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Analysis of Funded Engineering Education Projects

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Abstract

The National Science Foundation's Course, Curriculum, and Laboratory Improvement (CCLI) program in the Division of Undergraduate Education has been active since 1999; however, there has been little effort to establish or maintain records concerning the types of projects, extent of funding, and attributes of funded projects. Using data from interviews with NSF staff and stakeholders and archival evidence of historical grants, we created a profile that provides a cross-section of historically funded CCLI awards in engineering education and a snapshot of CCLI's current status.

Executive Summary

In today's rapidly changing global economy, science and technology are driving forces. American businesses are realizing the need for high-quality engineers in order to compete in the international marketplace. The economic and technological superiority of the United States depends on the strength of those working in science, technology, engineering and mathematics (STEM) fields. STEM workers are the key to a high-technology society. Their innovations sustain and cultivate the technological advantage of the country. Thus, STEM education has become a high priority for international businesses and national education policy.

The National Science Foundation (NSF) funds education research and development projects through its Course, Curriculum, and Laboratory Improvement (CCLI) program. To systematically build upon past studies, funding programs like CCLI need to know three things: 1) how their funds have been spent; 2) what they have learned from this research; and 3) what they would like to know next. If CCLI had a summary of its awards, it would have all of this information at its fingertips. Until recently, such information was not readily available.

This project filled this gap by creating a profile of the National Science Foundation's CCLI awards in engineering education. The profile helps the National Science Foundation to communicate with potential applicants and policy makers alike and thus helps to accelerate the pace of education reform.

Work on this project began with an extensive review of pertinent literature. Among the topics investigated were:

- The National Science Foundation and its role in the history and development of STEM education,
- The psychology of education and education pedagogy,
- Applying undergraduate education to careers in engineering,
- Efforts by engineering organizations such as the Accreditation Board for Engineering Technology and the Engineering Education Coalitions to improve undergraduate engineering education, and
- The future of undergraduate engineering education.

The literature review process also provided an invaluable understanding of terms and topics commonly used within the world of education research, particularly in engineering.

Following the literature review, a methodology for constructing the profile was created. The methodology was designed in a manner that would increase the efficiency of the database construction process and maximize the usefulness of the profile to CCLI Program Staff, potential CCLI applicants, and other NSF stakeholders. Two methods were primarily used for gathering necessary data: interviews and the construction and manipulation of an awards database.

Interviews were held with persons deeply invested in engineering education research and development such as:

- Current and former NSF Program Directors (PDs),
- Principal Investigators (PIs) working on CCLI-awarded projects,
- Government stakeholders including senior staffers from the Senate Committee on Health, Education, Labor, and Pensions (HELP), and
- Members of organizations committed to improving undergraduate engineering education such as the American Society for Engineering Education (ASEE) and the Accreditation Board for Engineering and Technology (ABET).

Interviews were used to determine which characteristics would be most important to include in the profile and to ensure that the profile had a broader context than merely the CCLI awarding process.

A combined database of 584 CCLI engineering education awards was constructed using information from the NSF's public awards database coupled with data manually extracted from the NSF's internal awards database. Using this database, analysis began on objective and subjective characteristics of proposals.

Aggregate objective data was collected and analyzed for all 584 proposals in engineering education since the inception of CCLI. A subset of 125 proposals was also created including all Phase 1 and Phase 2 proposals from the years 2006 and 2007. These years encompassed the entire period since CCLI overhauled its funding structure and research solicitation. For these 125 proposals, an in-depth analysis of subjective characteristics, found only by reading individual proposals, was conducted.

The aggregate data was investigated first in order to gain background knowledge on the people and institutions working on the projects funded by the CCLI. Analysis provided information on:

- The types of institutions receiving awards,

- The amounts awarded to these institutions, and
- Senior personnel involved with these projects.

After the historical analysis of all 584 awards, an analysis of subjective characteristics of Phase 1 and Phase 2 projects awarded in the years 2006 and 2007 was completed to better profile the current funding program. Topics investigated included but were not limited to:

- Academic discipline,
- Number of persons involved and impacted,
- Focus of the research or development,
- Evaluation methods,
- Dissemination methods, and
- Which ABET criteria for accreditation were targeted by the project.

Using Microsoft Excel, a template for rating proposals on these various subjects was created and then implemented.

After careful examination of the data, a list of recommendations was made and presented to the staff of the Course, Curriculum, and Laboratory Improvement program at the National Science Foundation. These recommendations include:

- Expanding the analysis of subjective characteristics to all 584 CCLI awards in engineering education since the inception of the program,
- Continuing to update the database as awards are made,
- Revising the current record keeping system to expedite the data entry process for future updates to the profile,
- Expanding work done in this project to other academic disciplines within CCLI including but not limited to Chemistry, Biology, and Physics,
- Expanding the profile to include characteristics which time did not allow this project to investigate, and
- Disseminating the results of this project to the entire engineering education reform community.

Access to information from sources such as the National Science Foundation greatly assists in advocating the engineering education reform movement. In order to maintain its place in the global economy, the United States needs well-trained professional engineers. As the demands on the engineering community change, so too should the way engineers are educated. The National

Science Foundation is in an ideal position to assist with this endeavor and should continue to play a leading role to improve engineering education.

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1. Introduction

In today's rapidly changing global economy, science and technology are driving forces. American businesses are realizing the need for high-quality engineers in order to compete in the international marketplace. The economic and technological superiority of the United States depends on the strength of those working in science, technology, engineering and mathematics (STEM) fields. STEM workers are the key to a high-technology society. Their innovations sustain and cultivate the technological advantage of the country. Thus, STEM education has become a high priority for international businesses and national education policy.

Ideally, businesses and educational institutions would have access to high-quality STEM graduates. Unfortunately, this is not the case. In fact, the percentage of undergraduates in STEM programs is falling rapidly, from 32% to 27% from 1994 to 2003 (Ashby, 2). As fewer students graduate with STEM degrees, the number of jobs available is increasing. Employment in STEM fields rose by 23%, which easily outpaces the 17% job growth outside of STEM fields (Ashby, 3). If these trends hold, there will undoubtedly be a shortage of STEM workers in the near future.

In response to this looming shortage, several organizations including the National Science Foundation (NSF), the National Academy of Engineering (NAE), and the American Society for Engineering Education (ASEE) have begun initiatives to improve the STEM curriculum and recruit more STEM students. The NSF has several programs to advance STEM education at a postsecondary level through its Division of Undergraduate Education. One such program is Course, Curriculum, and Laboratory Improvement (CCLI).

The National Science Foundation created CCLI in 1999 by combining three earlier programs. It is now the main avenue for educational research and development projects for STEM education at the undergraduate level (NSF 2007). In the eight years since the program began, CCLI has funded approximately 2000 projects for undergraduate education development (2007). Despite the large number, little effort has been made to characterize the nature and extent of these projects.

Since there has been no sophisticated analysis of CCLI project funding, the NSF cannot examine past and present projects collectively to determine their broader educational impact and effectiveness. Likewise, they cannot satisfactorily inform policy makers and other external stakeholders of the progress their programs have made in STEM education. In order to examine the educational impact and effectiveness of its programs, the NSF would first need a profile of CCLI expenditures for STEM education. The profile should include information about the academic field of the research, the nature of the effort (pedagogy development, assessment, material development, etc.), the participants (number of principal investigators, institutions involved, etc.), the evaluation efforts included in the project, and the manner in which the researchers allocated their funds.

We collected all available information and synthesized it into a profile of CCLI engineering education grants. To develop this profile we:

- Identified the important characteristics of project proposals to include in the profile. The categories of information include data such as: targeted field, award value, nature of research effort, etc.
- Applied the profile to the engineering education proposals the National Science Foundation's CCLI program has funded, assessed trends, and mapped the direction of the program.
- Identified how NSF personnel and applicants to NSF funding programs would use this profile in the future.
- Demonstrated how CCLI programs align with the direction proposed by professional engineering education organizations such as ABET (Accreditation Board for Engineering and Technology) or EEC (Engineering Education Coalitions).

The NSF program officers will help shape the direction of our research as we uncover patterns and trends among the proposals. We searched for patterns in given categories and presented the information to the NSF staff. They then provided a list of more specific information and new topics to investigate. This iterative process aided in making the profile as exhaustive as possible. To gain another perspective, we interviewed representatives from many groups outside of the NSF including policy makers, representatives from engineering accreditation boards, and engineering educators.

This analysis sheds light on CCLI grants for engineering education. It will aid the NSF in understanding the nature and extent of its engineering education programs. The profile reflects the input of stakeholders outside of the NSF who are deeply invested in these programs, particularly funding applicants and the larger federal STEM funding community. It will enable the NSF to more effectively communicate with engineering education faculty and thereby improve the dialogue between the NSF and principal investigators. Ideally, it will speed improvement in engineering research and development projects and accelerate engineering education reform.

2. Literature Review

In order to fully develop our profile, it is necessary to understand the broader context of undergraduate STEM education. In this chapter, we will begin with a short description of the National Science Foundation and its role in the history and development of STEM education. Next, we will review current theories of student learning and education pedagogies. In addition, we will explore the context of STEM programs in the larger business world, including recent developments by ABET and other professional organizations.

2.1 The National Science Foundation

The National Science Foundation (NSF) was created by Congress in 1950 as an independent federal agency with a mission "to promote the progress of science; to advance the national health, prosperity, and welfare; [and] to secure the national defense…" (NSF, 2007). Today it provides 20% of all federally-funded basic research in colleges and universities and is the leading source of funding for mathematics, computer science, and social science research. Its mission is vast and varied, as it touches virtually all scientific research in the United States. There are approximately 1,700 employees at the national headquarters, but through the grants it funds it supports thousands of researchers across the United States as well as in locations such as Antarctica and the many US Territories. A more complete description of the NSF may be found in Appendix A.

The NSF also serves as a forum for communication in the scientific community. As many ideas come through the organization, they are discussed both in terms of intellectual merit and broader impact by NSF staff. The organization has an average of "150 scientists from research institutions on temporary duty." (NSF, 2007) These scientists review grant proposals to ensure they are innovative and are valuable to the academic community.

Each year, a wide variety of projects receive funding. Of the many recipients, one of the most visible is public television. Other projects funded by the NSF are as diverse as the impact of wireless networking on fighting California wildfires, and looking into "A Mathematical Solution for Another Dimension." (NSF, 2007) It both solicits proposals for specific areas of research and accepts unsolicited proposals for grants.

The mission of the Division of Undergraduate Education (DUE) within the NSF is “to promote excellence in undergraduate science, technology, engineering and mathematics (STEM) education for all students.” (NSF, 2007) STEM is a large initiative not only for undergraduate students, but it also intends to foster interest from early childhood through post-secondary education. Because part of DUE’s mission is to increase the number of STEM graduates, it is important to recognize the trends of intended majors for incoming freshmen.

2.2 Population Trends in STEM Programs

On January 13, 2006, the National Science Board (NSB) presented President George W. Bush with its *Science and Engineering Indicators 2006*. Its purpose is to analyze “key aspects of the scope, quality, and vitality of the Nation’s science and engineering enterprise and global science and technology” (NSB, iii). Within its section on Higher Education in Science and Engineering, the report discusses many aspects of the population involved in undergraduate engineering. Included was a table of “Freshmen intending S&E majors.” An abridged version of the table is included below (Table 2.2-1).

	1983	1993	1999	2004
All intending S&E Majors	35.0	33.3	33.7	33.1
Physical Sciences	2.2	2.5	1.9	2.3
Biological/Agricultural Sciences	5.7	8.2	8.2	8.3
Mathematical/Statistics	1.2	0.8	0.6	0.7
Computer Sciences	7.7	2.1	5.1	2.0
Social/Behavorial Sciences	6.7	9.7	8.9	10.2
Engineering	11.5	10.0	9.0	9.6

Table 2.2-1: Freshmen intending S&E major, as percentage of undergraduate population (adapted from NSB, 2006)

The percentage of undergraduates in engineering programs has fluctuated since 1983; however, there is a general downward trend in the percentage of new students entering engineering programs, as illustrated in Figure 2.2-1.

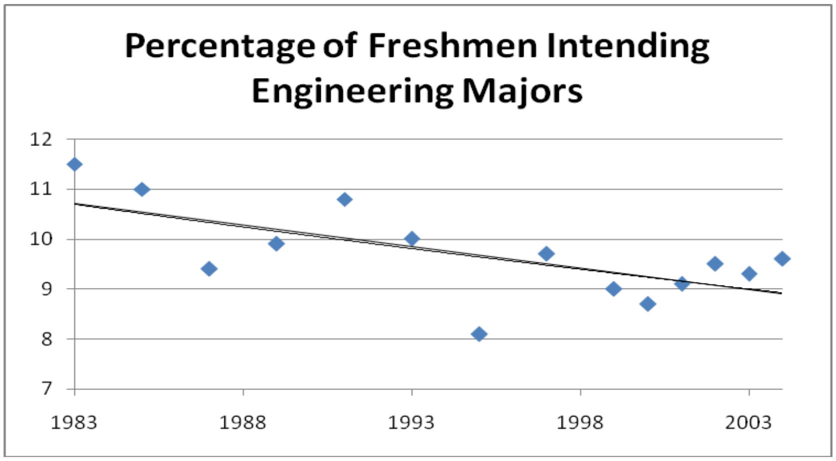

Figure 2.2-1: Freshmen Intending Engineering Majors (adapted from NSB, 2006)

This downward trend, coupled with an increasing demand for a technically trained workforce, has led to a shortage of engineers. According to Cornelia Ashby, Director of Education, Workforce, and Income Security Issues for the Government Accountability Office, "it is uncertain whether the number of STEM graduates will be sufficient to meet future academic and employment needs and help the country maintain its technological competitive advantage" (p. 17). Though modest gains have been made in recent years, the lack of engineers requires that current STEM programs produce the highest quality engineering graduates and encourage more students to study engineering in the future.

2.3 STEM Program Analysis

At the beginning of the Cold War, the United States government recognized an increased need for STEM programs. The Soviet Union presented a very real threat to the technological superiority of the United States. By the 1960s, the United States had established a model for STEM education in its undergraduate programs. Since then, little has changed, especially in engineering education. According to Juan C. Lucena (2003), "Today's contested but still dominant model of building blocks of math, science, engineering sciences, and engineering analysis lie in the scientization of engineering knowledge that began after World War II and reached its peak in the 1960s" (p. 421). The model Lucena mentions focuses on the synthesis of scientific principles into engineering curricula (p. 421).

Unfortunately, this approach is no longer sufficient in the modern age of globalization. Many reputable individuals and organizations are beginning to argue that engineering graduates in the United States are inadequately prepared for the realities of the engineering workplace

(U.S. Department of Education [DOE], 6). The National Academy of Engineering stated that universities must "broaden engineering education so that those technically grounded graduates will be better prepared to work in a constantly changing global economy" (Educating…, 1). Indeed, some prominent multinational businesses are now calling for improvements in engineering education and "corporate reformers have called for cross-cultural competency and flexibility in engineering education in light of the challenges of globalization" (Lucena, 421). Federal agencies such as the NSF and the Department of Education can play influential and leading roles in promoting innovative approaches to engineering education in undergraduate curricula, but the government needs a new set of goals and metrics for the programs it sponsors.

STEM Program Metrics

The success of STEM programs can be characterized both by their national impact and their individual goals. Whether a project meets its individual goals satisfactorily is often a question best answered by the sponsoring agency, be it the NSF, Department of Education, or another agency. However, at the turn of the 21st century the federal government felt it was necessary to establish definable metrics for the quality of STEM education programs on a national level.

The Academic Competitiveness Council

In February, 2006, President Bush signed into law the Deficit Reduction Act of 2005. Section 8003 of this act included the establishment of the Academic Competitiveness Council (ACC). The ACC's primary function is to identify and analyze the effectiveness of STEM programs, identify areas of project overlap, and recommend processes to integrate overlapping projects (Deficit Reduction Act of 2005, 2006). In order to do this, the ACC has adopted a series of scientific methods to analyze STEM programs (DOE, 14).

The ACC determined that current educational development programs did not feature adequate evaluation mechanisms for their programs (DOE, 31). As a result, many federal program agencies are now in the process of redefining their methods of analysis. The ACC hopes to deliver "consistent information on the effectiveness of federal programs" (DOE, 31).

Through its analysis, the ACC has developed a series of goals and metrics by which to analyze all federal STEM programs. Table 2.3-1 lists the ACC's metrics for evaluating undergraduate education. The ACC believes that its metrics are broad enough to define success for all federal agencies with STEM focus. According to the ACC, success can be defined quantitatively by "increas[ing] the number of undergraduates who enroll in and complete STEM degree programs and are prepared to enter STEM or STEM-related careers or advanced education" (DOE, 19). From 1995 to 2004, the percentage of students with STEM degrees decreased from about 32% to 27% of college graduates (Ashby, 6). Furthermore, data collected by the Bureau of Labor Statistics (Figure 2.3-1) show a decreasing trend from 1995 to 2004 in the number of STEM graduates in proportion to the number of STEM jobs in the workforce, from 9.48% to 8.58% (National Occupational… 2006). This suggests that current STEM programs have not been successful in producing sufficient engineers, and a new approach may be required.

