions

Characteristics of Faculty Collaborative Teams at Institutions Involved in Undergraduate STEM Course Reform

The NOVA Program involved collaborative teams of faculty from across the campus and included either the Colleges of Arts and Sciences or Engineering and at least one Education faculty member to plan and create courses that were strong in content and pedagogical methods. The 2007 survey investigated the status of the collaborative teams originally associated with the NOVA Program. These teams consisted of 354 faculty members, having 37 new faculty members added over time to replace members leaving at 24 of the original institutions.

Faculty collaborative teams were found to be an important factor in the continuity of NOVA courses offered at the institutions. Sustained offering of the NOVA reform course over many years at most institutions was strongly related to the presence of a permanent faculty team monitoring and, at times, directly involved in teaching of the STEM content course. Most of the institutions no longer offering the original NOVA courses reported the NOVA collaborative teams that had developed the courses had disbanded and were no longer meeting or monitoring the course.

Although collaborative faculty teams were a significant factor in developing and sustaining reform, teams were not stable at a majority of the NOVA institutions. Only 11, 10% of the 103 institution teams, remained intact by the time of the survey in 2007 (see Table 1). To be considered intact, the team contained the same members from its inception until 2007. Nine (82%) of these institutions with intact teams were still offering the NOVA reform courses at the time of the survey, two were not. Of the remainder with teams active at the institution and having one or two original members (n = 61), a subtotal of 51 (84%) were still offering the original reform course, while 10 were not.

Teams were completely replaced or abandoned at 31 institutions, 31% of the total. Twelve of the institutions (39%) at which reform courses were still being offered had completely replaced all faculty members of their original teams, while 19 institutions (61%) whose team members gradually left or at which the team disbanded, had stopped offering the NOVA reform course. In each of the cases surveyed where the teams were completely replaced, the sustained NOVA courses were being taught by new team faculty members added over time.

The reasons given for the replacement or reduction in collaborative team members or the disbanding of the team were that the team members now had new responsibilities at the institution, members had left the institution, members were now deceased, the need for the NOVA course had decreased, or the institutional budget had decreased affecting the course offering. Among those institutions with completely replaced teams where NOVA reform courses were no longer offered, 15 (80%) of the total of 19 teams had lost faculty because they all left the university or were deceased (see Table 1). Once developed, reforms created in the NOVA professional development program had continued in the large majority of cases. The single most important factor in the sustained offering of NOVA reform courses was identified as the continuous functioning of a collaborative team with its faculty team members remaining at the original institution.

Table 2
Collaborative Teams at Each NASA/NOVA Institution in 2007

Course Status	Team Intact	Two or More Team members Intact	One Team Member Intact	Entire Team Left Institution	Institutions Adding New Team Members as Replacements (Number Added)
Reform courses still offered 72 institutions	9	22	29	12	21 (34)
Reform courses stopped being offered 31 institutions	2	3	7	19	3 (3)
Total Teams at 103 institutions	11	25	36	31	24 (37)

Characteristics Identified as Key Reform Components among Reformed Undergraduate STEM Courses

Common course characteristics of the 185 courses at 103 institutions developed by faculty were reported in the 2007 national survey. Reform courses were implemented in interdisciplinary (e.g. aerospace science, natural science) courses as well as single subject area courses (e.g. biology or mathematics). All of the reform courses were available to non-majors, with elementary education majors forming one student component. Each of the courses was available as a means of fulfilling the science or mathematics approved component of the elementary teachers' education certification course program at the respective institutions.

The NASA/NOVA reform courses differed from each other not only in STEM content but also in the pedagogy implemented. Although there was diversity among the courses, consistent reform characteristics were identified by course instructors and team members developing the courses. These common components included:

- starting classes with materials students can see and touch
- asking students about their prior knowledge of the current content topic and/or ascertaining that prior knowledge through students' interactions with materials
- planning for, and allowing, students to become aware of their misconceptions
- actively involving students in many of the course learning experiences
- using simulations and role playing, as in demonstrating the citric acid cycle
- overt comments by the instructor to initiate reflection on their learning among students
- emphasizing student construction of knowledge through inquiry oriented learning
- de-emphasizing memorization of science concepts

Course instructors also were asked to describe the rationale they used to identify the major characteristics incorporated in the NOVA course. All instructors focused on implementing pedagogy that helped their students construct an understanding of the nature of science or mathematics and of the key concepts basic to the STEM topics studied. Since elementary education majors formed one of the student groups in the course, and sometimes the entire student body, instructors also had a focus on helping students transfer their own conceptual learning to everyday life and future careers. Laboratory activities and discussions, for example, at times considered which aspects of key concepts should be taught to students at various elementary grades. Such an approach was considered informative to all students in a course as they considered the development of a concept within the human mind. Course instructors noted that they encouraged elementary education majors to use many or all of the pedagogical strategies encountered in the reform course, such as ascertaining prior knowledge through involvement with materials, with their students when they became elementary school teachers.

Characteristics of NOVA Reformed and Comparison Undergraduate STEM Courses

The review of the literature investigating the impact of reform on learning and teaching found some common features turned off undergraduate students in STEM courses. These include:

1) a lack of relevance
2) science being presented as a set of facts
3) emphasis on competition
4) focus on algorithmic problem solving
5) passive student roles

The identified reform NOVA course characteristics align with the national science standards whose aim is to make STEM concepts more meaningful for all students. Common NASA/NOVA reform course features reported were:

1) involving all students in an inquiry/investigative approach to learning science,
2) using collaborative and cooperative learning groups during course activities,
3) applying continuous alternative assessment, rather than using only a few traditional exams.

Student learning activities reported during the reform course involved the laboratory, during and outside of a class, included about two-thirds of the class time per week (see Table 3). The other one-third of class time involved interactive discussions, use of technology, and lecture (see Figure 8).

Table 3
Instructional Methods Reported Used in NASA/NOVA Reform Courses

Instructional Method	**Average % of Time per Week**
Lecture	15%
Traditional Lab	03%
Discussion/Interaction with student groups	10%
Inquiry Based Integrated lab	68%
Integrated use of technology	04%

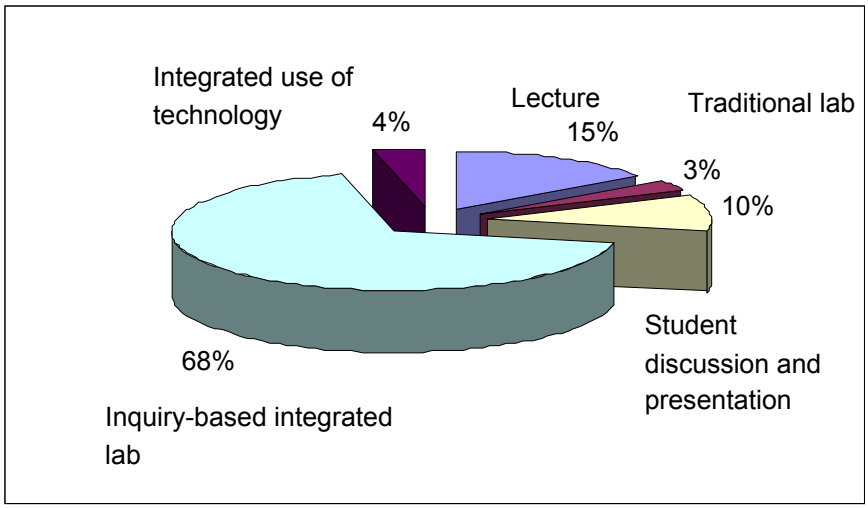

Figure 8: Pedagogy in Surveyed Population of Reform Courses

Overall characteristics of the NASA/NOVA reform courses surveyed included frequent offerings averaging twice a year, and generally offered in fall and spring (see Table 4). The courses had a high average enrollment of minority students (25%), were generally four credit hours rather than three credit hours, and included laboratory work as a regular part of the course, not an add-on that may be taken at another time. Lab and lecture were commonly reported as including the same content at the same time during the semester or instructors reported that the lab and lecture portions of the course were integrated in the same room and at the time. Still-active NOVA courses at the time of the survey in 2007 enrolled about 10,000 students annually. The population of courses surveyed represented a significant sample of the total number of courses and students enrolled in undergraduate science courses in the United States during 2007.