	Metric	Source and Supplemental Information
1	The number and/or percentage of students who declare and complete a STEM major or program of study (this includes students who transfer from 2- year colleges and go on to complete 4- year STEM degrees, even if they transferred prior to completing an associate's degree)	Institutions of higher education or IPEDS can provide the basic information on number of STEM graduates. • Persistence from freshman year (% of STEM-oriented freshmen getting B.S. degrees in STEM 5 or 6 years later); Data on freshman plans available from the Higher Education Research Institute (HERI) covering a large sample of institutions ("The American Freshman: National Norms"); similar data are available from ACT and SAT • National Center for Education Statistics • Unit Record System
2	The number and/or percentage of STEM graduates who stay in STEM by attending a STEM or STEM-related graduate program	Department of Education & NSF/ SRS recent graduates surveys (available biennially) provide aggregated data on total number of students who are enrolled in graduate programs. • Unit Record System
3	The number and/or percentage of STEM graduates who take a job in a STEM or STEM-related field	Department of Education & NSF/ SRS recent graduates surveys (available biennially); however, new definitions are required for STEM-related fields.
4	Employer satisfaction with student preparation and readiness to enter the STEM job market	American Customer Satisfaction Survey
5	Where appropriate, student achievement on national STEM exams, standardized tests within disciplines, and licensure exams	Professional societies • Testing services organizations

Table 2.3-1: Undergraduate National Goals and Metrics/Program, Project and Intervention Metrics (DOE, 40)

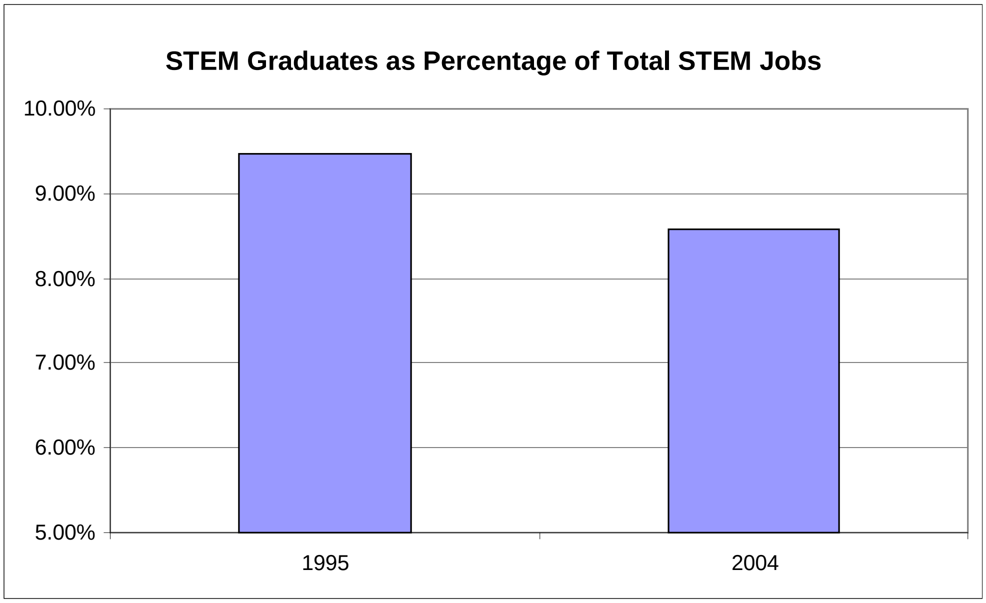

Figure 2.3-1: STEM Graduates as a Percentage of Total STEM Jobs (adapted from National Occupational…, 2006)

Qualitative success, though difficult to measure, can be defined by "encourag[ing] and support[ing] STEM professional collaborations, networks, communities, and alliances among educators, students, practitioners, government, professional organizations, and industry" (DOE, 19) and by "support[ing] advancement and development of STEM personnel, programs, and infrastructure in education institutions" (p. 19).

Standardized Testing

Standardized testing and licensure exams provide a quantitative testing metric and ensure an equal opportunity for all STEM students. They offer a concrete score to analyze the technical skills of a student; however, they cannot address the wider requirements of NSF stakeholders. Standardized tests cannot determine a test-taker's interpersonal communication skills and flexibility, crucial skills to a modern engineering career. Nevertheless, they can be valuable in determining the effectiveness of certain STEM projects. According to Philander Smith College President Walter Kimbrough, "assessment and accountability measures -- when used properly -- are important barometers to show the strengths and weaknesses of a postsecondary institution" (Dervarics, 304). However, testing is not always the most acceptable way to analyze a program. Chris Gallagher, an associate professor at the University of Nebraska-Lincoln, warns that "we could see standardized testing emerge as a powerfully controlling force in post-secondary institutions" if it is used improperly (2007).

Establishing valuable measures of success is only part of the problem in reforming STEM education. Even if these metrics exist, they are useless if the education process is not improved. These metrics are designed to measure improvement in engineering knowledge and increased job performance upon graduation. Thus, a complete understanding of engineering education programs requires awareness of how people learn, retain, and apply knowledge. Phillip Wankat (2002) confirmed this saying, "Ideally engineering and technology education would be built on a foundation of principles based on how people learn" (p. 3). Furthermore, engineering educators need to recognize that "today's concerns extend beyond undergraduate engineering per se, to the interplay of the engineering profession, the practice of engineering, and engineering education as a system" (Educating…, 15). Increased understanding in these areas will enable educators to skillfully adjust their pedagogies to educate more effectively, producing better scores on tests and ultimately better engineers.

2.4 The Psychology of Education

More is known about how the human mind gathers and processes information than ever before. This is particularly true for engineering education. According to Wankat (2002), "the scientific knowledge base on learning has only recently become well-enough established that educators can use this knowledge to design educational experiences that will result in learning" (p. 3). Many theories exist regarding the brain's ability to process information and synthesize it to solve problems.

Constructivism

As they complete formal schooling, students take progressively more challenging courses. They use the information they have learned in one class and apply it to the next in the sequence. This process of building on existing knowledge is known as constructivism. According to Wankat, "preconceptions are always present and they will affect the knowledge structure" (p. 3). Thus, if students are unfamiliar with the background information or were unable to properly synthesize the content required for the course, they will have significant difficulty processing this new material. Wankat goes on to state that "unless the incorrect preconceptions are forcefully corrected, they can remain embedded at the base of the new knowledge structures built by the students" (p.3). To be most efficient, professors would need to prevent these misconceptions from ever occurring.

Transfer

Not only do students learn by building on knowledge they already possess, they can create knowledge by applying information learned in other disciplines to the problem at hand. This process is called transfer. Engineers frequently apply transfer of information in their problem solving process. They learn the basics of many disciplines, such as static systems, thermodynamics, and fluid mechanics, and apply them to increasingly complex problems. Previously used solution techniques can also be adapted to solve similar problems. According to Jonassen, Strobel, and Lee, (2006) "engineers primarily rely on experiential knowledge" (p. 145). The foundation of experience is a critical instrument to the professional engineer. Therefore, effective undergraduate engineering programs should include a wide variety of complex problems that require engineers to think flexibly and utilize the transfer of knowledge.

2.5 Education Pedagogies

Using what is known about education, teachers can create learning experiences that help students more effectively retain and develop information. In the last few decades, great strides have been made in education research and many new teaching styles have emerged. In addition, older theories of hands-on education have had a resurgence in recent years and are now being modified and implemented fully in some academic programs.

Collaborative Instruction

Efforts to improve engineering education systems are increasingly focusing on collaborative instruction. Collaborative instruction involves creating instructor groups from persons of diverse academic backgrounds. The benefits of partnership are numerous. Through collaboration, institutions can improve curricula, enhance undergraduate learning by implementing inquiry-based courses, and facilitate education research (Schneider and Pickett, 259). Collaboration is becoming more valuable to educators in STEM fields; in fact, according to Schneider and Pickett (2006), "collaborative partnerships are considered essential in order to make real and lasting changes in STEM education" (p. 260). This is because the increasingly complex requirements for engineering education call for input from a variety of experts in a diverse array of fields. Without collaboration, it would be impossible to fully educate engineering students for the business world. Although these academic partnerships bring together diverse ideas and new solutions to problems and allow the production of a higher quality product, they also require consistent communication to maintain high levels of performance (Schneider and Pickett, 2006).

Student Engagement

Perhaps one of the most influential factors in student learning is the student's motivation to learn. If a student is apathetic or unenthusiastic about learning, he or she will not learn nearly as much as will a student engaged in the learning process . It is thus extremely important to know what motivates students and what bores them. Typically, students are more motivated to learn about subjects that are easier to understand. Wankat (2002) suggests that teachers should "make sure that almost everyone can understand and be successful at the beginning of each new section" (p. 6). In this way, fewer students lack engagement from the start. They will be more likely to successfully learn more advanced applications of the topic. Furthermore, the National Academy for Engineering stresses that "institutions must teach students how to be lifelong learners (Educating…, 2). To keep up with the fast pace of change required of engineering by industry, students must be engaged enough to continue the learning process beyond their formal schooling.

The Role of Professors

Like most of their peers in other disciplines, engineering professors generally hold advanced degrees in their respective fields but have little formal instruction in education. Wankat says "most professors are not aware of the scientific knowledge base and design their courses on a 'seat of the pants' feeling for what improves learning" (p. 3). Thus, many engineering professors may be underperforming educators. They may not understand what motivates students, or conversely, what leads to student lethargy. If engineering educators more clearly understood what drives students and how students learn, they could improve student engagement and, thus, undergraduate education. There is a noticeable lack of information regarding the number of engineering professors who hold education degrees. William Kelly, the head of the Public Affairs Department for the American Society for Engineering Education (ASEE) confirmed this via email, stating "we do not have this data. My guess is - a very small number" (Kelly, personal communication, Sept. 27, 2007). Recently, however, some universities are taking note of this problem. Beginning in 2008, Virginia Polytechnic Institute will offer a Ph.D. in Engineering Education (Crumbley, 2007). Virginia Tech is the second university, after Purdue University, to offer an Engineering Education doctoral program.

Undergraduate Research

Research opportunities have become valuable supplements to undergraduate STEM education. One study funded by the NSF showed that students who participate in undergraduate research are "more likely to pursue advanced degrees and careers in science, technology, engineering and mathematics (STEM) fields" (NSF 2007). The findings of this study were published in the magazine *Science* on April 27, 2007. Thus, to increase the number of students completing STEM degree programs, NSF stakeholders should provide more undergraduate research opportunities.

Inquiry-Based Learning

While traditional lecture-based education is the prevailing method of teaching on many college campuses, inquiry-based learning has unique advantages. In March, 2007, a "Comparison of Student Learning in Challenge-based and Traditional Instruction in Biomedical Engineering" was published in the *Annals of Biomedical Engineering*. It compared lecture-based classes with "inquiry approaches" which also go by the title of "Problem- and Project-based Learning, Authentic Inquiry, Challenge-based Learning and Discovery Learning" (Martin, Rivale, Diller, 1314). The study found that programs including inquiry-based learning are more effective than strictly lecture-based education in fostering innovation in undergraduate students.

2.6 Applying Undergraduate Education to Careers in Engineering

Programs that incorporate group projects, inquiry-based teaching, and senior capstone projects are more likely to achieve the desires of employers than programs focused on more traditional pedagogies (Ciancolo, Flory, Atwell, 2006). According to a review of 554 publications from universities, 284 "reported innovations in design education as one of the prevalent vehicles to educate flexible engineers" (Lucena, 425). Indeed, flexible engineers who can adapt to a variety of business problems are what modern, globalized businesses require to compete with foreign nations (Lucena, 425). Therefore, undergraduate programs must adopt new methods to educate their students if they wish to prepare them for successful careers in STEM fields.

Barriers to Systemic Reform in Engineering Education

Even though many educators realize the benefits of engineering education reform, many barriers still exist. A research-based culture still holds significant sway in curriculum development decisions. As Coward, Ailes, and Bardon suggest, "faculty that are oriented toward research… pursue their interests and either resist change in undergraduate teaching practices or [are] distracted from it. In the face of such conditions, institutions as a whole have less pressure to change" (Coward, Ailes, Bardon, 38). To stimulate change in the face of institutional inertia, a majority of faculty will need to recognize the value of educational reform.

Many new pedagogies require significant faculty and monetary resources to implement. Specific pedagogies focusing on laboratory-based instruction may even require investment in an entirely new set of equipment. In addition, educating engineering faculty on education research and methods is costly and time-consuming. Given the financial restrictions of smaller institutions, applying certain more costly innovations may not be feasible.

Despite the abundance of research on new and innovative teaching techniques, disseminating these efforts to faculty across the nation has been difficult. According to Jeffrey Froyd, an education researcher at Texas A&M University, "the traditional means of disseminating research results (e.g., conference papers, journal articles, etc.) are insufficient to catalyze systemic reform" (Educating…, 94). More faculty members at more institutions across the nation need to know about the research being done in engineering education to bolster this reform.

The Engineering Education Coalitions

The National Science Foundation, in its efforts to spearhead undergraduate engineering education research, continues to draw feedback from engineering firms and agencies. Indeed, it was the call from American businesses that forced the United States to re-evaluate its current engineering education programs and encouraged the NSF to establish the Engineering Education Coalitions (EEC) in the 1990s. In total, six coalitions of engineering colleges and universities worked over a period of fifteen years from 1990 through 2005. Each coalition worked for 10 years with an annual budget of $2-3 million (Coward et al., iii). Appendix B contains a table of the participating institutions in each of the coalitions and a summary of the major accomplishments of each coalition.

The EEC's primary function was "to produce new structures and fresh approaches affecting all aspects of U.S. undergraduate engineering education, including both curriculum content and significant new instructional delivery systems" (Lucena, 422-3). According to Jeffrey Froyd, "Reforms developed by EECs have reinvigorated undergraduate engineering curricula at institutions throughout the coalitions and beyond and are turning out graduates who are better prepared to meet the challenges of a constantly changing global workforce" (Educating…, 83). The developments of the coalitions focused on teamwork, "open-ended learning," and technology in the classroom (Coward et al., 37). According to the Foundation Coalition, one of the members of the EEC, engineering students should be able to work effectively in teams, communicate efficiently, adapt to changes and demands in a project description, and integrate knowledge from diverse academic backgrounds (1998).

Accreditation Board for Engineering and Technology

A major criticism of current engineering curricula is the relative lack of preparedness of engineers and scientists for the modern business world. According to Jonassen et al. (2006), "Workplace engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom" (p. 139). In order to respond to this criticism, undergraduate education programs need to be reformed to better prepare students for their careers in STEM-related fields.

In addition to the EEC, the Accreditation Board for Engineering and Technology (ABET) ensures engineering graduates possess a certain set of skills vital to the workforce. According to Thomas and Alam (2003), "it is the intent of ABET that engineering education be shaped by the consumers of … engineering graduates" (p. 10). Because of the wide recognition of ABET's authority, it serves as a regulatory body for engineering programs.

ABET was founded in 1932 by the Engineers Council for Professional Development. It is made up of 28 participating bodies including various engineering organizations and societies. Appendix C contains a list of the organizations that constitute ABET. ABET's mission, among other things, is to "anticipate and prepare for the changing environment and the future needs of constituencies" (*Criteria…,* 2007). In 2000, ABET released a new series of requirements for program accreditation. These requirements are designed to reflect the new demands for engineers capable of working in a globalized marketplace. The changes “shifted the basis for accreditation from inputs, such as what is taught, to outputs - what is learned.” (ABET, *Criteria…,* 2007)

For a college or university’s program to earn accreditation, ABET Engineering Criteria 2000 (EC2000) requires the students in an accredited program to attain the following:

> (a) an ability to apply knowledge of mathematics, science, and engineering
> (b) an ability to design and conduct experiments, as well as to analyze and interpret data
> (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
> (d) an ability to function on multi-disciplinary teams
> (e) an ability to identify, formulate, and solve engineering problems
> (f) an understanding of professional and ethical responsibility
> (g) an ability to communicate effectively
> (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
> (i) a recognition of the need for, and an ability to engage in life-long learning
> (j) a knowledge of contemporary issues
> (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (ABET, *Criteria…,* 2007)

Every ABET-accredited program must include these aspects in the curriculum. The assumption is that, if a school succeeds in achieving these goals, it will produce engineers who are well prepared for the workforce.

Despite these new accreditation criteria, engineering curricula do not fully prepare students for all aspects of their future careers. For example, many engineering students, who will be designing for consumers against strict budgets, do not take courses in finance, marketing, economics, or other non-engineering fields. George Hairston (2000), CEO of Southern Nuclear Operating Company, argues “this lack of knowledge leaves them less prepared for a rapidly changing workplace where varied skills are paramount, resulting in a slower than expected integration period” (p. 3). A goal of engineering programs should be to significantly reduce the adjustment period from college to the workforce.

There is no prescribed way to implement the ABET EC2000 requirements into an engineering education program. Faculty members have significant freedom in the design of their courses. Some utilize traditional lecturing practices, some use inquiry-based teaching or active learning methods, and some use a combination of both. Some employ group projects and some do not. There must be an ideal balance of these strategies to enhance undergraduate education.

Many new programs are developing methods to introduce design experiences with non-engineering constraints in first year curricula in an effort to educate engineers about the realities of business as soon as possible. The culmination of this strategy is the senior capstone project, in which students are exposed "to the key elements of design – design methods, project management, teaming, engineering economics, ethics, risks, and professional issues – before graduation" (Hughes, 2001). The capstone project allows graduates to enter the workforce with more knowledge of engineering systems and problems. By developing improved interpersonal communication and project management skills, these candidates are more desirable to employers.

Future Undergraduate STEM Content

The Engineering Education Research Colloquies (EERC), a body of more than seventy STEM education researchers, formed in 2006, defined five major research areas for the development of engineering education (The Research Agenda…, 259). These areas of research are: engineering epistemologies, engineering learning mechanisms, engineering learning systems, engineering diversity and inclusiveness, and engineering assessment. The areas were defined to "provide synergy and a roadmap for organizing our efforts for educating engineers for the dynamic world of engineering practice" (The Research Agenda…, 259). With the necessary research defined, researchers can more easily collaborate to transform engineering education for the years to come.

Ideally, in the future, professors of undergraduate engineering programs will more fully understand how a student learns and engineering curricula will provide ideal preparation for modern engineering careers. Educators will take advantage of all that is known about teaching engineers. Upon graduation, all students will have solved complex problems with conflicting goals, non-engineering constraints, and multiple solutions (Jonassen et al., 2006). Students will have a firm grasp that there is more than one good solution to an engineering problem, and great engineers will find better solutions. They will understand that engineering solutions are often optimizations of certain essential criteria against lesser, but still important, criteria. As stated by the EERC:

> “meeting these and future challenges requires a transformational change rather than incremental improvements in how we recruit and educate engineering students. Business, academic, and government leaders from across the engineering enterprise have repeatedly remarked that systematic research of how we educate engineers must be the path by which we transition from episodic cycles of educational reforms and move to continuous, long-lasting improvements in our education system.” (The Research Agenda…, 259)

Thus, engineering education research is paramount. To systematically build upon past studies, researchers need to be aware of them. To aid researchers, grant-awarding organizations, such as the NSF, need to know three things: 1) how their funds have been spent; 2) what they have learned from this research; and 3) what they would like to know next. If the NSF had a summary of its grant proposals focused on engineering education, it would have all of this information at its fingertips. This project aims to fill this gap by creating a profile of the National Science Foundation’s CCLI awards in engineering education. The profile would prove to be a useful tool in discussion about engineering education research with potential applicants and policy makers alike and, ideally, help accelerate the pace of education reform.

3. Methodology

The goal of this project was to develop and implement a profile of NSF awards for undergraduate engineering education research and development funded through its Course, Curriculum, and Laboratory Improvement (CCLI) program. The profile is an in-depth assessment of key characteristics that identifies and analyzes trends and patterns in the proposals that have received funding. The implementation of the profile "paints a picture" of the nature and extent of existing engineering education research and will aid in making the best use of the available resources for engineering education research in the future. To achieve this goal, we:

- Identified all CCLI projects focusing on engineering;
- Identified the important characteristics of project proposals and negotiation correspondence to include in the profile. The categories of information include data such as targeted field, award value, nature of research or development effort, etc.;
- Rated the proposals with respect to each characteristic for the profile;
- Assessed historical trends in engineering education proposals CCLI has funded;
- Identified how NSF personnel and applicants to NSF funding programs would use this profile.