Table 4
Frequency of Selected Reported NASA/NOVA Reform Course Characteristics

Characteristic	**Average**
Years course has been offered at institution	8
Number of times offered in a year	1.8
Course enrollment	39
Minority enrollment	25%
Credit hours	4 (range = 3 - 5)
Number of sections per semester	1.5 (range = 1 - 6)
Number of student enrolling in reform courses per year	~10,000

The national survey data included information on 12 STEM comparison courses, at the same institutions and in the same departments, which had not been involved in the NOVA course reform process. The reported national survey information from these courses indicated that lecture was utilized 68% of the time during weekly class periods, laboratory work was utilized 10% of the time, discussion and interaction of student

groups, 10%, integrated lab, 6%, and integrated use of technology, 6% (see Figure 9). Based on this preliminary reported survey data, there appeared to be a difference in the instructional process occurring in NASA/NOVA reform courses in comparison to other courses in the same department at these institutions.

One may ask the question, "Which of the courses represented undergraduate STEM learning for all students in the 21st century?" If we are to make a change in the way STEM disciplines are viewed by students, we have to change the way STEM content is being experienced by students. In traditional courses, where the majority of the time is spent in lecture, the stereotype that STEM concepts are irrelevant will continue to be perpetuated.

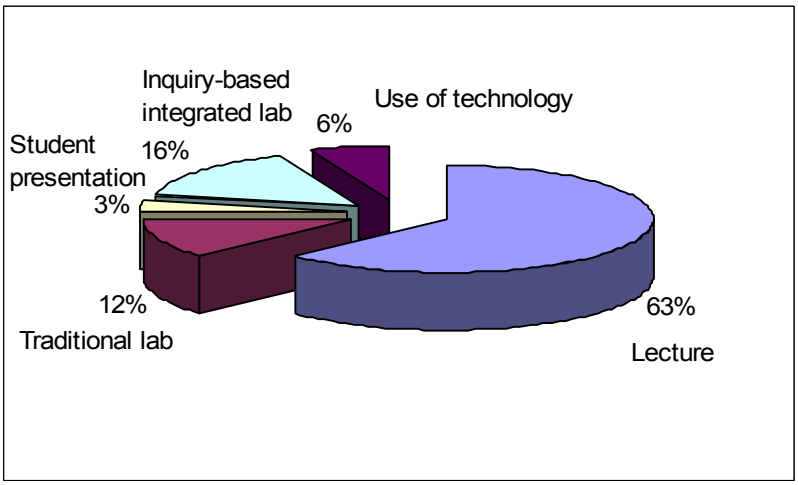

Figure 9: Pedagogy in Comparison (Non-Reform) Undergraduate Courses

National Survey Summary

The initial sample of NASA/NOVA institutions represented a range of Carnegie types from Research 1 through Bachelor's degree granting, and from large in size through small, with one primarily Native American serving institution among them. The population was found to be represented by a diverse set of institutions. The learning environment in reform courses at these institutions shared four common course features:

1) involving all students in an inquiry/investigative approach to learning science,
2) including fully integrated inquiry/investigative activities that involved the majority of a week's class time
3) using collaborative and cooperative learning groups during course activities,
4) using continuous alternative assessment, rather than using only a few traditional exams.

The reform courses were developed and offered at various times beginning in 1996. After eleven years, 70% of the population of institutions continued to offer a total of 146 reform courses. In addition to the reform courses created as a result of the NOVA

professional development program, additional courses (n = 118) were created at institutions as a direct result of the impact made by the original reform process on campus. These value-added reform courses represent an impact 64% greater than the original 185 courses developed in the professional development program over an 11 year time period. Once developed, reforms created in the faculty professional development program have continued in the large majority of cases. The single most important factor in the sustained offering of reform courses was identified as the continuous functioning of a collaborative faculty team with its' original team members or replacement members.

NSEUS Study of Undergraduate Science Course Reform: Focus on Variables of Impact on Faculty and Students

Effective undergraduate science teaching is a complex process requiring specialized knowledge and skills to do it well and facilitate student learning. There is a need to assure that science instructors transform science content knowledge and represent it in a way to promote student learning using research-based strategies (Loughran et al., 2006; Sorensen, Evans, & Andersen, 2009). It is important to investigate current efforts underway in undergraduate science course reform through the knowledge faculty members have available to implement reforms that impact the course learning environment and to study the impact of such actions on student outcomes in those courses.

As a part of the NSEUS research project study, data was collected on the impact of faculty-created undergraduate entry-level science course reform on students of all majors. This student group contained kindergarten - 8 elementary teachers who took these reformed science courses during their undergraduate programs and are now in-service elementary teachers. In addition to students, data was collected examining the level of teaching for inquiry demonstrated by higher education faculty in different types of courses, reformed and comparison courses.

Background

This NSEUS study addressed four assumptions connected to *the National Science Education Standards* (National Research Council [NRC], 1996; Siebert, & McIntosh, 2001); what students learn is greatly influenced by how they are taught, the actions of teachers are deeply influenced by their perceptions of science as an enterprise and as a subject to be taught and learned, student understanding is actively constructed through individual and social processes, and actions of teachers in teaching science are deeply influenced by their understanding of and relationships with students.

Science teaching requires specialized knowledge refined by faculty over time and through extensive experience (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000). We should expect to see differences among faculty instructors of science in our undergraduate science classrooms based on differences in their knowledge of teaching, its application to actual classrooms with students, and the context faculty find themselves in relating to their institution (Sorensen, et al., 2009). For those undergraduate science courses involved in reforms set in interpreting the guidelines of the *National Science*

Education Standards, the knowledge of teaching science, as opposed to a person's knowledge of science, has a great impact on and is particularly important to, the teaching and learning of science by students (Gess-Newsome, 1999; Magnusson et al., 1999; Mason, 1999; Morine-Dershimer, & Kent, 1999).

Research literature describes the learning environment as having an effect on student approaches toward learning, which in turn impacts student learning outcomes (Diseth, Pallesen, Brunborg, & Larsen, 2009, Kreber, 2002). When students have a more positive perception of their learning environment, they are more likely to take a deep approach to learning attempting to use evidence to make connections between the concepts being presented.

Research Design

The NSEUS study began by examining faculty beliefs and goals, instructional actions, learning environment, and classroom context in reformed and comparison undergraduate science courses at higher education level institutions. The study compared these factors to the learning outcomes of students in the courses. Also considered was how differences within and between courses affect current students' short-term outcomes. The use of both quantitative and qualitative methods strengthened the research design. The research design allowed triangulation of data from the literature, the interviews, and the classroom observations.

We investigated undergraduate student's perceptual understanding of the learning environment experienced in courses selected from a national population of higher education institutions addressing the question, "*Do students perceive differences in the level of reform in their science courses."* Students' perceptions and preferences for their learning environment influence their learning in terms of content knowledge, literacy skills, and attitudes.

Selected Sample

The participating institutions, and one or more of their science courses, were involved in the NASA Opportunities for Visionary Academics (NASA/NOVA) faculty professional development program initiated in 1995. The multifaceted NASA/NOVA program was designed to foster reform in higher education through the development and modification of entry-level, undergraduate science courses. The study's population thus included teams of faculty from a diverse national group of 103 institutions that had undergone reform over a 12 year period in one or more of their undergraduate science courses.

From this national population, faculty at institutions who had participated in the NASA/NOVA professional development project and who taught undergraduate science were selected to participate in the NSEUS study. Faculty were called and emailed to solicit their participation. A sample of courses at 30 institutions was finally selected based on the following selection criteria: 1) the NOVA course was still currently being taught; 2) the course focused on the science disciplines (single or integrated); 3) the course was an entry level science course; 4) the course instructor was involved in the NOVA professional development program or related training activities; 5) the course was

required or an elective in the program of study for elementary education majors; 6) the reformed course contained elements of the original NOVA model; and 7) institutions of the courses selected represent diversity in geographical distribution and diversity in character (Carnegie Classification level and type).

Data collection from the beginning original survey to the final course visitation semester for the various selected institutions was completed over a four and one half year period. Attrition from the time of the original survey to the final visitation semester occurred for several documented reasons 1) four NOVA courses ceased to be offered due to death or transfer of the course instructor to another institution, see selection criterion 2; 2) the change in curriculum focus of courses at two of the institutions and limited to secondary science education majors only, see selection criterion 5; 3) the course curriculum was changed at one institution to become a capstone course to be taken during the senior year, see selection criteria 2; 4) faculty instructor at one institution part way through the data collection period decided not to complete the study; 5) post test data failed to be completely collected from one institution, and 6) the curriculum, instruction, and/or character of the course were changed at two institutions so that the reform character of the course ceased to exist. These were found at institutions with budgetary deficiencies and included creating large lecture classes, dropping labs and other features of the original course so that the original NOVA team members indicated that the reformed course ceased to exist.

The final sample size resulted in 20 higher education institutions where data sets were collected. The institutions that participated in this study were located throughout the United States and were diverse. The final sample of institutions represented the population of institutions closely. Pre and post testing along with on-site case study institution visits were completed with 38 faculty teaching entry level reformed and comparison undergraduate science courses.

The NOVA reform courses were all taught by faculty who had received professional development and funding for course development through the NASA/NOVA Program. Each of the courses met the selection criteria described for the sample. In the population survey, completed in 2006-07, it was found that the learning environment in NOVA reformed courses shared four common course features:

1) involved all students in an inquiry/investigative approach to learning science;
2) included fully integrated inquiry/investigative activities that involved the majority of a week's class time;
3) used collaborative and cooperative learning groups during course activities; and
4) involved continuous alternative assessment, rather than using only a few traditional exams. (Sunal et al, 2008a).

The research model on which this study report was based included three sets of data. 1) Comparison faculty instructors: interviews of faculty instructors, who experienced the NOVA professional development model, designed to construct inventories describing expectations, knowledge, beliefs about student learning, and experience (course structure, instructor pedagogical content knowledge, and collaboration); 2) Reformed undergraduate science course: observational ratings and narrative description of events in the reformed undergraduate science course associated with the a faculty instructor's implementation of the course class sessions (learning environment, course structure, and pedagogical content knowledge); and 3)

Undergraduate students learning outcomes – short term: students ratings and narrative description of events through focus groups of the course associated with the faculty instructor (learning environment, course structure, and pedagogical content knowledge) (See Figure 10). This data was analyzed to determine relationships between the faculty instructor and students' perceptions of the learning outcomes as a result of the course experiences.

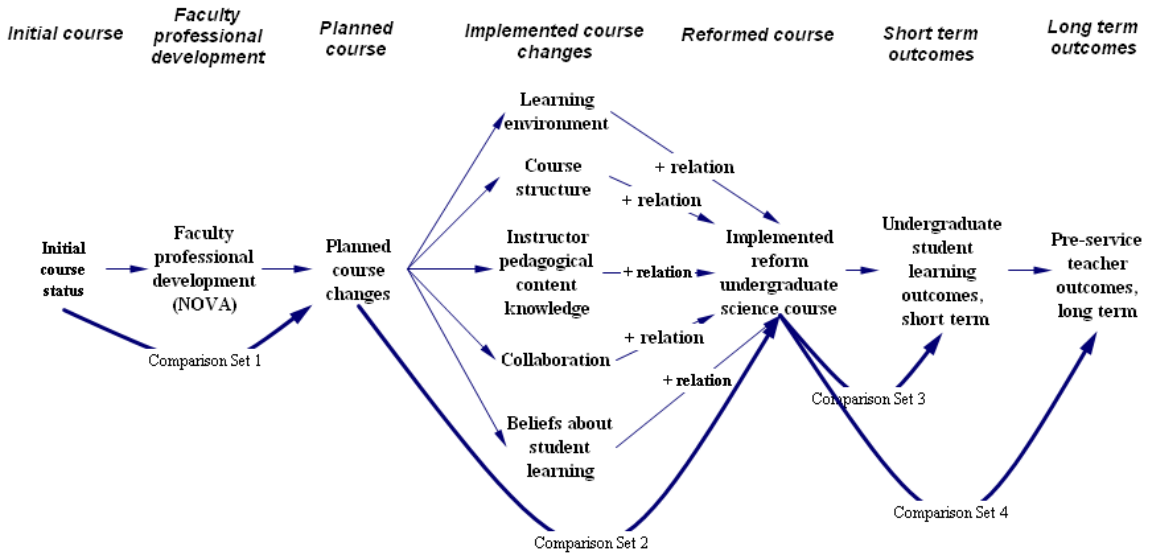

Figure 10: Reform undergraduate science course research model

The comparison (traditional) sampled courses were taught by faculty who had not received professional development or funding for course development through the NASA/NOVA Program. The comparison course selection was based on the following criteria: 1) the course was currently being taught; 2) the course focused on the science disciplines (single or integrated); 3) the course was an entry level science course, similar to the NOVA course; 4) the comparison course instructor was not involved in the NOVA professional development program or related activities; and 5) the course was required or an elective in the program of study for elementary education majors (See Figure 11). The research model design for the comparison courses included three sets of data. 1) Comparison faculty instructors: interviews of faculty designed to construct inventories describing expectations, knowledge, and experience (course structure, instructor pedagogical content knowledge, beliefs about student learning, and collaboration); 2) Comparison undergraduate science course: observational ratings and narrative description of events in the course associated with the a faculty instructor's implementation of the course class sessions (learning environment, course structure, and pedagogical content knowledge); and 3) Undergraduate students learning outcomes – short term: students ratings and narrative description of events through focus groups of the course associated with the faculty instructor (learning environment, course structure, and pedagogical content knowledge) (See Figure 11). This data was analyzed to determine relationships between the faculty instructor and students' perceptions of the learning outcomes as a result of the course experiences.