3.1 Identifying Awards in Undergraduate Engineering Education

Perhaps the most important step to creating the profile was deciding what information to include. On its public project database, CCLI lists several categories of information for each proposal. Data are available regarding the dollar amount awarded to each project, the term of the award, and the institution sponsoring a project to name a few. Despite the availability of the data, efforts to synthesize this information by NSF had been limited.

The National Science Foundation's online award database contains a few thousand awards from CCLI across all disciplines. To extract only projects focusing in engineering, we searched the database for all CCLI proposals awarded by NSF program officers who worked in engineering. The list of NSF program officers who had worked in engineering since the inception of CCLI was supplied by our National Science Foundation liaison, Dr. Russell Pimmel. Searching the database for only CCLI projects approved by these program officers reduced the list to approximately 800 proposals. These proposals were entered into a preliminary database.

A review of the proposals at this time indicated that not all were specific to engineering. Some of the engineering program officers had also awarded proposals focusing in disciplines outside of engineering. Collectively, we read all of the abstracts for the remaining projects. If the abstract listed a non-engineering discipline code or was unrelated to engineering, the project was removed. After removing all non-engineering projects the database contained 584 awards.

3.2 Identifying Characteristics for the Profile

We rated each proposal according to several classes of characteristics. Each characteristic was assigned a value describing the proposal. The final profile contained two distinct types of characteristics: objective and subjective. Objective characteristics are explicitly stated either in the public database or in the front material of the proposal, and subjective characteristics required a judgment by the reviewer.

3.3 Objective Characteristics

Objective characteristics described fundamental information about an award. Some of these items were selected from information in the existing online database and other items were obtained from the proposal itself. After creating an exhaustive list of possible characteristics, the most relevant of those fields were chosen to analyze. The original list of objective characteristics was compiled through brainstorming and an analysis of the relevant literature. This list was designed to include as many facets of the proposals as possible. In order to narrow the list to a more manageable and relevant set, a combination of a review of previously sponsored evaluations performed by SRI International and a cost-benefit analysis were used. SRI International has released several reports on contract for the NSF, including one concerning the Course, Curriculum, and Development (CCD) program, the predecessor to CCLI. Many of the characteristics in these reports matched those in our preliminary list; therefore, those characteristics that were common to both our list and the SRI reports were included in the final list. In addition, under the advice of Dr. Pimmel we recognized a set of certain characteristics that would be too time-consuming to include. Dr. Pimmel identified a list of characteristics that he felt were important to the profile. We analyzed the amount of time necessary to include certain characteristics and balanced this against their importance as identified by Dr. Pimmel.

Using these techniques, a final list of characteristic was established. The final list of objective characteristics is found in Appendix D.

Each objective characteristic was assigned an indisputable value. For example, the value for the total budget is apparent regardless of the reviewer. While certain fields in the online database may have contained more than one entry (for example, an award with two NSF program element codes), no decision was required by the reviewer, as every proposal contained this information clearly stated in its electronic file in the NSF database. Information was entered into a Microsoft Excel spreadsheet with drop down boxes to maintain consistent coding of characteristics between proposals and reviewers.

Using Microsoft Excel, these characteristics were analyzed in a variety of ways. The software's ability to rapidly sort information and create charts made it exceptionally valuable. By charting these characteristics both against each other and against time, it was possible to recognize trends in the data. In addition, aggregate data were collected and analyzed, including total money awarded by CCLI for engineering education research and the total number of engineering education grants awarded since the beginning of the program.

3.4 Subjective Characteristics

Defining subjective characteristics required more input than is available in the public NSF award databases themselves. Each subjective characteristic required the reviewer to read into a proposal to extract a value. Due to the strict time limitations on our research, it became apparent that we would only be able to review a limited number of proposals. Furthermore, it was necessary to select a smaller number of subjective characteristics to investigate in order to effectively analyze the data in a reasonable amount of time.

An initial list of subjective characteristics was formed from our literature review process, observations from reading proposals from the current solicitation period, and suggestions from Dr. Russell Pimmel, our liaison at the National Science Foundation. In order to finalize our list of possible subjective characteristics, interviews with program officers, program directors, and division directors (all past and present employees of the NSF), principal investigators, and external stakeholders were used. The initial list of subjective characteristics served as a basis for discussion regarding which characteristics should be included in the profile.

Following the interviews, some new characteristics were added to our list and some characteristics were removed. If a characteristic named by an interviewee was missing from the initial list, it was considered for addition. Characteristics were added to the list if the benefits of analyzing that characteristic outweighed the time and effort necessary to evaluate it. Characteristics were removed from the list if no interviewees found the characteristic valuable or if the characteristic were deemed too time-consuming to evaluate. A determination of the benefit of analyzing certain characteristics was made through consideration of interviewee responses and suggestions from Dr. Pimmel. A complete list of subjective characteristics examined in the profile is found in Appendix E.

Interviews with Program Directors and Division Directors

Program Directors (PD) and Division Directors (DD) are, primarily, in charge of overseeing the review process of incoming proposals. Ultimately, they decide whether a project will be funded or declined. Because of this, they have intimate knowledge of the proposal review process and have presuppositions regarding the demographics of funded projects. Interviews with PDs were used to determine which characteristics to include in the profile, the perceived direction of CCLI grant funding, and funding strategies. Practice interviews were conducted with Dr. Russell Pimmel and Dr. Dan Udovic, a PD working with CCLI awards in biology. The practice interviews allowed opportunities to test interview questions and rehearse the interviews before conducting them with the engineering program directors. Interview questions were revised after these practice interviews to increase clarity and focus. We interviewed seven PDs and two DDs in total. A final list of the interview questions asked of the PDs and DDs is listed in Appendix G.

Only three of our potential program director interviewees and two division directors were still working at the NSF building in Arlington. For these interviews, it was appropriate to meet in person. A lead interviewer asked questions while a scribe recorded the responses. Since many candidates could not be met in person, however, the remaining interview candidates were contacted by phone. Two scribes were used for phone interviews in order to assure all data were collected.

The interviews were conducted in a semi-structured manner, allowing the interviewee to expand on a specific point if desired. It was important, however, to assure that the conversation followed the same path in each interview. In this way, it was possible to remain confident that the answers were elicited by a similar thought process across all interviews.

Interviews with Principal Investigators

Since a main goal of this project was to aid communication between the NSF and grant applicants, it was important to consider principal investigators (PI). PIs develop project ideas, draft proposals, and carry out the research after the proposal is funded. Interviews with PIs were designed to determine additional characteristics to include in the profile. Questions asked their opinions on the direction of engineering education research, reasons for applying to the CCLI program, and what information would be valuable to PIs during the proposal writing process.

A list of PIs to contact was provided by Dr. Pimmel. The selected PIs represented a diverse array of institutions and academic disciplines. Some PIs were from community colleges and others were from large research universities. The PIs chosen were also particularly active in engineering education research and reform. The PIs interviewed also represented a wide geographical area, so interviews had to be completed by phone. A chief interviewer asked the questions while a scribe recorded the responses. Interviews were conducted in a semi-structured fashion, which allowed for interviewers to ask probing questions while assuring the conversation generally followed the same path. In total, we interviewed five PIs. Questions asked of the PIs can be found in Appendix H.

3.5 Addressing Other Stakeholders

Our final product can have benefits beyond the NSF grant awarding process. To gain insight into what information is useful to organizations outside of the NSF, we interviewed policy makers and members of professional societies within engineering. With their input, our profile has context greater than the proposal awarding process within CCLI.

Legislative Committees

The National Science Foundation is funded by the United States government. Thus, legislators who write and approve funding legislation are major stakeholders in NSF programs. We contacted and interviewed two Senior Education Advisors for United States Senators involved in education policy to hear their insight into how legislators view STEM education and how they might use this profile. To ensure politically neutral discussion, we simultaneously interviewed a Democratic staff member and a Republican staff member from the Senate Committee on Health, Education, Labor, and Pensions. Interviews focused on the need for STEM education and the focus of STEM education policy. A complete list of interview questions is found in Appendix I.

Engineering Organizations

A number of organizations other than academic institutions and research and development funding entities are involved in engineering education development. Among these are the American Society for Engineering Education (ASEE), the Accreditation Board for Engineering and Technology (ABET), and the National Academy of Engineering (NAE). Because these organizations are intimately involved in engineering education, their input was required to make the profile truly multifunctional. We interviewed a representative from each organization. A list of the interview questions for representatives of engineering organizations found in Appendix J.

Applying Values to Subjective Characteristics

For each of the subjective characteristics, we applied a similar method of analysis as for objective characteristics. A Microsoft Excel spreadsheet was developed with drop-down boxes to ensure responses were limited to a given set to expedite data analysis. Each rater was given a set of proposals to read and assess values. Since each subjective characteristic described a trait a proposal might display, the corresponding value would classify the proposal as displaying the characteristic or not. A glossary including definitions for the characteristics can be found after the appendices. Because these subjective characteristics are sometimes harder to identify, all three raters were enlisted to discuss ambiguous proposals. This rating scheme was designed to ensure reliability between raters and proposals.

3.6 Narrowing the Data Set

For objective characteristics, it was possible to analyze all 584 awards in the database. Data analysis was performed using Microsoft Excel. This process was efficient for any number of projects and did not require the reviewer to read individual proposals. All analysis involving objective characteristics was performed on the original database. However, we realized that this database would be too large to perform effective analysis for subjective characteristics. It was necessary to narrow the original database to a smaller, more manageable size, before analysis could continue. All analysis involving subjective characteristics was performed on a smaller database that was sampled from the original.

Sampling

Because subjective characteristics require a more in-depth reading of the proposal to rate, they take longer to analyze than the objective characteristics. A database that was both small enough to analyze in the given time frame and also large enough to provide accurate data was necessary to perform analysis on the subjective characteristics. After finalizing the list of characteristics that we would use, each team member reviewed three projects individually to find an estimate of the time required to review each proposal. It was determined that each proposal took approximately 30 minutes to review. We then decided to set aside three days for proposal reviewing and determined that we could complete 108 projects within the time period. Dr. Pimmel advised that it would be more helpful to external stakeholders if more recent projects (since the new designations in 2006) were analyzed instead of taking all projects since 1999. He also noted that Phase III projects were so diverse in their goals and methods it would be difficult to characterize them generally. Therefore, we composed our sample of all Phase I and II projects from the years 2006 and 2007, providing both a current and significant sample. A breakdown of this sample used for extracting subjective characteristics is listed in Appendix K. A total of 90 unique projects were identified from a total of 125 awards (collaborative projects include multiple awards to different universities for the same project).

Manipulating the Data

Once all of the proposals were rated, the raw data needed to be extracted into a more analyzable form. To do this, data were first grouped by value for each characteristic to learn the total number of proposals with each value. Then, these groups of similar values were sorted by year to assess chronological trends in characteristics. Graphs with trend lines were made with the data to help visualize these tendencies. After the trend analysis, multiple characteristics were correlated to each other to see if there were patterns between characteristics. For example, the focus of research and development was correlated to the phase of the project to identify if some types of research and development occur more often in projects of a certain phase. Graphs were also used to help evaluate these data.

Completing this methodology led to the creation of a profile of CCLI awards in engineering. This profile is a careful assessment of key characteristics that details general trends in engineering awards since the inception of the CCLI program and comprehensively examines the awards from 2006 and 2007. The profile considers the objective and subjective characteristics of proposals deemed most valuable by those most familiar with the NSF awarding process. The subsequent chapter presents our findings.

4. Results and Analysis

This chapter contains the findings of the research described in the preceding chapter. The results are coupled with analysis. The chapter begins with an overview of all engineering education proposals funded since the inception of CCLI and continues with a much more detailed analysis of the projects funded in 2006 and 2007. All confidence levels were determined using a Z-test for proportions.

4.1 Aggregate Data and Historical Trends

For data previously available in the NSF Awards Database, we were able to consider all 584 CCLI engineering education proposals. The following sections detail our results both aggregately and as historical trends. Topics covered in this section include the demographics of sponsoring institutions, investigators doing the research, and types of projects funded.

Types of Institutions

In the period between 1999 and 2003, most awards were given to small and medium-sized institutions (under 25,000 undergraduates). Only about 15 percent of all awards were given to schools with more than 25,000 undergraduates. However, since 2004, there was a large increase in awards to large schools, with awards to these institutions comprising just over 25 percent of all awards. This increase came at the expense of smaller universities (those with fewer than 10,000 undergraduates). While traditionally making up between 35 and 40 percent of all funded awards since 1999, beginning in 2005 small schools began comprising only 25 percent of all award recipients, a number on par with the largest schools. Medium-sized schools (between 10,000 and 25,000 undergraduates) have been steady at about 45 percent of all awards since 1999. The dramatic rise in awards to large schools coincides with the cessation of funding for two of the Engineering Education Coalitions: the SUCCEED coalition and the Gateway coalition. It is possible that these universities, seeking a method to replace coalition funding, began applying for CCLI grants in 2004. In fact, these schools alone collectively applied for 10 awards in 2004, which made up 16% of all 2004 engineering awards. Figure 4.1-1 displays these trends.

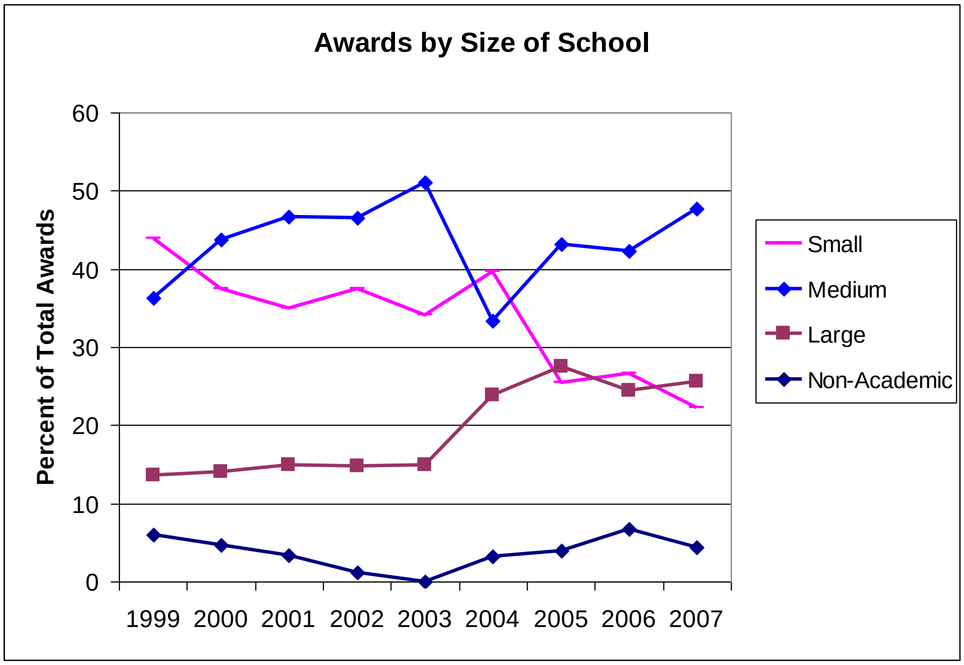

Figure 4.1-1: Awards by Size of School

The distribution of awards to public and private universities has been dominated by public universities. For every year since 1999, public universities have received approximately 70 to 80 percent of awards. While the number has fluctuated in this time, there is no statistically significant change since 1999. Figure 4.1-2 displays these numbers.

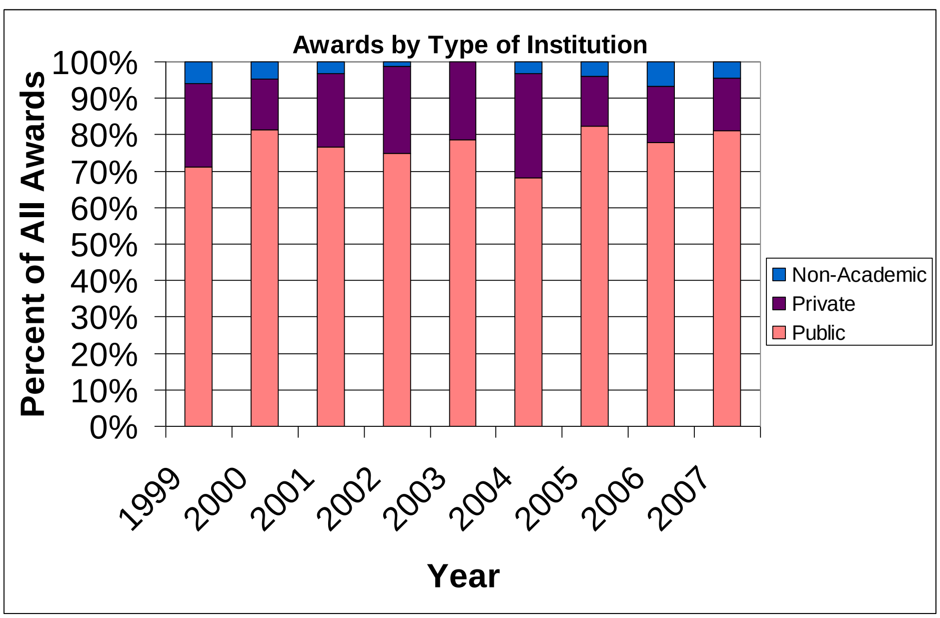

Figure 4.1-2: Awards by Type of Institution

Another way we looked at the data was by highest degree awarded. The majority of the organizations given awards were Doctoral universities. Masters universities followed, though at a diminutive amount in comparison. About five percent of awards were given to non-degree awarding institutions such as professional societies. Community colleges and technical schools awarding associates degrees also received a small portion of the awards. Figure 4.1-3 displays this information.

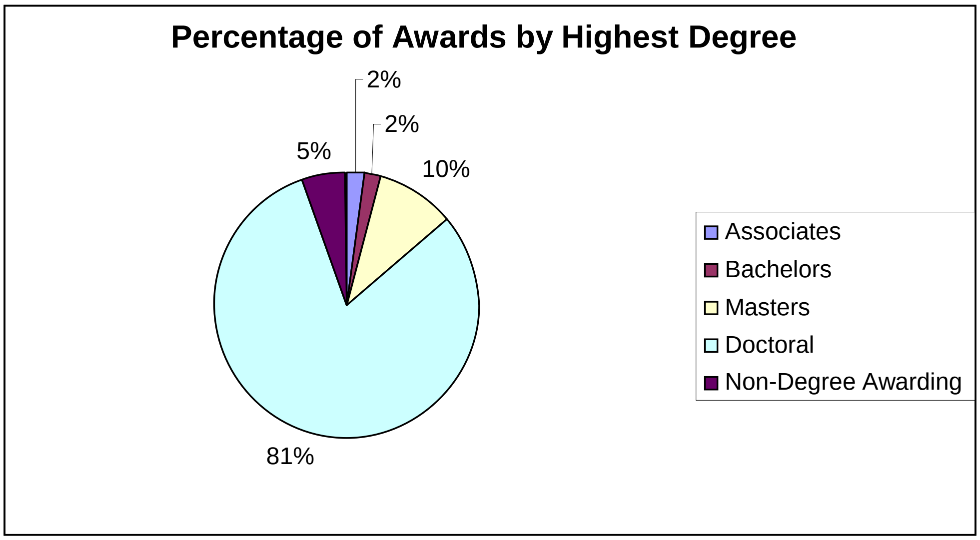

Figure 4.1-3: Percentage of Awards by Highest Degree

The total number of awards made vs. undergraduate population was relatively equally distributed. However, as shown in Figure 4.1-4, the number of organizations receiving these awards varied significantly.