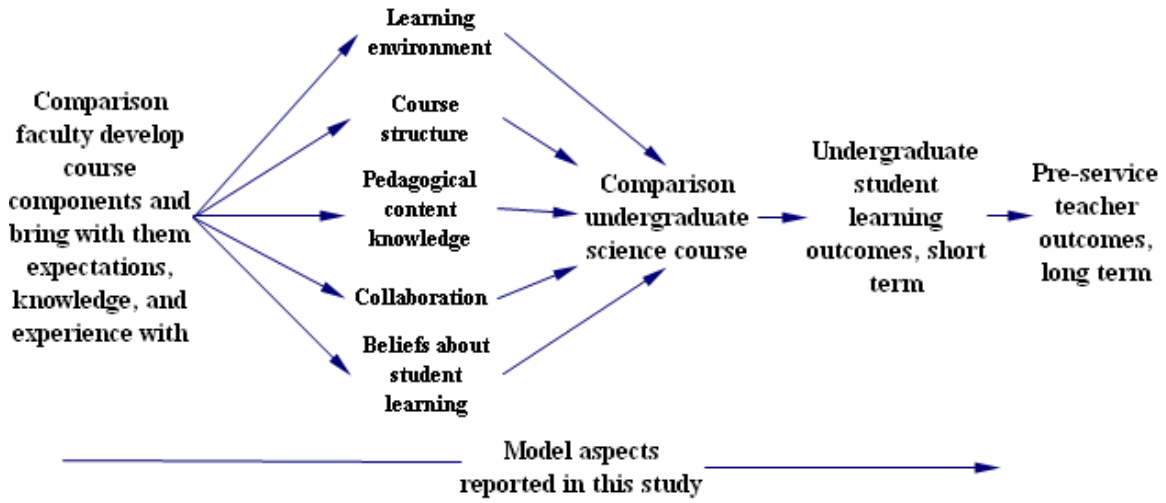

Figure 11: Comparison undergraduate science course research model

Data Collection Procedure

Multiple quantitative and qualitative data sources were used. The research procedures and instruments from reviewed studies were used to develop the study data collection instruments and procedures. (Backer, 2002; Francis, Adams & Noonan, 1998; Krinsky, Anderson, & Kidane, 1998; Project Kaleidoscope, 2005; Slater & Sireci et al, 2003; Swanson & Bilderback, 1998; Wycoff, 2000). Data was collected from all undergraduate students in a course section. A pilot study was conducted in to determine the feasibility of the data collection protocol.

Data was collected during the first two weeks of each semester. This pre test data used online surveys of student perceptions of their course's learning environment. Data was collected from faculty instructors in an online survey describing descriptive data on the course, curriculum, and activities to take place over the semester.

During the middle of the semester, a weeklong site visit to each institution was conducted by several NSEUS observers. Faculty instructors of reformed and comparison courses were observed in all class activities occurring during the week long site visit. Observers used the *Reformed Observation Teaching Protocol* (RTOP) a criterion referenced observational rating instrument designed to measure the degree of reform in a science classroom (Sawada & Piburn, 2000). These observations lasted anywhere from 60 to 90 minutes and typically consisted of a lecture, laboratory, discussion section, or a class that had a combined lecture and laboratory. At least two trained observers observed classroom instruction. The RTOPs were individually scored immediately after the classroom observation and then discussed to resolve any discrepancies between researcher ratings. The laboratories and lecture were combined to give an average RTOP score for each faculty member.

For every instructor whose classroom was visited, a personal semi-structure interview was conducted and course artifacts were collected including syllabi, and samples of lab sheets, course handouts, and quizzes. Notes from the semi-structured interviews, course artifacts, and observation field notes from the *RTOP* narrative were

used to create profile matrices of instructor/teacher pedagogical content knowledge using *Pedagogical and Professional-experience Repertoires (PaP-eRs)* (Loughran et al, 2001. *Content Representation (CoRe)* charts (Loughran, Mulhall, and Berry, 2004 were created for each of the faculty instructors. Students enrolled in the NOVA and comparison courses were also invited to participate in separate focus group interviews.

At the semester's end, post-test data were collected from the students. The students completed the *perceived CLES* on-line. The perceived CLES differs from the *preferred CLES* in that the questions are worded to capture the level of constructivist learning the student experienced in class. Table 5 describes the relationship between NSEUS research questions, variables measured, instruments used, and analysis conducted with the study instruments.

Table 5
Variables, Data Collection, and Analysis

Research Question	Variables Measured	Instruments	Analysis
1	Reform faculty curricular priorities, lesson planning, instruction, & pedagogical decision making (PCK)	CLES (Instructor), RTOP, CoRe & PaP-er, faculty interviews, content analysis of course materials and artifacts	Qualitative and quantitative comparisons will be made between reform variables predicted by the undergraduate science course impact research model
2	Reform and comparison faculty curricular & instructional priorities, classroom learning environment, course structure, PCK, collaboration, undergraduate student learning outcomes	CLES (instructor & student), RTOP, CoRe & PaP-er, faculty & undergraduate student interviews, content analysis of course materials and artifacts,	Qualitative methods, multivariate analysis of variance, and effect sizes will be used to compare reform and comparison courses based on the implementation of reforms and student learning outcomes
3	Reform faculty curricular & instructional priorities, classroom learning environment, course structure, PCK, collaboration, student learning outcomes	CLES (instructor & student), RTOP, CoRe & PaP-er, faculty & student interviews, content analysis of course materials and artifacts,	Qualitative comparisons will be used as well as regressing student achievement onto the levels of reform science course characteristics
4	Reform and comparison faculty curricular & instructional priorities,	CLES (instructor & student), RTOP (instructor), CoRe &	Qualitative methods, multivariate analysis of variance & effect sizes

	classroom learning environment, course structure, PCK, collaboration, graduated K-6 teacher outcomes in elementary school classroom learning environments, student achievement	PaP-er, faculty interviews, content analysis of course and K - 6 science materials and artifacts	compare undergraduate course characteristics & teaching characteristics of graduates of reform courses and comparison courses

The study involved comparative and relational analyses investigating (1) comparisons between reform and non-reform classes at the same institution and (2) comparisons of courses demonstrating differing levels of reform among institutions. Quantitative and qualitative procedures were used for analyzing data in different stages of the research model (Table 5) to increase validity. Comparison analyses examined differences between the courses. Relational analyses examined relationships between the characteristics of the courses and level of student outcomes.

Data Collection Instruments

The study data collection protocol involved classroom observational field notes, semi-structured interviews, and ratings of observed classroom teaching from multiple instruments and sources. The study data collected from each faculty instructor for completion of the Content Representation (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eRs) included responses to background and demographic questions, individual structured interview responses, and classroom observation field notes supported by reports of teachers' thoughts and actions. The data collected for the Reformed Teaching Observation Protocol (RTOP) ratings were narrative records of observations made of undergraduate science classroom activities developed over a week period.

The individual background and demographic questions and structured interviews occurred before the undergraduate science class sessions. A description of the instrumentation is presented below. Several NSEUS trained observers participated during each site visit to assure coverage and observer reliability.

Since personal bias is a factor in any study due to the influence of observers' experiences and beliefs (Gall et al., 2003: Janesick, 2003), precautions were taken to avoid this bias. The RTOP, observed class sessions/lessons, field notes, interviews, and the CoRe instrument were scored immediately following observations made in each classroom and after conducting interviews. More than one observer recorded data independently. The observations were then discussed and averaged. Reliability of separate data sources was evaluated to meet a high quantitative criterion of greater than 0.80. After the classroom observations, interviews, and CoRe reports were completed, the information was used to develop the PaP-eR report. Applying the four PCK rubrics to the PaP-eR was used to determine a PCK score. Reliability was again checked and validated.