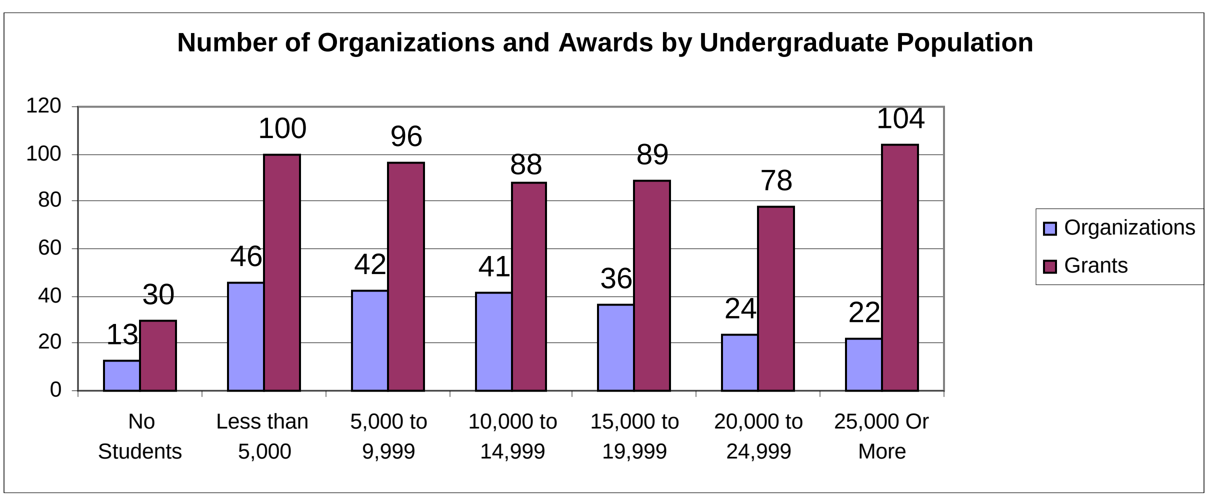

Figure 4.1-4: Number of Organizations and Awards by Undergraduate Population

Figure 4.1-5 shows once undergraduate populations grew to 15,000 or more students, the average number of awards per organization greatly increased.

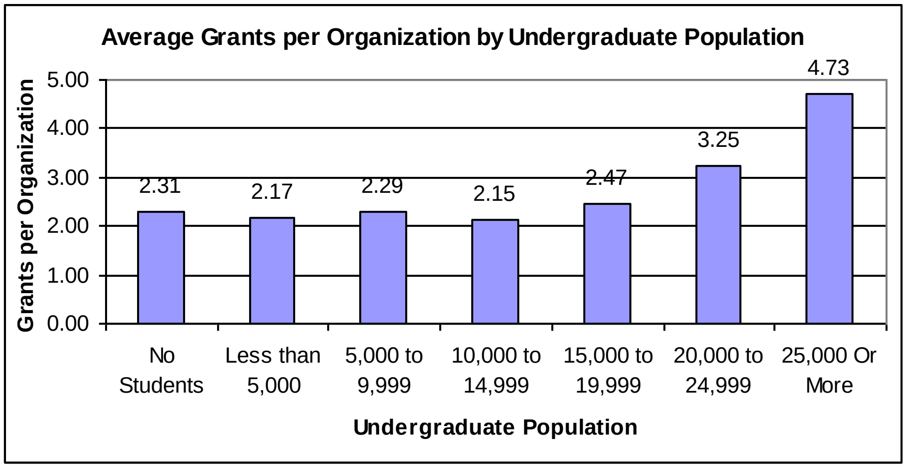

Figure 4.1-5: Average Awards per Organization by Undergraduate Population

The majority of organizations were given one award. Generally, as the number of awards given to an organization increased, the number of organizations receiving that many awards decreased. This is shown in Figure 4.1-6.

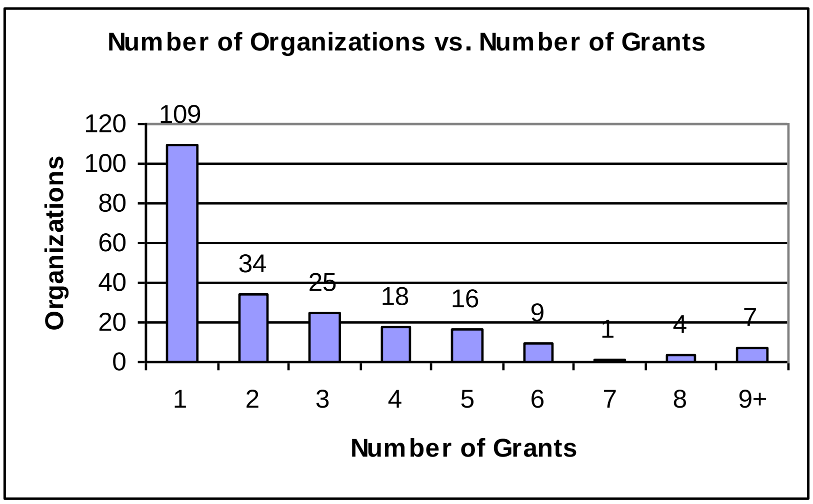

Figure 4.1-6: Number of Organizations vs. Number of Awards

Figure 4.1-7 displays that the total amount awarded per organization was diverse. Because some organizations were given a higher number of awards and other organizations had a smaller number of high value awards, the total amount awarded to an organization varied.

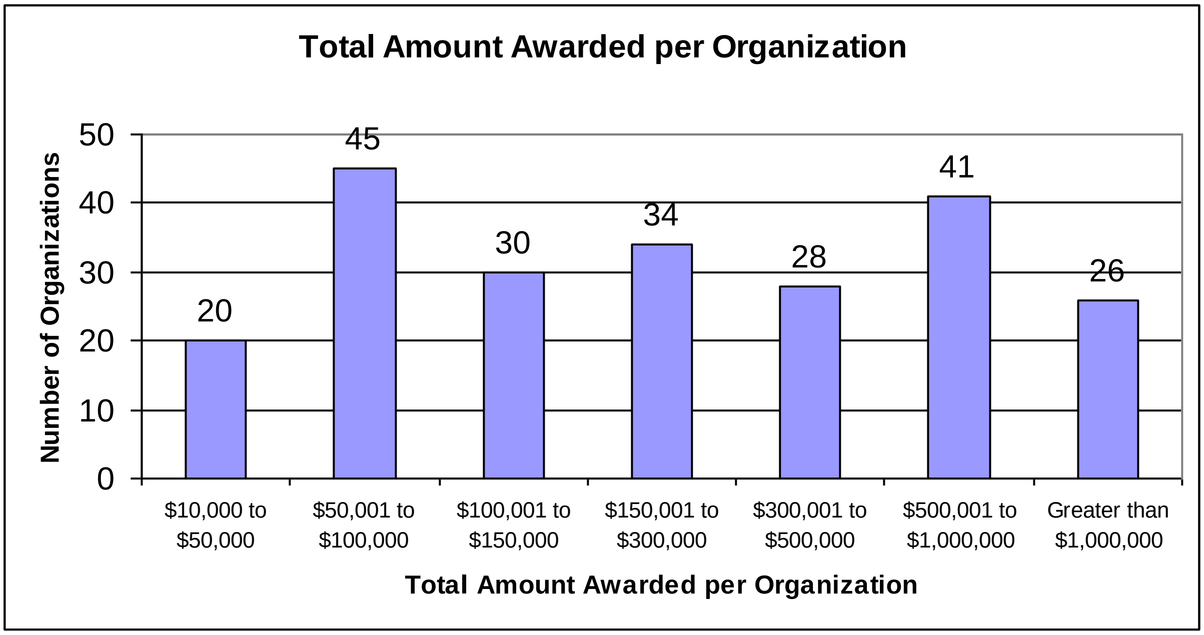

Figure 4.1-7: Total Amount Awarded per Organization

Awards

Since the inception of the CCLI program, $99,688,322 has been awarded to engineering education research and development projects. The majority of awards have had values of less than $150,000. These smaller awards amount to 69% of all awards. There have been multiple awards for larger denominations however, with more than five percent of all awards having a value of more than $500,000. Figure 4.1-8 displays the distribution of awards by size.

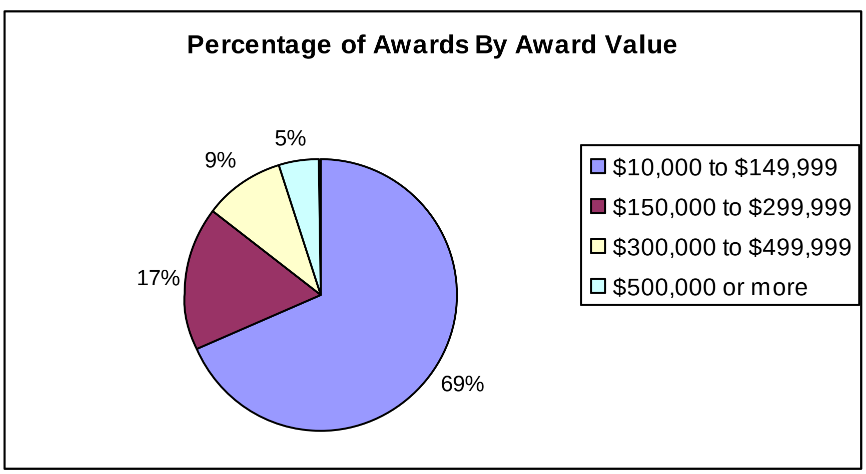

Figure 4.1-8: Percentage of Awards by Award Value

In the period before the CCLI designations shifted (1999 – 2005), most awards were worth less than $150,000, with only about 20 percent worth more than this figure. However, after the new Phase 1, 2, and 3 designations were introduced, the number of small awards has decreased. Since 2004, nearly 40 percent of awards were valued at more than $150,000. This trend corresponds to an increase in Phase 2 and 3 awards and an overall shift in philosophy towards larger, regional and national awards. Figure 4.1-9 shows this trend.

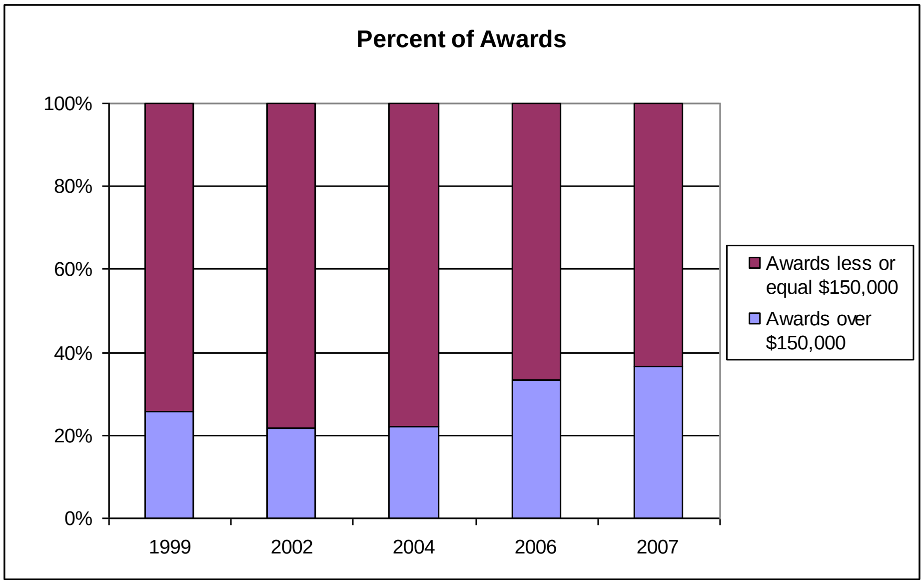

Figure 4.1-9: Awards by Award Size

Many awards are funded for a term length of around 36 months. A total of 205 awards were funded for 36 months, which comprises 30 percent of all awards (n = 584). In addition, many awards are awarded for terms between 30 and 42 months. The number of these awards comprises 67 percent of all awards. Longer award periods are also somewhat more common than awards with shorter terms, with awards for 48 or more months totaling 140, while awards less than 30 months in length totaled 80. These numbers are shown in Figure 4.1-10.

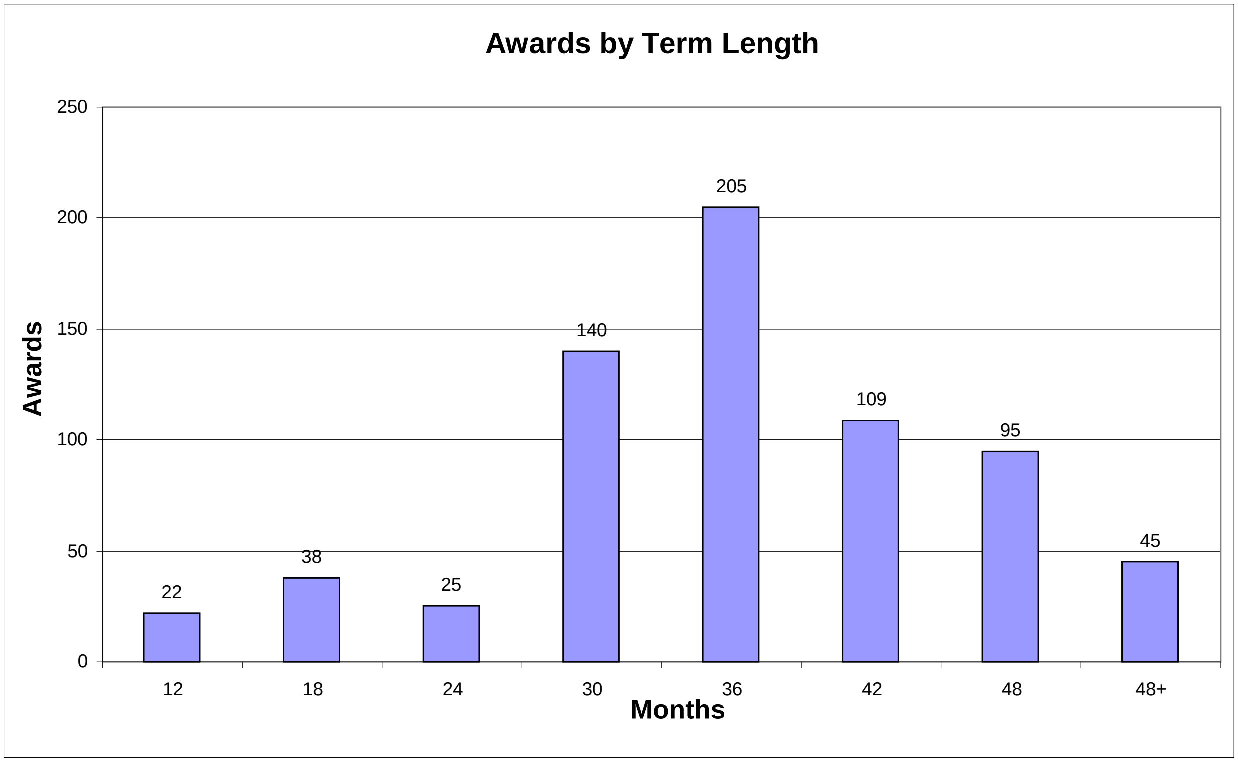

Figure 4.1-10: Awards by Term Length

A shift has occurred in the focus of awards since 1999. Adaptation and Implementation (A&I) proposals have shown a steady decrease in awards. In 1999, 38 A&I proposals were awarded, while only 19 A&I proposals were funded in 2005. Educational Materials Development (EMD) projects began with 24 projects each of the first two years before peaking at 42 projects in 2002. After this peak EMD projects resumed their earlier levels, with 25 projects in both 2004 and 2005. National Dissemination (ND) projects remained roughly constant at a low level over the course of the CCLI program. Fewer than five ND projects were awarded each year. In 2002, a new program code was introduced called Assessment of Student Achievement (ASA). Since ASA was only in existence for four years, it is difficult to identify any trends in the data; however, fewer than 10 awards per year were made in this category. These data are reflected in Figure 4.1-11.

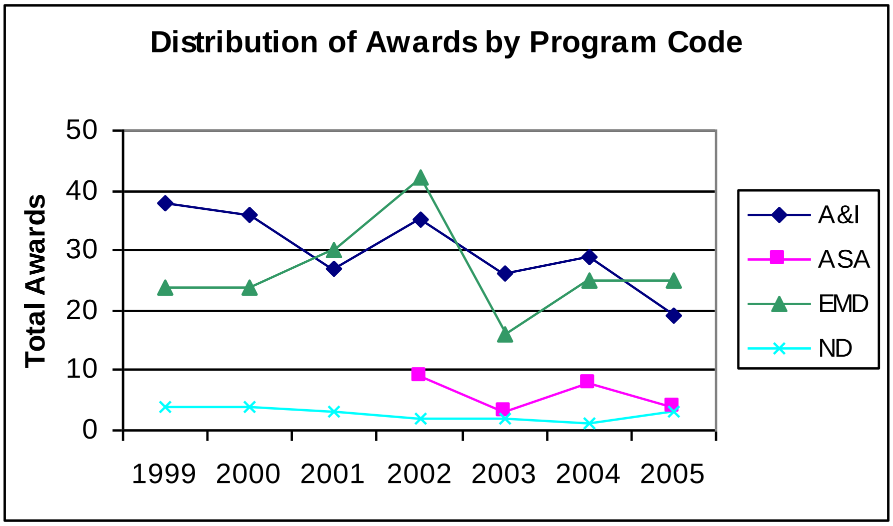

Figure 4.1-11: Distribution of Awards by Program Code

In 2006, the program designations changed from descriptions of the type of project to a system which reflected the stage of development for the project. Since then, proposals have been categorized as Phase 1 (Exploratory), Phase 2 (Expansion), and Phase 3 (Comprehensive). Phase 1 projects have a budget of up to $150,000 ($200,000 when four-year colleges collaborate with two-year colleges) and a term of 1-3 years (CCLI, 7). These projects are "expected to be significant enough to contribute to the STEM education knowledge base" (7). Phase 2 projects have a total budget of up to $500,000 and a term of 2-4 years. "Phase 2 projects build on smaller-scale successful innovations or implementations, such as those produced by Phase 1 projects, and refine and test these on diverse users in several settings" (7). Phase 3 projects have a total budget of up to $2,000,000 and a term of 3-5 years. These projects "include a diversity of academic institutions and student populations" (7). They also focus on outreach and dissemination activities that have a national impact.

Figure 4.1-12 shows an annual breakdown of projects by phase since 2006. There was a noticeable increase in the number of Phase 3 projects from 2006 (2%) to 2007 (10%).

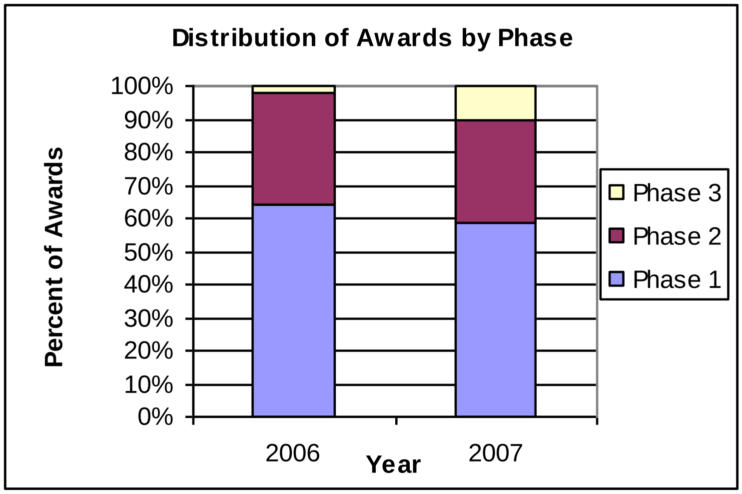

Figure 4.1-12: Distribution of Awards by Phase

We explored the number of proposals awarded each year. Though there seems to be no linear trend to the data, there is significant deviation between years. As few as 47 proposals were awarded in 2003 and as many as 90 were awarded in 2007. These data are shown in Figure 4.1-13.

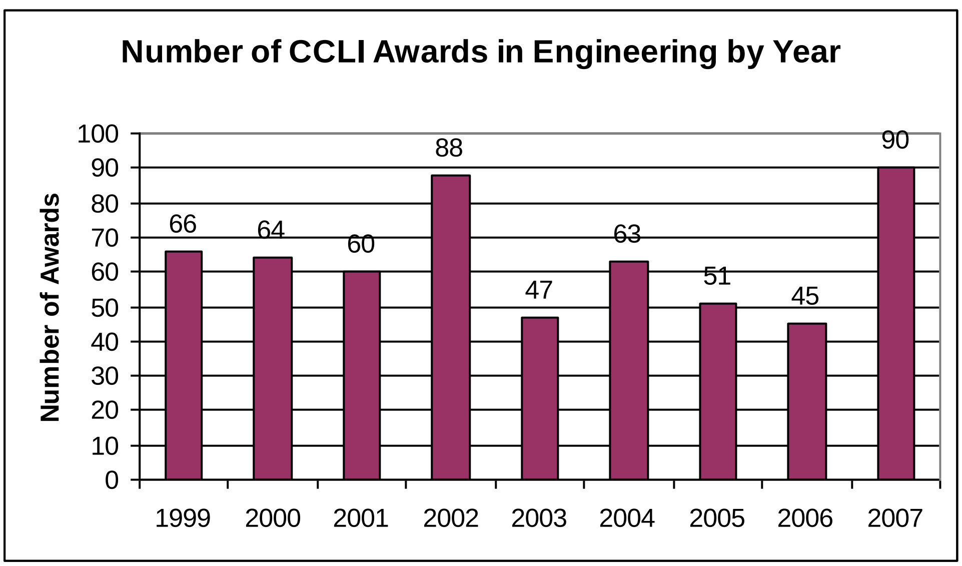

Figure 4.1-13: Number of CCLI Awards in Engineering by Year

The total value of awards changed from year to year as well, in some cases very drastically. When the CCLI program began in 1999, $14.2 million were awarded to institutions. This value gradually declined until a trough of $7.6 million was reached in 2004. However, over the next three years, a dramatic increase of almost $10 million occurred to a total of $17.5 million in awards by 2007. This is the result of a substantial amount of co-funding from other programs for CCLI awards. In some cases, fluctuations in CCLI engineering spending can be attributed to proposal pressure. These data are shown in Figures 4.1-14 and 4.1-15.

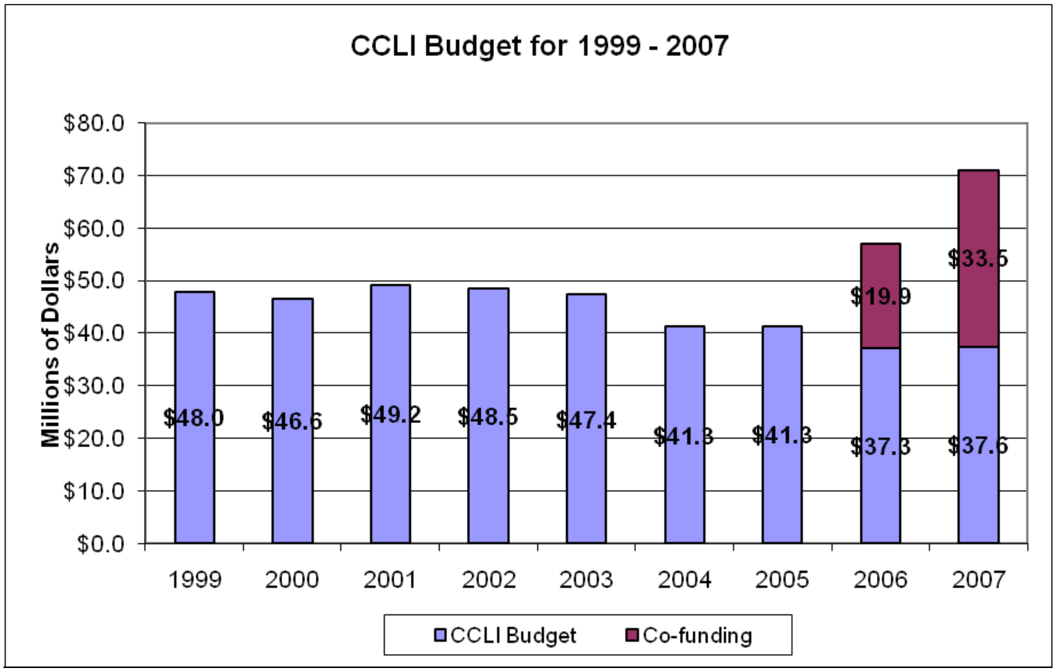

Figure 4.1-14: CCLI Budget for 1999 - 2007

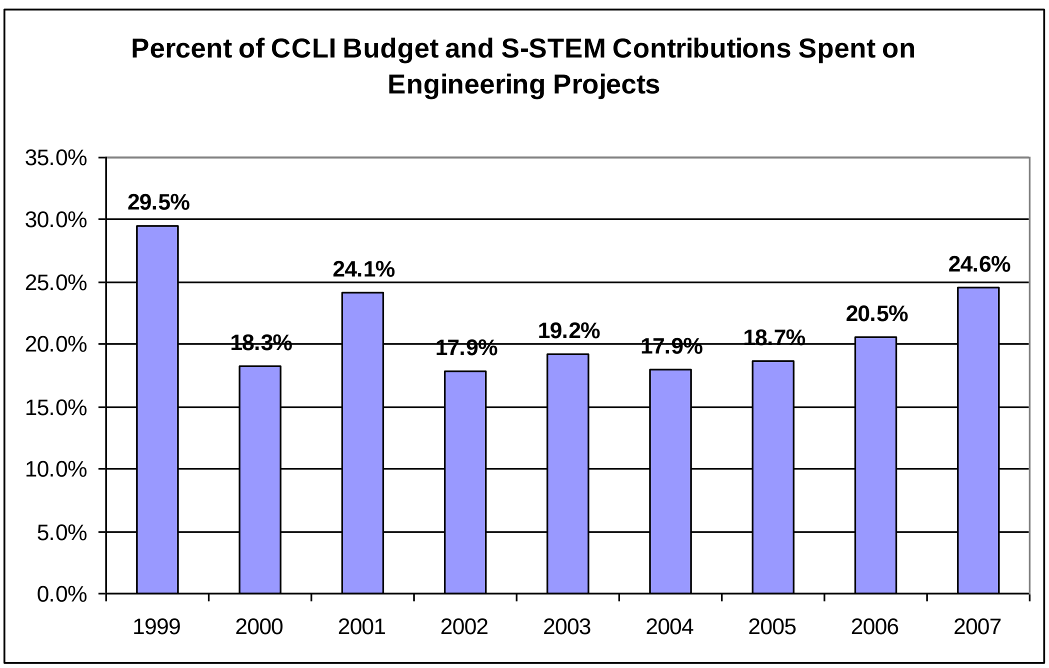

Figure 4.1-15: Percent of CCLI Budget and S-STEM Contributions Spent on Engineering Awards by Year

The changes in award values over time were also investigated. Since the beginning of the CCLI program, engineering education awards have shown an increasing trend in value. The twice trimmed mean was slightly more than $121,000 in 1999. The trimmed mean was calculated by excluding the two highest values and the two lowest values in each year. This was done to decrease the effect of outliers on the averages. One award in 1999 had a value of $5.99 million, which was ten times larger than the next most valuable award. Without trimming the mean, the result would have been skewed greatly in that direction. The trimmed mean reached a peak of almost $225,000 dollars in 2006. These numbers are reflected in Figure 4.1-16.

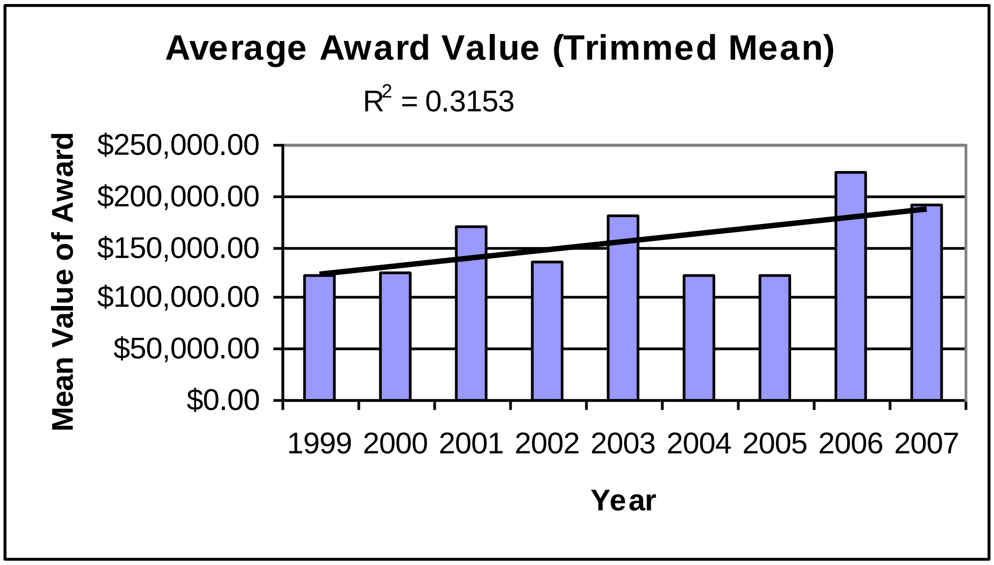

Figure 4.1-16: Average Award Value (Trimmed Mean)

Geography

The next characteristic of proposals we looked into was geography of the sponsoring institutions. All but two states or territories have had institutions receive awards. New Hampshire and West Virginia are the exceptions. The geographic distribution of the states was examined regionally, using regional designations specified in literature published by the US Department of State (US Diplomatic…, 2006). A list of states by region can be found in Appendix L. There was an uneven distribution of awards between regions, with the Mid-West (151) receiving more than five times more awards than New England (27). Figure 4.1-17 displays this information. In addition, only 28% of New England's accredited schools received awards, and the Mid-West region received the most with 47% of accredited programs receiving awards. These data are found in Figure 4.1-18.

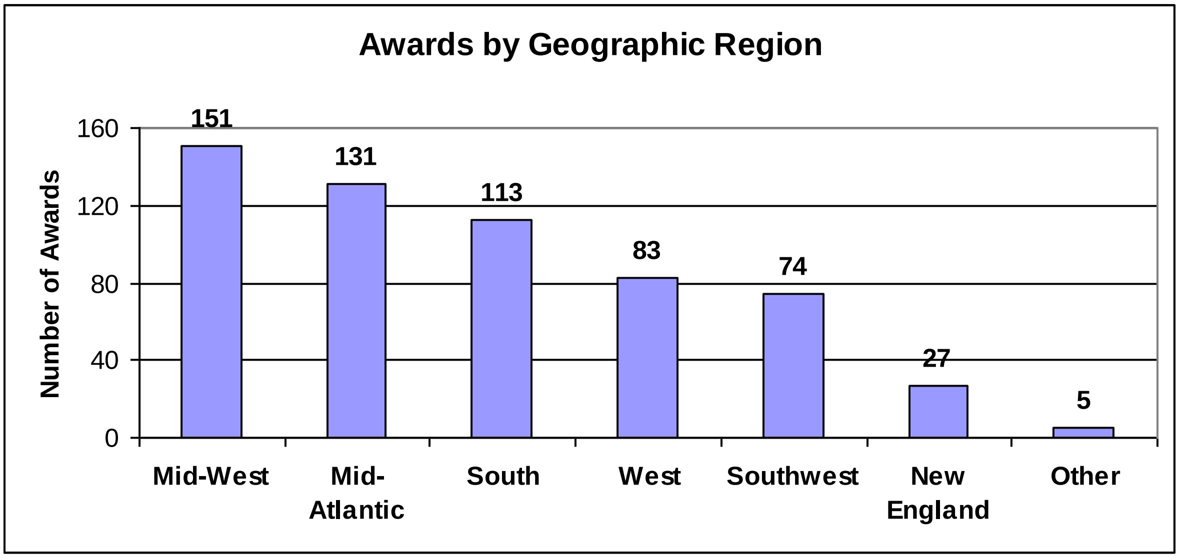

Figure 4.1-17: Awards by Geographic Region

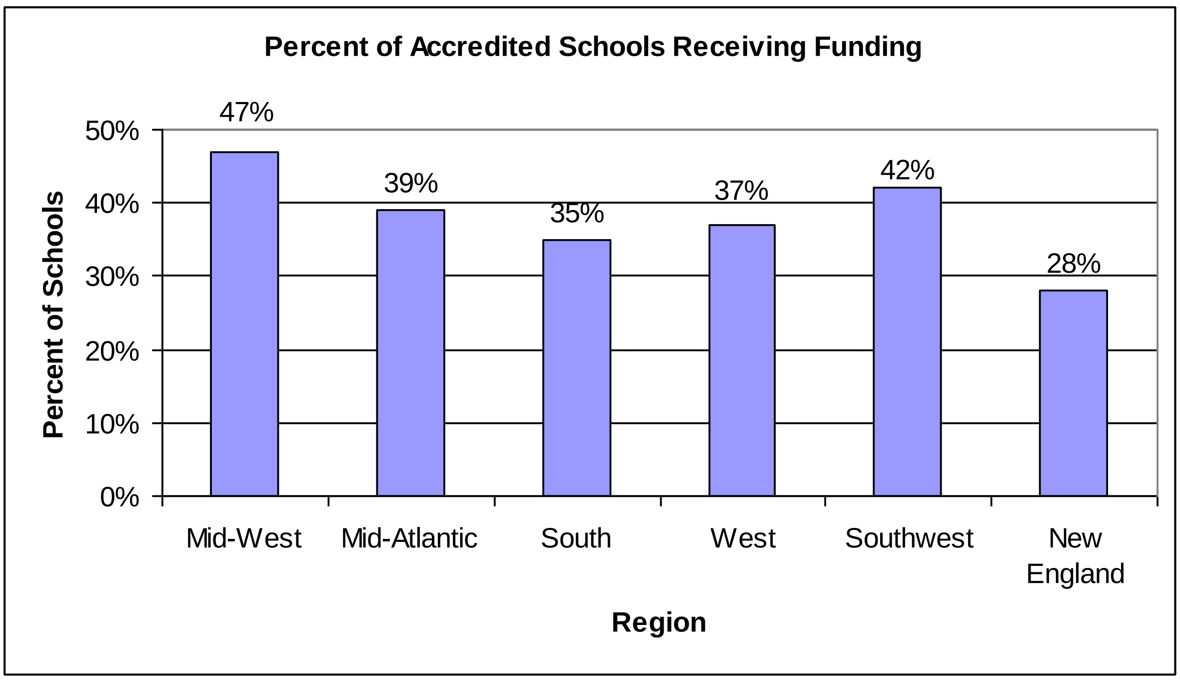

Figure 4.1-18: Percent of Accredited Schools Receiving Funding by Geographic Region

Senior Personnel

After that, the number of senior personnel (principal investigators, co-investigators, and other persons directly involved in the research) working on projects was examined. The majority of projects had two or fewer senior personnel. Of all the 584 projects, 55% (322) had either one or two senior personnel. On the other hand, many projects had five or more senior personnel, including three projects which had seven senior personnel. These data are displayed in Figure 4.1-19.

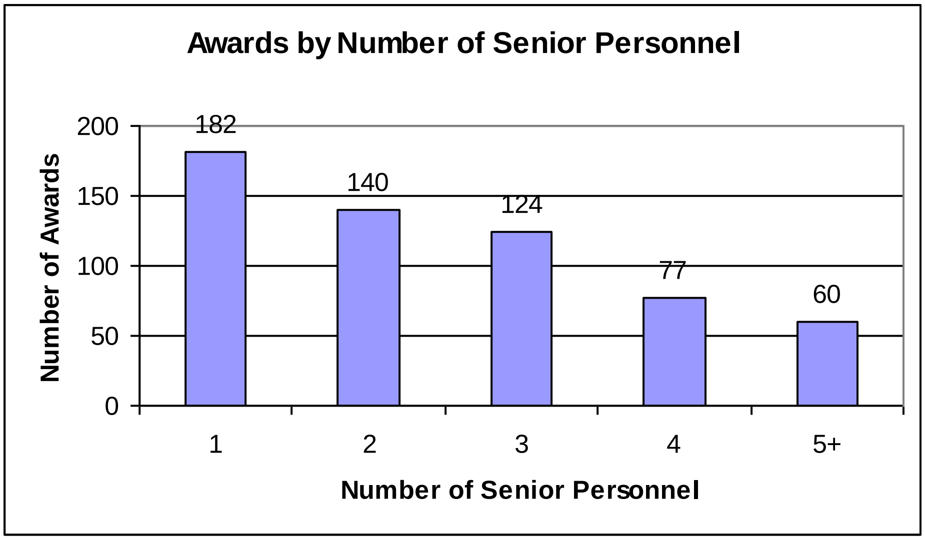

Figure 4.1-19: Awards by Number of Senior Personnel

A further exploration of the number of senior personnel working on projects involved the changes in the average number of senior personnel per award each year. Though the numbers fluctuated to as high as 2.8 in 2003 and as low as 2.0 in 2004, the average number of senior personnel hovered around 2.5. There is no noticeable increasing or decreasing trend to the data. This is shown in Figure 4.1-20.