Constructivist Learning Environment Survey (CLES)

The Constructivist Learning Environment Survey (CLES) was designed to monitor the development of constructivist approaches in the classroom (Taylor, Fraser, & Fisher, 1997). The CLES measures the role of students in the classroom in helping to construct their own learning as perceived from the teacher's and/or students' points of view. It is divided into five key dimensions of a critical constructivist, standards-based science learning environment:

- Personal Relevance (the degree that what goes on in the learning environment relates to the students' lives)
- Uncertainty of Science
- Critical Voice (whether or not students' have a voice in the classroom)
- Shared Control (level of control shared between students and teacher)
- Student Negotiation (degree to which students have the ability to negotiate with the teacher about the nature of learning activities and assessment criteria)

Categories in the instrument are (1) learning about the world, (2) learning about science, (3) learning to speak out, (4) learning to learn, and (5) learning to communicate. Five items are given for each of the five dimensions with possible responses of; Almost Always, Often, Sometimes, Seldom, and Almost Never.

The CLES instrument has been found to have high reliability on small and large scales (Johnson & McClure, 2004). Results on the CLES have been shown to be very close to what researchers would expect from classroom observation. The alpha coefficient for reliability was 0.92 for an individual student and 0.98 for the class mean.

Reformed Teaching Observation Protocol (RTOP)

The *Reformed Teaching Observation Protocol* (RTOP) is a classroom observation protocol designed to measure quantitative characterization of the degree to which a science classroom is "reformed" (Sawada & Pilburn, 2000). The RTOP draws guidelines from documents published by the National Research Council, American Association for the Advancement of Science, Project 2061, and the National Council for the Teaching of Mathematics. For this instrument, the characteristics of reformed teaching practices are based on national standards for science education. The RTOP observer uses extensive note taking that is followed by rating a list of classroom characteristics on a continual scale of 0-4 ("never occurred" to "very descriptive"). The RTOP was found to have high inter-rater reliability (Sawada & Pilburn, 2000). In this NSEUS study, observers trained in its use developed correlation ratings above 0.85 while observing the same reform and comparison classroom settings (Piburn et al., 2002). The RTOP instrument analyses followed the authors' use of categories and weightings for the items (Piburn et. al.).

Interviews and RTOP rating observations were conducted with 19 reformed and comparison undergraduate science course instructors. The RTOP instrument is comprised of 3 sections to be rated by the observer, (1) lesson design and implementation, (2) content (propositional knowledge and procedural knowledge), and (3) classroom culture (communicative interactions and student/teacher interactions). Each section contains specific items to be rated by the observer. In addition, specific criteria are used when scoring items under each section (see Table 6 below).

Table 6

Reformed Teaching Observation Protocol (RTOP) rating Categories

1. **Background Information**

2. **Contextual Background and Activities (Narrative)**

3. **Lesson Design and Implementation (5 rating statements)**
   Ratings focus on students' prior knowledge and the pre-conceptions, engagement in a learning community, whether exploration precedes formal presentation, alternative modes of investigation or of problem solving, and ideas originating with students.

4. **Content (10 rating statements)**
   Ratings focus on propositional knowledge (content, coherence, abstraction, and connections) and procedural knowledge (representing, predicting, thought provoking, reflecting, challenging).

5. **Classroom Culture (10 rating statements)**
   Ratings focus on communicative interactions (communication through a variety of means, teacher questions, student talk, student questions, climate of respect) and student/teacher relationships (active participation, alternative strategies, teacher patience, teacher as resource person, and teacher as listener).

Additional comments (Optional)

Content Representation (CoRe) and Professional and Pedagogical experience Repertoire (PaP-eR)

Pedagogical content knowledge (PCK) in science refers to combining pedagogical and science content knowledge that is related to ways that best communicate and represent knowledge of science so that it is comprehensible to others, in this case, to students. A teacher's PCK is specific to the particular science concept taught. Two means of capturing and portraying science PCK linked to particular science content and to teaching practice, were used: observing individual science lessons and interviewing both the undergraduate course instructors and elementary in-service teachers. Observation, interview, and analysis protocols for PCK were developed by van Driel, Verloop, and de Vos (1998) and by Loughran, Mulhall and Berry (2004) in the Content Representation (CoRe) and Pedagogical and Professional Experience Repertoires (PaP-ers) instruments. Both instruments, CoRe and PaP-ers, were used together to capture and portray pedagogical content knowledge (PCK) of both undergraduate science course

instructors and K-6 in-service teachers. The procedures for use of each instrument, modified from the original (Loughran, Mulhall, & Berry, 2004) for this study, are described below

CoRe

1. In an interview, the instructor/teacher is provided with questions/prompts related to general and specific aspects in the planned lesson for a science concept/topic to be taught. A narrative is developed that represents a first draft of an instructor's/teacher's PCK for this science concept. The prompts include:

   - What will be the main ideas of this NSEUS identified class session or lesson?
   - What do you intend the students to learn about these ideas?
   - Why is it important for students to know this?
   - What do you anticipate will be some difficulties and/or limitations connected with teaching this idea?
   - What knowledge about students' thinking influences your teaching of this idea?
   - What other factors influence your teaching of this idea?
     a) Describe how you will teach the main ideas in this lesson.
     b) Why will you be using this procedure to teach these main ideas?
   - What are specific ways you will use to determine students' understanding or confusion around this idea?

2. Each CoRe statement is developed, then refined, and then validated during interviews.
3. The process provides a way to enable instructors/teachers to flesh out explanations of their own PCK for a specific science concept that they may not normally think about.

PaP-eR

1. The specific science lessons discussed with CoRe are observed and extensive notes are taken. In some cases, these lessons are audio or video taped.
2. Specific instances, or examples, of how PCK was applied in the observed lesson that were described in CoRe are noted in a matrix for each CoRe question prompt.
3. Additional actions and interactions, observed or otherwise recorded in the science lesson taught, that expand the instructor's/teacher's PCK repertoire are added to the matrix.
4. Each PaP-eR matrix is developed, then refined, and then validated during interviews, finally completing a description of an instructor's/teacher's PCK related to the science concept/topic taught.

Interviews and Focus Groups

Faculty course instructors and in-service teachers who were reform or comparison course graduates were interviewed individually. Faculty interviews focused on their experiences related to planning, developing, and teaching the undergraduate science course. In-service elementary school teacher interviews focused on the purpose and rationale for teaching the observed Kindergarten-grade 6 science lesson and how it related to other lessons recently taught in science during the science unit and to the elementary science curriculum. Current undergraduate students in the sample courses were interviewed in focus groups of four or five students. These interviews focused on students' understandings, opinions of, and perceptions about science, science courses at the college or university, the specific science course in which they were enrolled, and views of science teaching (see Figure 12). All interviews took place during site visits in the semester in which the courses were taught. The interviews usually occurred immediately after their course session was observed by one of the researcher observers.

Sample Undergraduate Student Focus Group Questions

Science Courses taken at the University:
Have you taken other university level science courses (e.g. biology)? If so, identify them.
When I say the word "science" what is your reaction? Describe your' interest in this course and in science in general.
Have your attitudes towards science changed as a result of a college science course(s)? If so, in what way(s)? If not, why do you think this is so?
What has been the most important university science course (to date) that will prepare you for your career? Why do you think so?
How has your understanding of science changed as a result of this course?
What specific activity or assignment enabled you to change your belief about an issue in science or a science concept that you held prior to taking this course?
Which instructional strategy did you experience as most beneficial to your learning science in this science course?

Science lesson just experienced/observed:
How typical is this lesson for this class? If this is <u>not typical</u> describe the typical class session in this course.
What were the main ideas of this class session or lesson?
Why is it important for students to know this?
What confusion did you experience in learning this idea?
Describe how you would like to see an instructor teaching the main ideas in this lesson. Why should this strategy be used to teach these main ideas?
How did the instructor determine students' understanding of, or confusion about, this idea?