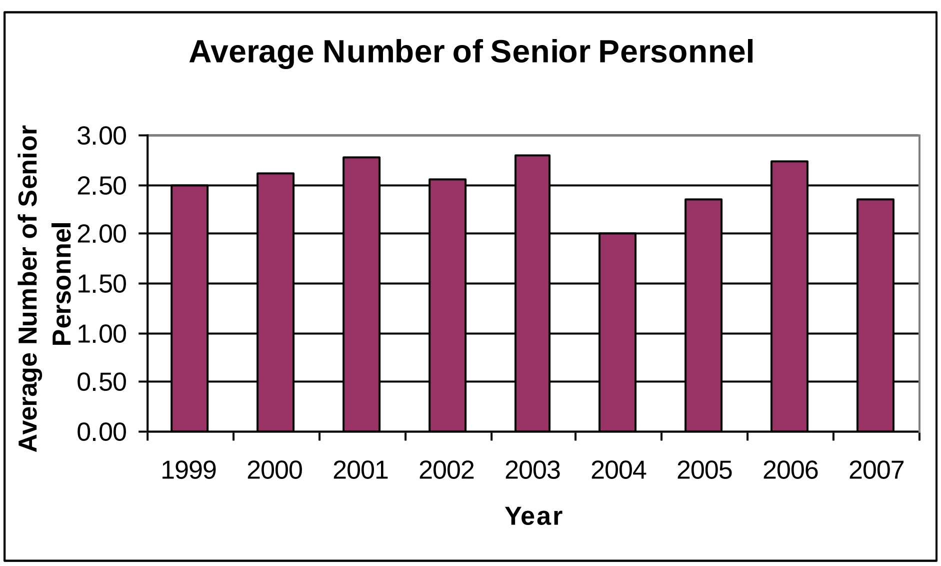

Figure 4.1-20: Average Number of Senior Personnel

The principal investigators conducting this research almost exclusively held doctoral degrees. Of the projects awarded for 2006 and 2007, only one was led by a PI without a Ph.D. On average, PIs had earned their degrees 14 years prior to receiving the awards. PIs were also likely to have applied for NSF funding in the past. On average, investigators had received eight prior NSF awards and been declined twelve times. Though nearly all PIs held doctoral degrees, the academic rank of the faculty conducting the research was more varied. Nearly equal numbers of full professors (30%), associate professors (36%), and assistant professors (34%) received awards. These data are displayed in Figure 4.1-21.

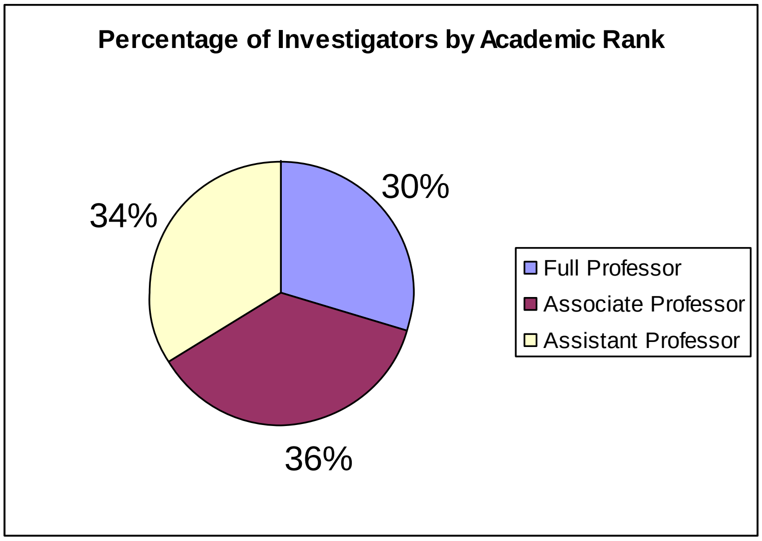

Figure 4.1-21: Percentage of Investigators by Academic Rank

4.2 Projects Funded in 2006 – 2007

Dr. Pimmel advised that a current cross-section of CCLI funding would be more useful to external stakeholders, especially principal investigators. These stakeholders have little interest in the historical trends in CCLI; instead, they would be primarily attentive to the current state of CCLI. Therefore, we analyzed all Phase 1 and 2 projects from 2006 and 2007. The NSF's internal proposal database contained full proposals for all of these projects, which were read and scored individually according to the finalized grading rubric. The results and analysis that follow exclusively describe the proposals from 2006 and 2007.

Rating Proposals

Values assigned to subjective characteristics described whether a proposal displayed the characteristic. Because many CCLI projects were multi-focused, they frequently displayed more than one characteristic in a specific area. For example, a project could have included both a materials development portion and a faculty development portion. Thus, this project was considered as both a materials development and faculty development project. Consequently, this project was double counted in the results for project focus and the percentage breakdowns sum to greater than 100%. Similarly, other areas like dissemination methods, where projects frequently used more than one method, and outreach to underrepresented groups, where multiple groups were often targeted, include projects that displayed more than one characteristic in a given area. As such, these percentage breakdowns also sum to greater than 100%.

Academic Discipline

In terms of academic discipline, the most work in a single subject was in Electrical Engineering. Mechanical Engineering followed. Examples of projects in the Engineering-Other category include but are not limited to: Industrial Engineering, Biological Engineering, and Service Engineering. When the projects were separated by phase, it became apparent that the most Phase 2 projects were in Engineering-Other. Chemical, Civil, and Electrical Engineering followed. Mechanical Engineering only had one Phase 2 project, despite the large number of Phase 1 projects in that discipline. These data are displayed in Figure 4.2-1.

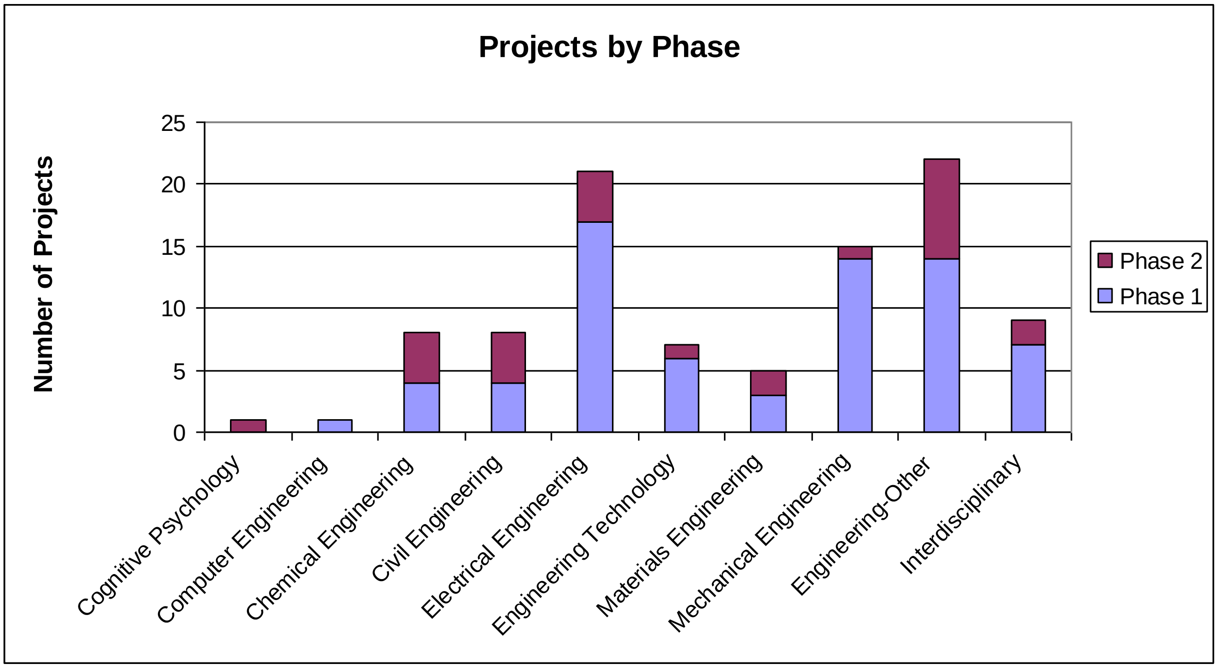

Figure 4.2-1: Projects by Phase

People Involved

Every proposal contains a project data form in which the principal investigator self-reports the number of people affected by the proposed project. The average number of undergraduates affected by each project was 1181, with 21 graduate students, 68 faculty, and 139 K-12 students also affected per project. However, Phase 2 projects exhibited impact on a much larger number of participants across the board (100% confidence). Nearly three times as many undergraduates (2219) were impacted by Phase 2 projects as compared to Phase 1 projects (821). Even larger disparities existed within other demographics: 3.6 times as many faculty were impacted by Phase 2 projects compared to Phase 1 projects, and 6.3 times as many graduate students were affected by Phase 2 projects as Phase 1 projects. Figures 4.2-2 and 4.2-3 illustrate these data.

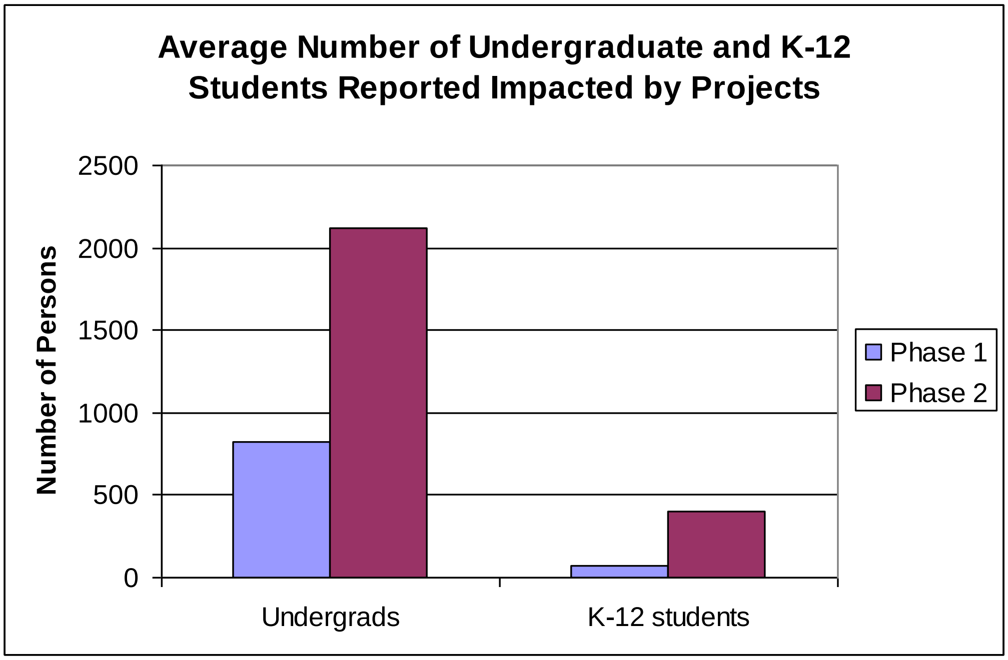

Figure 4.2-2: Average Number of Undergraduate and K-12 Students Reported Impacted by Projects

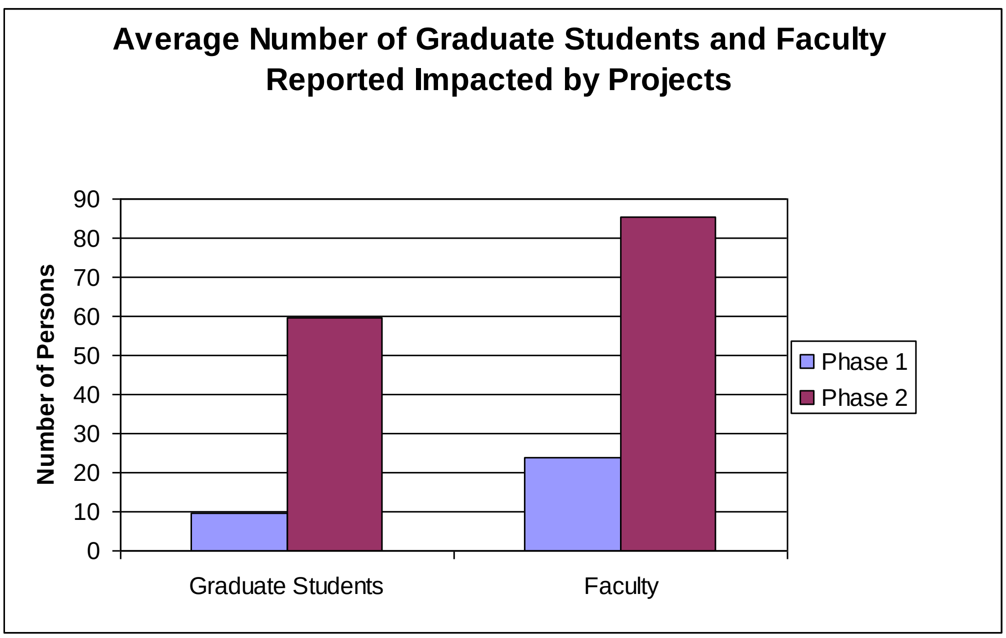

Figure 4.2-3: Average Number of Graduate Students and Faculty Reported Impacted by Projects

Project Scope

Sixty percent of all projects focused on multiple courses. However, a significantly larger portion of Phase 2 projects focused on multiple courses (22 of 27) compared to Phase 1 projects (42 of 70), and there is 96% confidence of this result. Approximately 45% of Phase 1 and 2 projects were multi-disciplinary, with 30 of 70 Phase 1 and 14 of 27 Phase 2 projects exhibiting multi-disciplinary focus. Figure 4.2-4 illustrates these data.

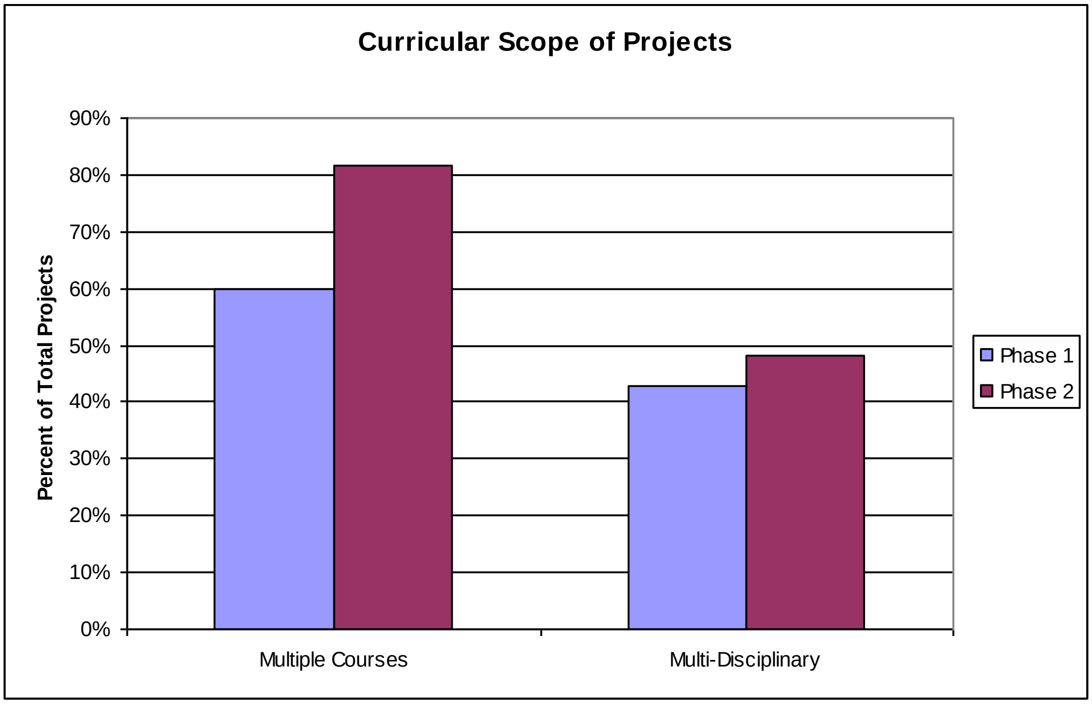

Figure 4.2-4: Curricular Scope of Projects

Of the 97 Phase 1 and Phase 2 projects in 2006 and 2007, 4 projects (or 5%), did not affect any courses directly. These projects focused primarily on faculty development and did not make any modifications a course. The majority of projects affecting multiple courses affected both levels of undergraduate study. A breakdown of the targeted course levels of projects is shown in Figure 4.2-5.

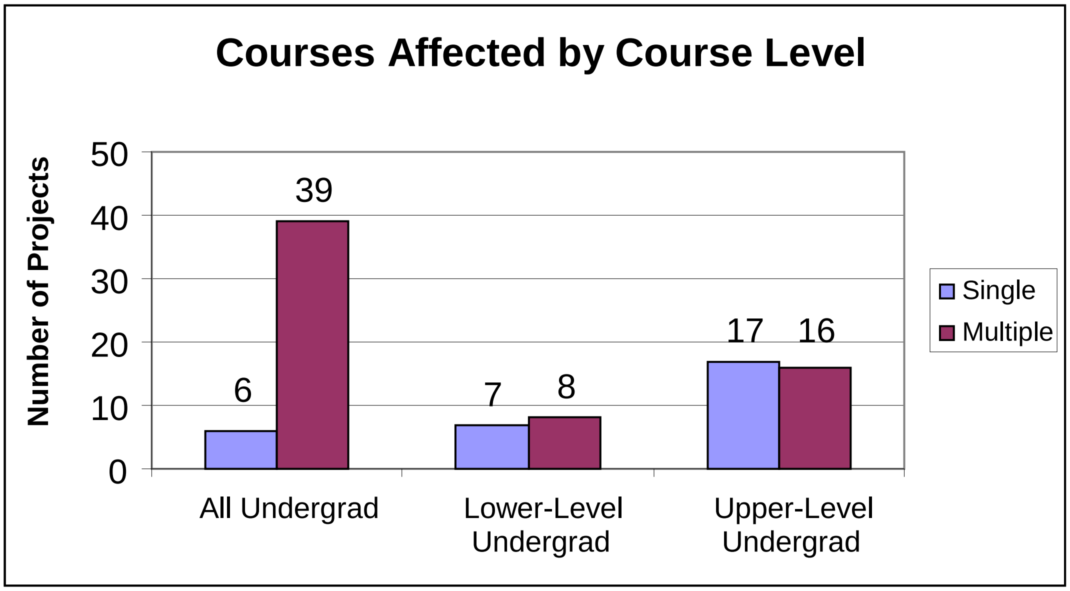

Figure 4.2-5: Courses Affected by Course Level

Type of Research and Development

Materials development was the most highly represented focus area of the project set (representing 71% of all projects) followed by curriculum development (57%), faculty development (30%), and pedagogy development (29%). Development of assessment tools and research each comprised approximately 10% of the project set. Collaborative projects reflected this distribution as well, with the exception of pedagogical development projects, of which there was only one.