For education majors only:
Have your ideas of <u>how you will teach science</u> changed as a result of taking this course/studying science this term?
Do you think that you can become an effective teacher of science? Why or why not?
What do you feel is the best way to teach science in elementary school? Why?
What science content areas do you feel most prepared to teach?

Figure 12: Sample undergraduate student focus group interview questions

Results and Analysis

Quantitative Results

Constructivist Learning Environment Survey (CLES) Assessment Results

The CLES instrument was designed to access students' perceptions of the extent to which the classroom learning environment allowed them to reflect on their prior knowledge, development as autonomous learners, and negotiate their understandings with other students (Taylor, Fraser, & White, 1994). The instrument was given twice during the semester to the undergraduate students (see Table 6).

The CLES instrument was administered through use of online assessment at each sample site. Course instructors notified students that they would be getting an e-mail, an ID number, and a web address to visit during a specific set of eight days. After initial notification, instructors requested student participation in each class meeting over a three day period. No incentive was offered for participation in the online-administered instruments. The students were told, with each request, they would be able to visit the site only once for each survey instrument. If a student left the site, it would not be possible to return at another time to complete the instrument. The participation level of each course differed, with a range of 32% to 75%. Such a range is similar to that being reported by recent research documenting limitations beginning to be reported in online assessment with today's often technology-savvy undergraduate students (Donovan, Mader, & Shinsky, 2007).

There was no significant difference between the reform and comparison courses at the beginning of the course on the pre-test. The post-test results found a significant difference between the reform and comparison course students. Students in the reform course showed a higher sense of overall satisfaction with the classroom environment, than did students in the comparison course.

Table 6

Sample CLES Results from Pilot Study Test Site #1

CLES Pre-Test Statistics					
Course	Sample Number	Mean		Standard Deviation	
Reform	32	3.02		0.82	
Comparison	38	2.91		0.65	
T-Test					
F	Sig	*t*		Sig (two-tailed)	
4.0	0.052	0.62[1]	0.60[2]	0.54[1]	0.55[2]

[1]Equal variance assumed
[2]Equal variance not assumed

CLES

Post-Test Statistics					
Class	Sample Number	Mean		Standard Deviation	
Reform	31	3.65		0.76	
Comparison	33	2.98		0.76	
T-Test					
F	Sig	*t*		Sig (two-tailed)	
0.02	0.888	3.54[1]	3.54[2]	0.001[1]	0.001[2]

[1]Equal variance assumed
[2]Equal variance not assumed

Pilot Study: Undergraduate Student Focus Groups Assessment Results

Focus group interviews were conducted with students in both the reform and comparison undergraduate science courses at Test Sites #1 and #2, totaling four focus groups. Eighteen students participated at both sites for the four undergraduate science courses with four to five participating in each group. About half of the students were pre-service teacher education majors, while the others were mixed among several non-education majors.

Pre-service teacher candidates who completed the reform undergraduate science course indicated positive views of the courses saying they viewed them as better preparation for the profession than would be a traditional science course. Pre-service teachers in the reform course further reported they felt their teacher "cared" and was interested in their successful science progress and learning of important content. Those students in the comparison courses said they felt their instructor "did not care" and was unconcerned about their science learning.

In the reform course, pre-service teacher candidates expressed more positive attitudes toward science and mathematics, making statements such as this representative one, "I did not like science before taking this course, but I like science now." Students in the comparison undergraduate science course generally indicated they did not like science and that the "comparison" course did not help them to develop a more favorable attitude toward science.

Students in both the reform and comparison courses basically described their secondary school science classes as one said, "dismal." Most of the students in both courses could remember doing science laboratory activities in elementary and secondary school and expressed enjoyment in participating in the activities. Students in both courses also described what they wanted to see in a science course at any level, Kindergarten-grade16: hands-on/minds-on activities, more interaction with the teacher with less lecture time, make sure everyone learns before moving on, and more interaction with each other.
Similarities and differences were noted between the focus groups enrolled in the reform and comparison courses at both test sites. The consensus similarity for both groups was

that the students wanted science content to include theoretical and abstract ideas along with more practical applications and more overt connections to society and personal lives (See Table 9). The major consensus among the reformed course students that differed from the comparison students was that they felt comfortable with the course and had gained an increasing interest in science. Comparison students' consensus was that science was foreign to them and that they had to endure what they viewed as the discomfort engendered by taking a science class just because they were required to take and pass science classes.

Table 9
Undergraduate Student Focus Group Comments

Samples of Reform Course Students' Comments	Sample of Comments Expressed by both Focus Groups – Common Themes	Samples of Comparison Course Students' Comments
• I didn't like science before, but I like science now. • Class material is presented in a way I can understand. • Material is presented in several ways during class. • I can learn the material. • I can tell you the purpose of this class. It is … (Purpose of the lesson as stated by teacher was the same as the purpose stated by the student.) • I think the overall goal of this class is … (Overall goal of the course as stated by the teacher was the same as the overall goal for the course stated by the student.) • This lesson can be used when I teach elementary school, even if I have to modify some of the material. • I can teach science.	• Hands-on is the best way to present material. • Make the content relevant. • Make the content practical and connect it to students' lives. • Experiences in elementary and high school were generally dismal: we read the book and answered the questions at the back of the chapter; we had to know the definitions. • I'm not a math person.	• I don't like science and this course does not make me like science. • Material is presented over my head. • Material is only presented one way. • I need help with the problems. • The teacher doesn't explain well. • The purpose of the lesson is unclear to me. • I am not sure what the overall goal of this class is. • The lesson has no applicability to my future career as a teacher. • I don't know if I can teach science very well, and I am not sure I want to.

Pilot Study: Reformed Teaching Observation Protocol (RTOP) Assessment, Interview Results, and Content Representation (CoRe) and Professional and Pedagogical experience Repertoire (PaP-eR) Assessment Results

Short Term Results for Undergraduate Science Course: Instructors' Science Class Observations and Interview Results

Four college instructors were visited, interviewed, and observed teaching in the science classes at two institutions. The reform course instructor demonstrated a positive attitude toward teaching a "reformed" type of undergraduate science course.

> This [class] works so well that I am trying to change my other classes to not lecture so much because they get the totally glazed-over look. They don't seem interested at all. And, this class is completely different. You are taking people who have no interest in [science] at all in the first place and, at the end of each unit, I actually ask them to write a little reflection. And, often they will say, "I've never liked science before in my whole life. This class is so fun that I'm changing my attitude.

During the class observations, students in the undergraduate reform courses were observed by the researchers to be engaged with the instructor and with the content for the entire lesson. There was a great deal of interaction, student to student, teacher to student, and student to teacher, during the observations of the reform course. The teacher usually gave a brief lecture to introduce the lesson, then the students were engaged in inquiry investigations for the rest of the lesson. Both instructors in the reform courses indicated they learned to use "constructivist teaching techniques" in the NOVA professional development program and/or from team members who participated in the program.
The teaching strategies actually being used in the comparison courses did not always correlate with what the comparison course faculty member thought he/she was doing in class. Goals expressed for the undergraduate science reform and comparison courses were similar: help increase student interest in science, make science relevant to students and their careers, become science literate, and to meaningfully understand the key concepts covered in the course. An example of a goal statement expressed by one reform course instructor that was very similar to those expressed also be comparison course instructors was, "A lot of them [students] do not have the best attitude towards science. It's not their favorite subject. They're afraid of it. They don't enjoy it. I'm trying to get them interested and engaged." Based on evidence observed using the RTOP observation instrument, although the comparison and reform instructors had similar goals, the reform faculty were observed to accomplish them while the comparison faculty did not. While the goals were similar, reform and comparison course instructors used different strategies for accomplishing their goals. In observations made in the comparison classrooms students appeared bored and unengaged with the teacher and the content; almost no student to student interaction and little teacher to student or student to teacher interaction. Comparison course faculty typically lectured and showed a *PowerPoint* presentation during class.