For Phase 1 projects, the distribution of projects to small (less than 10,000 undergraduates, 18 total institutions), medium (between 10,000 and 24,999 undergraduates inclusive, 58 total), and large (25,000 or more undergraduates, 24 total) schools was comparable to the actual distribution of schools by size; however, Phase 2 projects are represented much more heavily by small schools than would be expected by their distribution (100% confidence). In addition, medium schools are more likely than large schools to fund Phase 2 projects (89.6% confidence). Figures 4.2-6, 4.2-7, and 4.2-8 provide more information about the focus of projects.

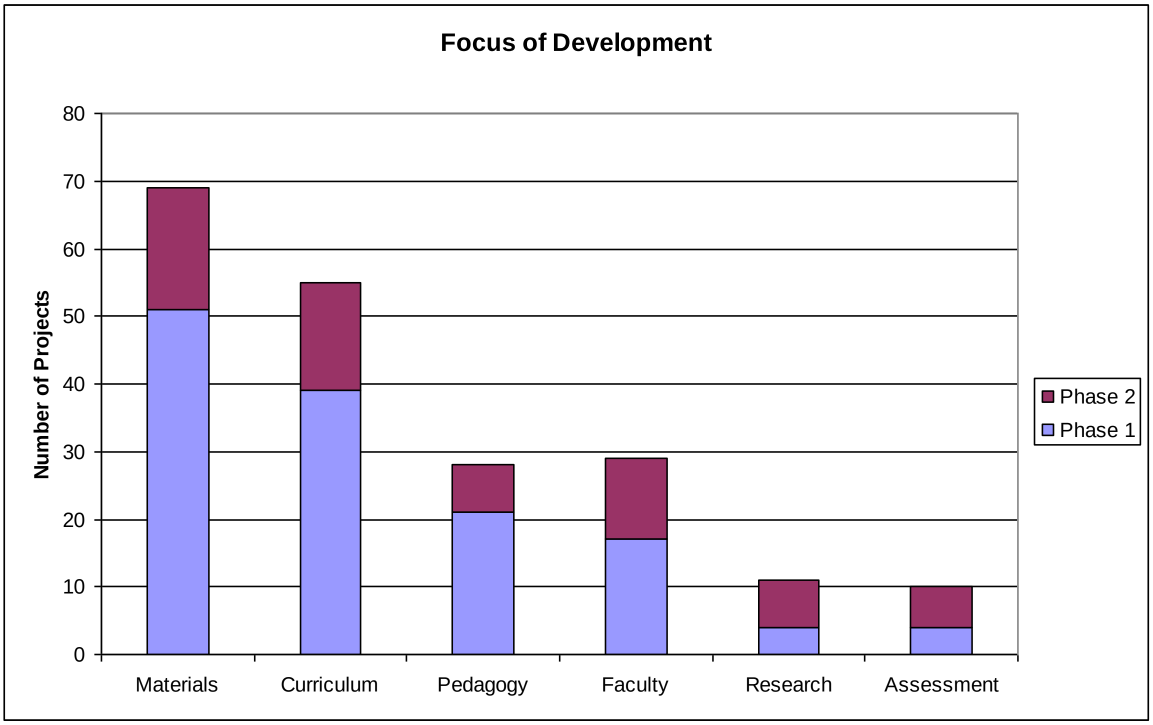

Figure 4.2-6: Focus of Development by Phase and Size of School

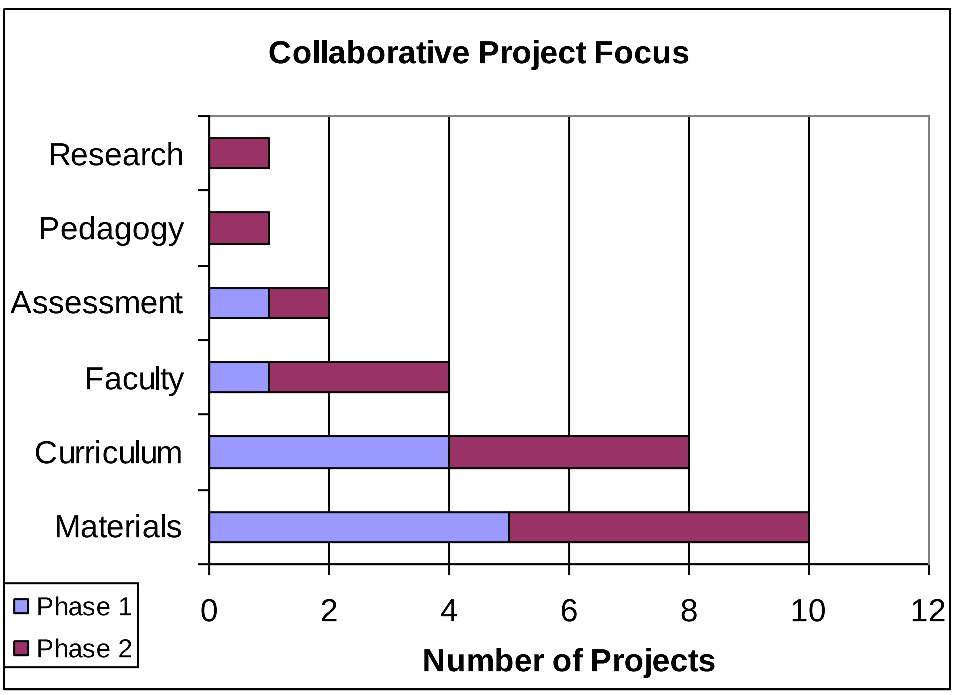

Figure 4.2-7: Collaborative Project Focus

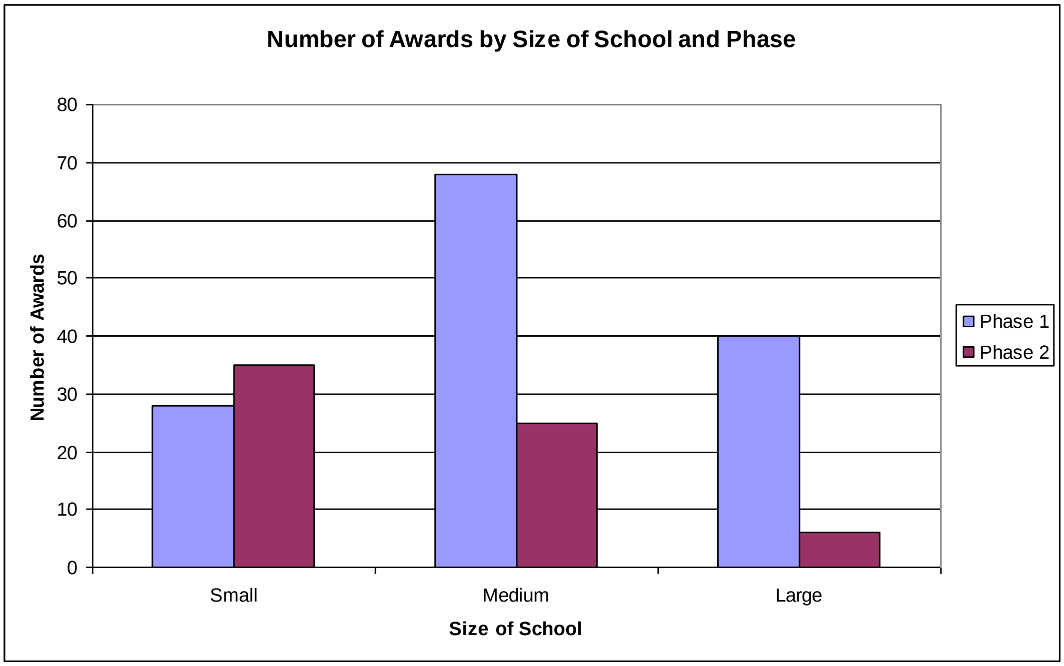

Figure 4.2-8: Number of Awards by Size of School and Phase

Materials Development

The most common focus of CCLI engineering education projects was the development of educational materials. This covers a broad range of items from technological materials such as software, online tutorials, and methods for simulation and visualization to new textbooks, workbooks, case studies, and manuals. Two projects even developed educational video games.

Technology developments comprised a major portion of the educational materials developments. A breakdown of the technology developments is found in Figure 4.2-9.

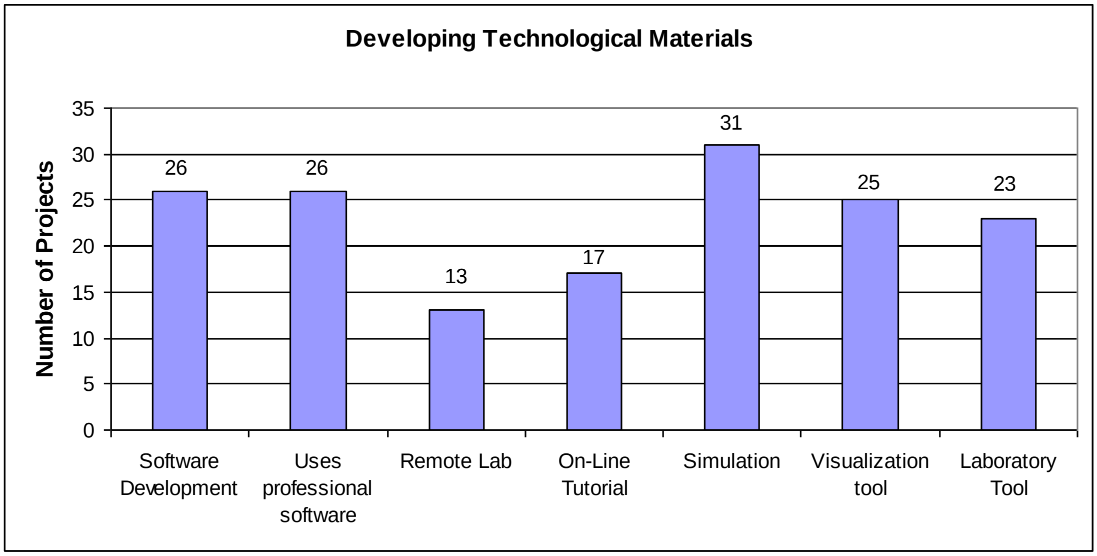

Figure 4.2-9: Developing Technological Materials

The most common development (41 projects) was to create or improve sets of experiments. Also popular were the development of modules (37). More data about educational materials are displayed in Figure 4.2-10.

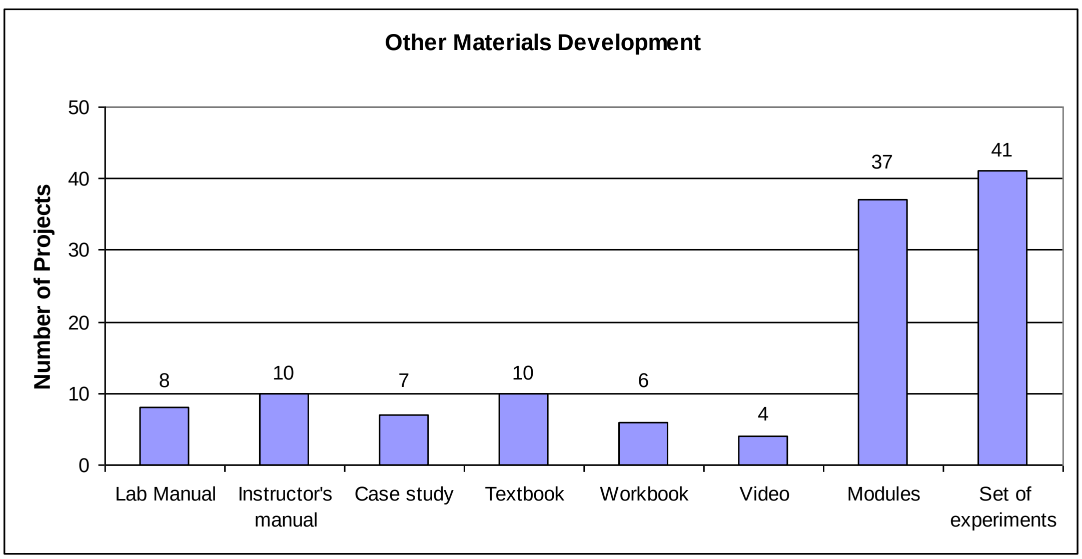

Figure 4.2-10: Other Materials Development

Pedagogy Development

Pedagogy development was a main focus of 29% of all projects. Efforts to improve pedagogy were diverse, however. Many of these efforts were focused on laboratory classes, with over 43% of projects working to improve the way laboratory classes were taught. Twenty-one percent of Phase 1 projects and 26% of Phase 2 projects focused on developing lecture techniques. These data are shown in Figure 4.2-11. Nearly four-fifths of all projects incorporated an active learning component and 28% involved some kind of group work. Fifteen percent of projects included a distance learning component. One noticeable difference between Phase 1 and Phase 2 projects involved peer-led learning. Only 1% of Phase 1 projects involved peer-led learning, while 19% of Phase 2 projects included a peer-led learning component.

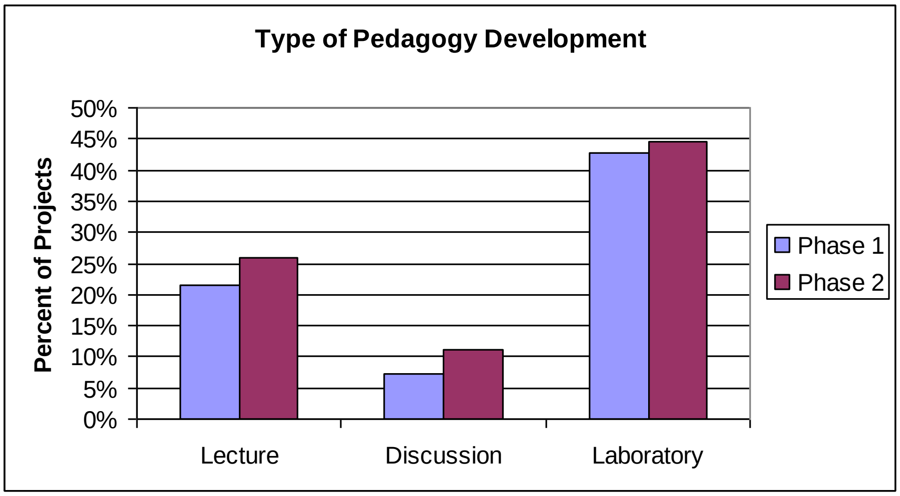

Figure 4.2-11: Type of Pedagogy Development

Evaluation Methods

Evaluation methods varied greatly from proposal to proposal. Many techniques were common among them, however. The most popular evaluation method was the use of student surveys. Sixty-nine percent of all projects included a student survey in the evaluation plan. Pre- and post-tests, including the use of concept inventories were also very popular, with 52% of projects utilizing this method. Other recurring methods include student interviews (40%), faculty surveys (28%), and student focus groups (26%). Additionally, there were some slight differences between the evaluation procedures of projects of different phases. Phase 2 projects were more likely to have both summative and formative evaluation measures than Phase 1 projects. These data are displayed in Figure 4.2-12.

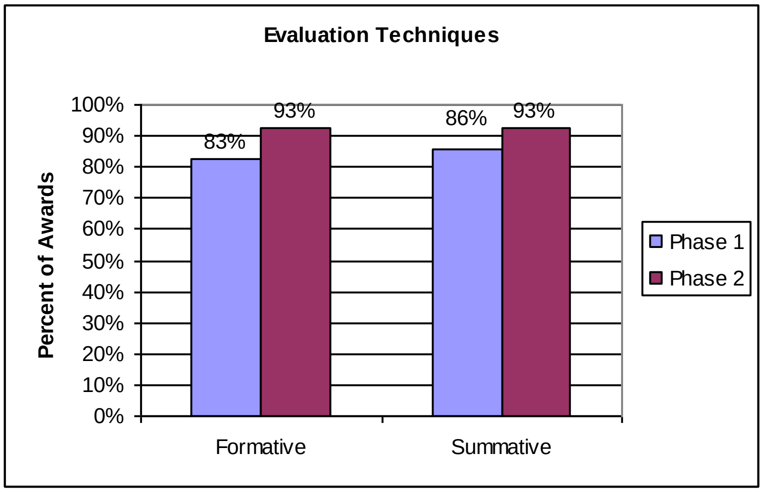

Figure 4.2-12: Evaluation Techniques

The person conducting the evaluation varied from project to project as well. A significant portion of projects included experts skilled in evaluation either directly or by contract. As can be seen in Figure 4.2-13, 62% of Phase 1 projects included expert evaluators, while 81% of all Phase 2 projects included this component. In addition, exactly half (11 of 22) of Phase 2 projects involving expert evaluators made use of personnel outside the sponsored institution, either evaluation specialists on contract or expert faculty from other universities. The remainder made use of specialists from within the institution itself. Comparably, 20 of 43 Phase 1 projects involved external expert evaluators while the remaining 23 involved internal expert evaluators. Overall, Phase 2 projects were more likely to use expert evaluators than Phase 1 projects (95% confidence).