The RTOP overall average score for the reform instructors was 3.2 and the RTOP average for the comparison course instructors was 1.5. There clearly was a difference between the four undergraduate instructors that was supported in the interviews with the instructors, during student focus group interviews, and the extensive classroom observation notes taken by the researchers. One commonality overtly expressed in interviews by several of the pilot group instructors, both reform and comparison, was frustration as to the lack of administrative support to create better instruction. While both reform and comparison course instructors continued working toward essentially shared goals for their classes, they indicated that efforts at higher quality instruction were impacted by lack of administrative instruction and the lack of evidence that such instruction was a goal of the administration.

Table 10
Undergraduate Science Classroom Observations Using the RTOP

Sample of Classroom Observations Made in the Reform Undergraduate Science Course Classrooms	Sample of Common Classroom Observations Made in Both Types of Undergraduate Science Classrooms	Sample of Classroom Observations Made in the Comparison Undergraduate Science Course Classrooms
• Extensive student-student interaction during the class • Extensive teacher-student interaction during the class • Lectures were short and provided in a "just in time manner" coordinated with students' inquiry activities • Lecture and laboratory were integrated	• Teachers used technology: smart boards, *PowerPoint* etc. • Content presented in both courses was current, appropriate, and accurate.	• Little requested, or planned, student-student interaction • Teacher lecture took up the majority of the time • Students appeared bored and unengaged with the teacher and the content • Lecture and laboratory were separated in time

Long-term Results for Graduated Students: Kindergarten-Grade 6 In-service Teachers' Science Classroom Lesson Observations and Interview Results.

Twelve in-service teachers were visited by pilot study researchers. The in-service teachers had graduated from the pilot university. As undergraduates, they had taken either the selected reform or the comparison science course. The visits were coordinated with, and selected in cooperation with, the college or department of education at each college or university.

The selection of in-service teachers was through a stratified random process. In-service teachers within a reasonable driving distance of two or less hours from the university, who were graduates from the institution in the past two to four years, were first identified. These in-service teachers' classroom experience thus would include at least one and up to four, years. Next, the identified teachers' course transcripts were scanned to identify the presence or absence of the reformed or comparison undergraduate science course. All students enrolled in a Masters' degree program were eliminated. From each list, three teachers were randomly selected for visitation in the pilot study. Arrangements were then completed, including IRB applications, with the school district, principal, and teacher. Interviews were conducted with each of the 12 in-service teachers following the science lesson observations. The results are summarized by type of course experience, (see Table 11).

Differences between the in-service teachers were found that related to earlier comments made by students currently enrolled in the reform and comparison undergraduate science courses (see Table 11). In elementary classrooms whose teacher previously completed the reform course, RTOP classroom observations indicated these teachers were more likely to focus on the science standards based pedagogy in their observed elementary science lessons: constructivist teaching techniques using more inquiry, hands-on/minds-on activities, less teacher talk, and cooperative groups. These

elementary classrooms had more student to student interaction and students were more likely to generate questions used by the teacher to continue the lesson. It also was observed that students in these classrooms were more engaged in the lesson, appeared less bored, and were more excited.

During the interviews, the six in-service teachers who completed the reform courses indicated that those courses were more appropriate preparation for teaching than were the undergraduate traditional science courses they had taken. These teachers described elementary science in their classrooms in terms of the experiences they had in the reform course. One in-service teacher commented as follows.

> Hands-on activities in the classroom. Earth/space to biology, engineering types of stuff. Activities that are hands-on. We got to do activities we can use in the classroom. We were each assigned two activities to present to the class. We had to teach the activities. You have to let the students be involved instead of just feeding it to them.

Another teacher noted,

> The … [reform] science course really excited me. I do a whole space unit. I really enjoyed my biology class because we went out to the creek and dug up animals. I really enjoyed the hands-on past. It is my favorite subject to teach.

Science instruction in elementary classrooms was similarly described by other in-service teachers with reform course experiences. The focus of the comments was on science as interactive and meaningful. "Hands-on. Letting the student do the work. Think the technology helps a lot. The children love going to the board." "I don't use many workbooks in science." "I try to use hands-on as much as possible." "It was the hands-on that really got me."

During interviews, in-service teachers who completed the comparison undergraduate science course described elementary classroom science instruction as text-book driven. In describing her science lessons, one comparison teacher reported "Once I became a teacher with my own book and my own grade level, I taught science. We adopt textbooks and the textbooks have changed. There's been lots of change so we have to change what we teach." This teacher's comments were representative of those who had taken the comparison course.

A major barrier to effective science teaching was identified as a lack of time by all of the in-service teachers. Elementary teachers are pressured to ensure their students have high stakes standardized test scores on reading and mathematics. A comment similar to that made by other teachers is the following in which a teacher discusses her science in terms of restrictions placed upon time available for science by the time required to be available for reading and mathematics.

> Time. You have to make time for science. I turn it into a reading lesson. You have science and social studies twice a week. The … core curriculum test. It is very demanding and we are very responsible for it. Reading and mathematics is on the third grade test. It has mostly word problems set up in multiple choice formats.

The RTOP overall average score for the in-service teachers who have graduated and participated in the undergraduate reform course was 2.2. The RTOP average for the comparison course in-service teachers was 1.2. There is a difference between these 12 in-service teachers that is supported in the interviews and the extensive classroom observation notes taken by the researchers.

In summary, based on RTOP observations and an interview, in-service teachers who completed the comparison undergraduate science courses were more likely to present in their observed science lessons as a reading lesson where students read passages out loud and searched for answers to the teacher's questions. These same teachers were more likely to be over-reliant on the textbook and used the teacher's guide to ask the students questions about the science textbook readings.

Table 11
Elementary School Science Classroom Observations

Sample of Classroom Observations of In-service Teachers' who Had Completed a Reform Undergraduate Science Course	Sample of Common Classroom Observations Made in Both Groups of In-service Teachers' Classrooms	Sample of Classroom Observations of In-service Teachers' who Had Completed a Comparison Undergraduate Science Course
• used more hands-on/minds-on activities • relied less on the textbook and more on students activities and discussion • described their science lessons using terms compatible with constructivist pedagogy	• Teachers used technology: e.g. smart boards, *PowerPoint* presentations	• presented a reading lesson using the science textbook • had elementary students read passages out loud, • teacher asked questions, • students searched for answers in passages

Pilot Study: Results Summary

Quantitative Data Summary

The quantitative results can be summarized as follows: (1) students in reform-based science courses perceived a more positive classroom learning climate than did those in comparison courses. Significant differences existed between the reform and comparison courses. Reform course students perceived a learning environment more compatible with the reform goals of the national science standards, than did students in comparison courses. (2) Little or no growth in science content achievement or

understanding, in perceptions of science, or of the impact of science on society was found over a one semester period in the undergraduate courses.

Qualitative Data Summary

Using triangulation among the qualitative data sources in this small pilot study, the results demonstrated agreement on several important outcomes. The reform undergraduate courses demonstrated a higher level of reform characteristics than did the comparison courses. Differences between reform and comparison courses were found in: short-term impacts on students and long-term effects on graduated in-service teachers in their own classroom science teaching; identification of characteristics of reform courses producing significant impacts; and identification of characteristics of effective faculty. The more positive classroom learning environment results were related to long-term learning outcomes. Reform course undergraduate students also had a much more positive attitude toward science than comparison undergraduate students and had a better understanding of the relevance of the course's material to their own lives. Not all reform elementary science lessons, however, by in-service teachers who were reform course graduates were rated higher than those science lessons of the comparison course graduates.

All faculty and elementary teachers described at least a partially reformed view of how science should be taught and a majority claimed to incorporate such strategies into their classrooms. The ideas expressed in interview responses, however, did not always correlate with classroom observations. Many of the faculty and teachers seemed to know what needs to be done (at least generally) to effectively teach science, but did not have the knowledge, skills, time, and/or incentive to accomplish the kind of teaching they described. One comparison faculty member, for example, claimed that he tried to incorporate strategies into his teaching that engaged students, made the information relevant to their lives, and encouraged them to understand rather than memorize. Evidence from both the comparison undergraduate focus group interview and the observation of this instructor's class, however, demonstrated primarily traditional teaching methods with passive student roles. This is an indication that, although the faculty member knows what characteristics are related to research supported teaching and learning, he may not have the general pedagogical knowledge, pedagogical content knowledge (PCK), or the related skills to be an effective instructor who was described in the interview.

Transfer from a reform class to a traditional class in the same or another science discipline was described as sometimes occurring, although it did not occur quickly. For example, one reform faculty member explained that initially reform-based practices were confined to the class that she designed. After teaching the course for several years, however, she has started to try to incorporate the same types of strategies into her other undergraduate science courses.

Even modeling of inquiry-based activities in a reform undergraduate course does not guarantee that the knowledge of inquiry-based teaching in that one science concept

area will transfer to the teaching of other science concepts when the course graduate is an in-service teacher. In her interview, for example, one elementary teacher described the best way of teaching science as being inquiry-based. The activities that she described for teaching earth and space science, as modeled in the reform course that she took, did sound like inquiry-oriented activities. The "hands-on" biology activity that was observed in her classroom, however, was a "color, cut, and paste" activity and was not at all inquiry-based. It seems that all of her inquiry-based activities came from her experiences in the earth and space science reform course. Because she does not have an adequate model for teaching other science disciplines in an inquiry-oriented manner, such as biology in the case of the lesson that was observed, she used activities she thought were inquiry-based, but actually were not when teaching biology concepts. In another and similar example of failure to transfer knowledge of instructional pedagogy learned from a reformed course, an in-service teacher described the inquiry-based activities that she learned in a life science course for elementary teachers as being a great resource for teaching hands-on science. Because she teaches pre-K, however, she did not think that she could incorporate any elements of those activities into her current classroom.

Besides modeling, transfer also seems to be an issue with confidence in teaching science. While the elementary in-service teaches who were reform course graduates expressed confidence in teaching the science subject that was the focus of the reform course, they were less confident when teaching other science disciplines.

Additional constraints to reform-based teaching common among both faculty and elementary in-service teachers, included lack of time and lack of incentives. For faculty members, the emphasis in higher education institutions was reported as being on research rather than teaching. Faculty at the pilot institutions had a large teaching load, so any spare time was usually spent on research rather than on investigating effective teaching strategies or conversing with colleagues about instruction. Because of a lack of time for communication, knowledge and skills about reform-based teaching were not disseminated to faculty members; although the reform and the comparison instructors worked on the same campus and, in one case, in the same building and department, Although they shared the same instructional goals, there was little communication about instructional strategies between faculty due to a lack of time and incentives. Similar and even greater forces affect elementary teachers, who feel constrained by state-mandated standards, high stakes testing, and lack of time to teach science. Since the focus of state standards and testing programs is primarily on mathematics and reading, elementary teachers need to have extraordinary incentives and creatively make time to teach effective science.

Issues affecting change vary according to the beliefs of faculty members about undergraduate student learning and teaching, the extent of reform characteristics effectively utilized in the undergraduate science course, and other factors. While most faculty members attempt to implement innovative change in coursework, their success can be limited, and the reform components unconnected, but their effectiveness can be improved.

Implications for Future Research in the Teaching and Learning of Undergraduate Science

Undergraduate science courses influence the science literacy of all affected students, and especially, elementary teachers' ability to implement standards-based reform in their own classrooms. Changing undergraduate science courses is perceived to be deceptively easy, but there are many issues that higher education faculty must confront before innovations can be implemented and sustained. To develop expertise in teaching undergraduate science, faculty members require additional knowledge and professional skills in relation to basic issues involving models of innovation in undergraduate science, effective components of successful science course reform, methods for conducting educational action research, and awareness of research supported best teaching practices.

This study, the National Study of Education in Undergraduate Science (NSEUS), was designed to establish criteria for identifying varying levels of standards-based reform in undergraduate science courses and to examine the impact of reform in terms of the improved science literacy of all affected students. The institutional population for this study is national (see Figure 3). This research investigation seeks to advance the understanding of characteristics of entry-level undergraduate science courses impacting subject matter knowledge among all undergraduate students and the pedagogical content knowledge of pre-service teachers that translates into more effective science teaching in the school classroom.

The initial major elements of the NSEUS five year project, included (1) a literature review of research on previous undergraduate science reform, (2) a national survey of faculty and courses at institutions involved in a professional development program aimed at a program of undergraduate science reform, and (3) a pilot study determining the feasibility or proof of concept, of the procedures and instruments for gathering data (see Figure 15). Additional results can be found in accompanying papers.

NSEUS RESEARCH PARTICIPANTS

Participants: Science faculty, students, and in-service K-6 teachers of reformed and comparison undergraduate science courses at selected institutions.

- **Year 1**

National Survey and Literature Review Synthesis: **Population = 103 higher education institutions reforming courses from 1996-2007 using a similar professional development model**

- **Years 1-2**

Pilot Study and Selection of Sample: **Sample = 2 institutions, 4 courses, 12 in-service elementary teachers**

- **Years 3-5**

National Study: **Sample = 20 US institutions, approximately 40 entry level undergraduate science courses, 100 in-service elementary teachers**

- **Years 5-6**

Analysis of Data and Dissemination: Sample data and national conference

Figure 15: NSEUS Research Participants

The goal of the National Study of Education in Undergraduate Science (NSEUS) is to determine the feasibility of creating reforms in undergraduate science in order to provide an alternative to existing traditional undergraduate courses. The success of the preliminary work in provided guidance and a process for the study to continue. The NSEUS study of a sample from a national population of institutions involved in a long-term professional development program, and reforming of undergraduate courses is continuing (see Figure 15). Data has been collected from the national sample of 20 institutions (see Figure 16). The selection was completed using a stratified random process. Institutions were stratified by Carnegie type and the sustained offering of the reform courses. The characteristics of the sample relate closely to the population of institutions from which they were selected. NSEUS research project collected data beginning in the 2006 academic year and was completed in 2012.

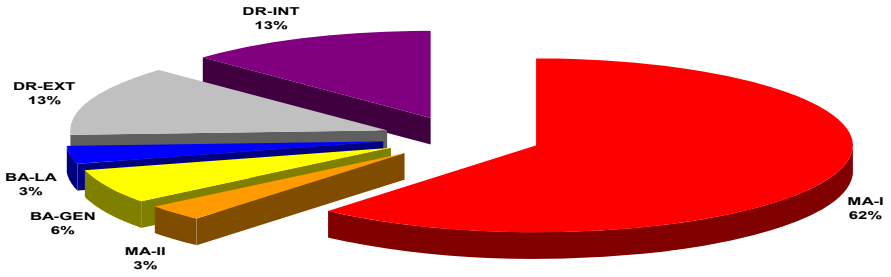

Figure 16: Carnegie Classification of NSUES Institution Sample

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