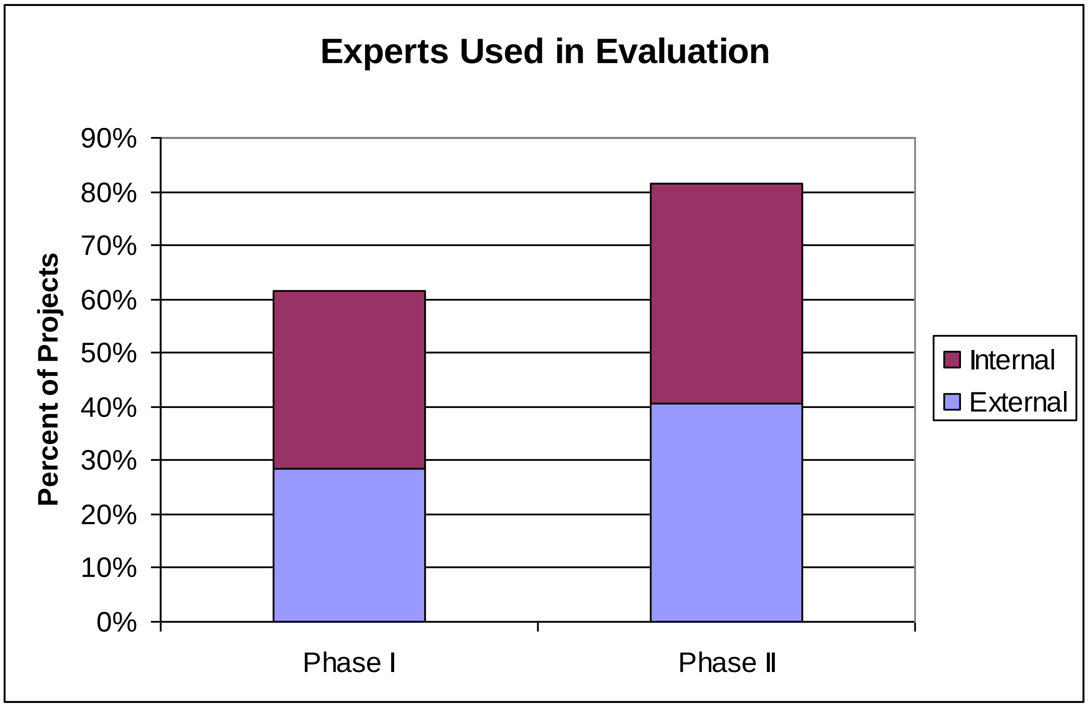

Figure 4.2-13: Experts Used in Evaluation

Dissemination Methods

Proposed dissemination methods varied from project to project. A few projects utilized very unique dissemination methods including a mobile demonstration booth and the creation of a new academic journal. Many projects used similar dissemination methods, however. A vast majority of proposals used websites, conferences, and/or journals to disseminate their findings. Conferences and/or websites were used by 82% of all projects, with journals close behind at 72%. Though these methods were popular among all projects, certain dissemination methods were more popular among Phase 2 proposals, such as workshops and the use of mail and email. For example, workshops were used by 67% of Phase 2 projects, but only 30% of Phase 1 projects utilized that method. These data are shown in Figure 4.2-14.

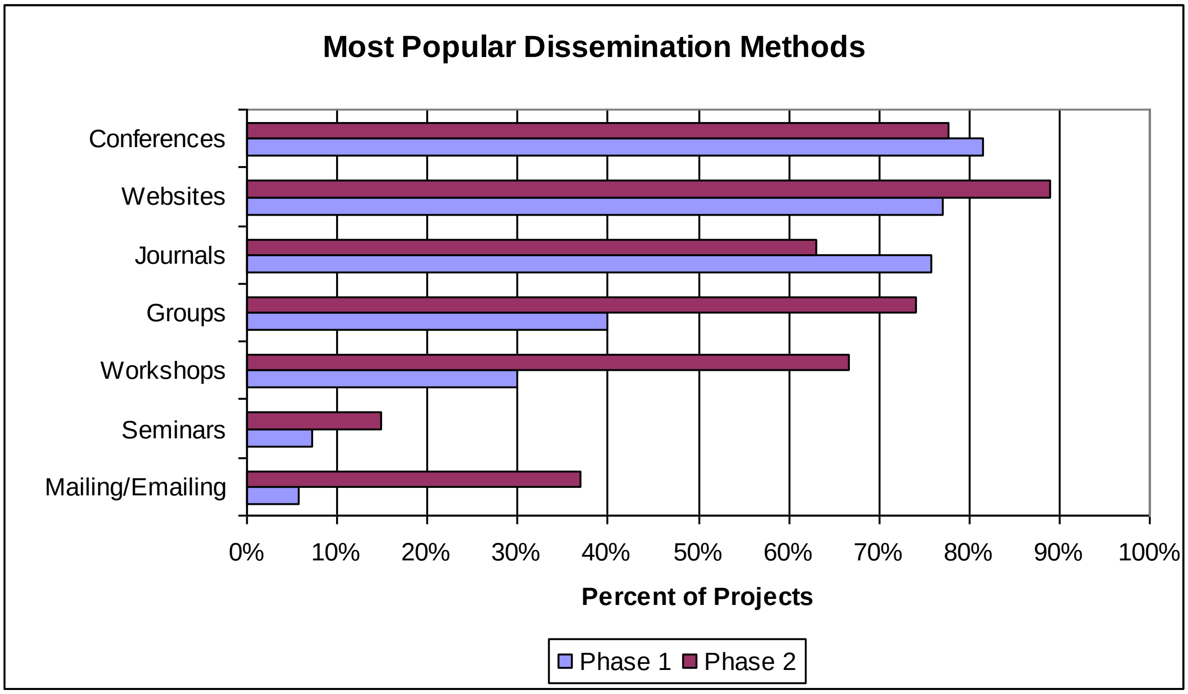

Figure 4.2-14: Most Popular Dissemination Methods

Outreach to Underrepresented Groups

Many projects included efforts to address underrepresented groups in engineering, often aimed to increase interest and retention of these groups. Almost two-fifths (39%) of all projects specifically considered underrepresented groups. Many of these projects targeted minorities (32%) and women (25%). A small number of projects also focused their efforts on addressing persons with disabilities. These categories are not mutually exclusive: projects may have addressed more than one population group. These results are displayed in Figure 4.2-15.

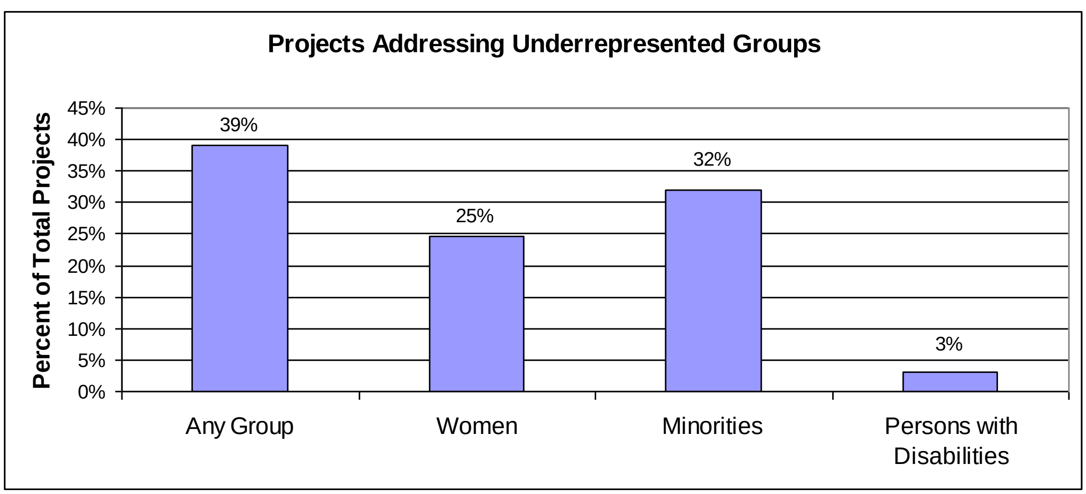

Figure 4.2-15: Projects Addressing Underrepresented Groups

ABET Criteria

With the recent ABET EC 2000 criteria the focus of projects has addressed these concerns. Over 40% of projects focused on designing and conducting experiments. Approximately 25% of Phase 1 projects focused on improving student ability to design a system, with 41% of Phase 2 projects containing this focus. In addition, almost half of Phase 2 projects involved teams while about 30% of Phase I projects involved teams. Overall, Phase 2 projects exhibited slightly more focus on addressing ABET criteria when compared to Phase 1 projects, including more concentration in communication, ethics, and problem solving (71% confidence). Figure 4.2-16 shows these trends.

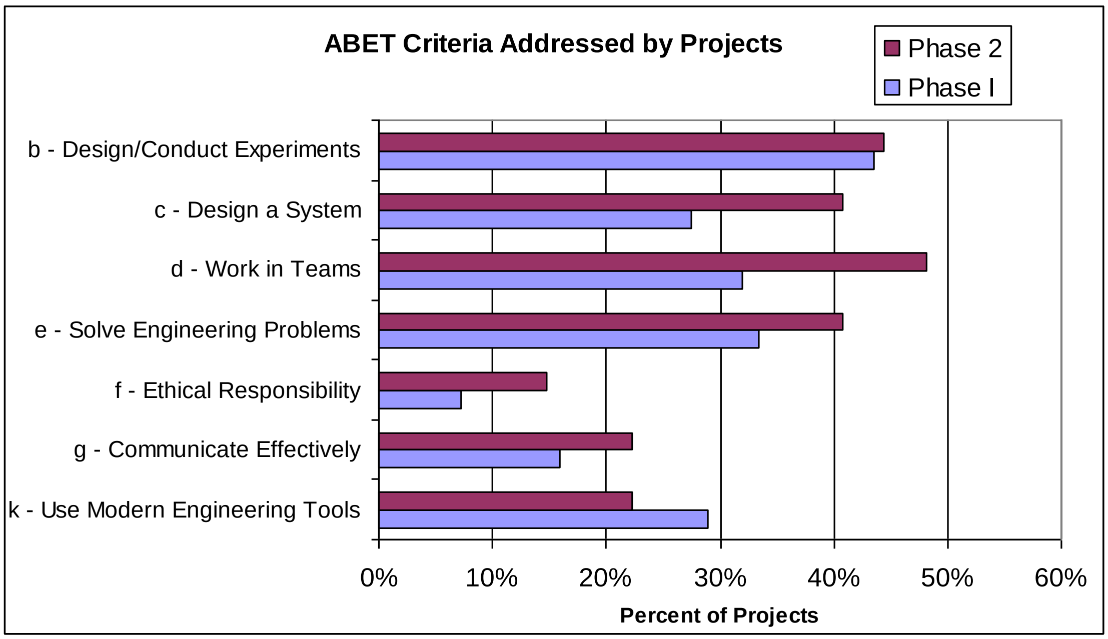

Figure 4.2-16: ABET Criteria Addressed by Projects

5. Further Observations

5.1 Proposal Pressure

NSF program directors recommend proposals by choosing the most competitive proposals. Each program director has their own unique definitions for competitive. In addition, there is no quota for awards based on discipline. If it is assumed that a certain percentage of all proposals will be funded, it can also be assumed that a smaller number of proposals in a certain discipline will result in fewer awards in that discipline. Because of this, the number of engineering awards per year may fluctuate based on the total number of engineering proposals that were submitted. This result manifests itself in a number of ways. Certain years may experience a lower amount of total funding for CCLI engineering awards, and certain disciplines may experience more or less than their fair share of awards when compared to aggregate proportions such as national undergraduate enrollment in that discipline. This may also be the cause for shifts in the annual number of proposals in specific phases or program codes, or the types and sizes of schools awarded to on any given year.

5.2 Differences between Phase 1 and Phase 2 Projects

Through our analysis, it became clear that Phase 1 projects and Phase 2 projects are distinctly different. Differences emerged in nearly every measure of scope, from the people affected to evaluation and dissemination methods. Though these disparities may have been expected, they are no less noteworthy. With one of the major objectives of Phase 2 projects being to increase dissemination and implementation of previous research, it was expected that Phase 2 projects impact a higher number of people at all academic levels than Phase 1 projects, as it is shown in Figures 4.2-2 and 4.2-3. Figure 4.2-4 shows Phase 2 projects included more multiple course impact than Phase 1 projects. Phase 2 projects also had a higher number of expert evaluators (Figure 4.2-12), and types of dissemination methods (Figure 4.2-14).

5.3 Relations between Interviews and Results

One of the goals of performing interviews was to understand the direction and status of the engineering education reform movement as seen by its stakeholders, including professional organizations and the NSF. By identifying the successful aspects of the movement as well as the failures we hoped to determine how closely the NSF's CCLI program aligns with the goals of other stakeholders. In order to do this, it was necessary to build a cross-section of the recent projects funded by CCLI in addition to determining the techniques and methods that are considered most effective in reforming engineering education. By doing this, it is possible to recognize whether the projects funded by CCLI contain characteristics of accepted, successful engineering education reform.

Many interview respondents expressed concerns, both positive and negative, about certain areas, including the need for effective dissemination and assessment, the importance of soft skills in engineering, the value of innovative and effective new pedagogies involving active learning techniques, the balancing act between innovation and adaptation of novel ideas on a limited resource budget, the cultural barrier at major universities, and the importance of revolutionary versus evolutionary change. In order to address these concerns, inferences from the data must be made.

Assessment

Education has for countless years been considered a soft science; however, many respondents expressed the need for education reform to be a process that includes scientific methods and analysis. Formative and summative evaluation of funded projects must be used to ensure the effects of a project are well understood. CCLI funded projects meet this concern. Over 80% of Phase 1 and over 90% of Phase 2 projects exhibit both formative and summative evaluation techniques. In addition, as many as 80% of Phase 2 projects involve the use of experts specifically for project evaluation. CCLI funded projects exemplify a keen awareness of the importance of proper, scientific project analysis.

Dissemination

A frequently cited cause of the slow place of engineering education reform is the inability to disseminate and implement effective new pedagogies. Even for new pedagogies that, after formal analysis, turn out to be ineffective, the importance of disseminating the methods and techniques used in the study cannot be understated. Yet, over 60% of all projects continue to rely on "traditional" dissemination methods, including websites, journal publication and conferences. In fact, almost 90% of Phase 2 projects involved the use of a website as a means of dissemination, and approximately 80% of both Phase 1 and Phase 2 projects involve presentation at conferences. While these methods can be efficient means of dissemination for certain topics, respondents often mentioned the ineffectiveness of these passive dissemination techniques. Only a small number of Phase 1 projects expressed the use of unique, active dissemination techniques; however, approximately two-thirds of Phase 2 projects involved workshops, the most common form of active dissemination. Despite this, CCLI projects overall rely primarily on passive techniques as their primary method of dissemination, reinforcing the concerns of stakeholders.

Soft Skills in Engineering and ABET Criteria d, f, and g

The ABET EC2000 criteria have shifted the views of many engineering programs across the country to outcomes assessment. This has caused a dramatic shift in all aspects of engineering education. Although the new criteria are less than a decade old, representatives from leading professional organizations feel that they have been fully synthesized, or at least recognized, by most departments across the country. Of the new criteria, there is a new focus on soft skills in engineering, including teamwork, communication, and professional ethics. While team-based pursuits are incorporated into CCLI programs quite often (almost 50% of Phase 2 and just over 30% of Phase 1), only about 20% of all projects focus on communication skills, and even fewer (approximately 10%) focus on professional responsibility and ethics. With the exception of team skills, ABET's and others' concerns over the lack of focus on soft skills in engineering education has gone largely unheeded by CCLI programs.

Active Learning Pedagogies

Interview respondents expressed a concern that some new pedagogical techniques were not focusing on active learning, which has been proven to be more effective than passive, lecture-based methods. Fortunately, this concern seems to be addressed by CCLI investigators. More than three-quarters of unique projects expressed some sort of active learning component, with much of the remainder containing faculty development or research type projects for which this may not be applicable. The data suggest that CCLI investigators recognize the importance of active learning techniques in their projects.

Scope

According to respondents, in order to accomplish effective reform in engineering education, strong ideas must impact the maximum number of persons that can be achieved within a project's budget. As a matter of fact, the average number of undergraduates impacted by each project is self-reported by principal investigators to be over one thousand, and the average number of faculty impacted by each project is about 17.

While incremental change is important and necessary in the effective development of engineering education reform, large scale, curriculum wide change is also significant in the process. The ABET EC2000 criteria have already jumpstarted the move towards revolutionary change by imposing the new accreditation criteria; therefore, it is expected that principal investigators continue this trend. Over 60% of all projects and 80% of Phase 2 projects impact more than one course, a component of systemic change. Not only that, but multi-disciplinary efforts extend to nearly 45% of all projects, representing a strong push by investigators to include change across an entire curriculum, or at least more than one aspect of a curriculum. These statistics indicate that CCLI investigators have a keen interest in sustaining revolutionary versus evolutionary change.

Faculty Inertia

Interview respondents from professional organizations and universities noted that, while many faculty are active in the engineering education reform process, there is still a significant portion of those who are not interested in education research and would rather focus efforts on their disciplinary research. The data in this report is reflective of the portion of faculty who are deeply committed to improving undergraduate engineering education; therefore, it is difficult to say with certainty how widespread this phenomenon of faculty inertia may be. However, interview respondents cited the lack of reward system for education research for faculty, limited time resources, and the lack of prestige education research offers as major hurdles for engineering programs to overcome should they wish to further engineering education reform. Combined, these hurdles represent a cultural barrier that slows the progression of reform.

6. Recommendations

After completing the project, we have identified several recommendations to present to the National Science Foundation to continue the construction of the profile of CCLI awards in engineering and expand the work to other disciplines. This chapter contains these recommendations.

We recommend that the National Science Foundation expand the examination of subjective characteristics to all 584 awards in engineering. This will allow for comprehensive historical analysis of CCLI funding in engineering. Furthermore, it will provide a complete overview of the research and development efforts in engineering education funded through CCLI.

We recommended that CCLI continue to update this database as new awards are made. The current database thoroughly analyzes awards from 2006 and 2007. These data will soon become outdated, and their usefulness will expire. If the database were continually updated, the profile would remain applicable indefinitely. CCLI would always have an up-to-date profile of their awards, both from the past funding cycle and as trends since the beginning of the program.

We recommend revisions be made to the current record-keeping system to allow for minimal manual extraction of data from the proposals. Budget information, academic discipline, geographic information, and other objective data could automatically be extracted to a database using a computer application when an award is made. Program directors could code proposals for subjective characteristics as they recommend them for funding. Since program directors are quite familiar with proposals at this time, coding then would eliminate the need to re-read proposals at a later date. This would greatly expedite the construction of the database.

Furthermore, we recommend that CCLI expand this profile to disciplines outside of engineering. The information provided by the engineering profile would be equally valuable to other disciplines. A database of a similar nature is currently under construction for awards in the Biological Sciences. If databases were constructed for Chemistry, Computer Science, Geological Sciences, Mathematics, Physics, Social Sciences, and Interdisciplinary programs, CCLI would have a complete profile of all of its awards. A coordinated interdisciplinary effort would ensure these databases were compatible. This could improve interdisciplinary communication between program directors and help focus solicitations for new research and development.

The profile could be expanded to include some characteristics that have not been included to date. The profile should include a section detailing the use of concept inventories as an evaluation method. It should also include a characteristic specifying the development of concept inventories as an assessment tool. Concept inventories were a recurring theme in many proposals, but the profile has failed to consider them specifically. An in-depth analysis of the ABET criteria fulfilled by development projects could prove insightful. If researchers were aware of the underdeveloped aspects of engineering education, they could work to fill this void.

Adding information to the profile could fill gaps regarding what has been learned through the research supported by CCLI and what needs to be learned next. If the profile included additional information, it would better guide communication and cooperation between the many stakeholders in engineering education.

Also, an investigation into the outcomes of the projects funded is recommended to gain further insight into the effectiveness of engineering education reform. While dissemination of projects is being performed on a project-by-project basis, the analysis of the results of funded projects would be better able to show what is and what is not working in engineering education. A general overview of engineering education reform would assist in breaking down the barriers hindering improvements in undergraduate education.

Finally, and most importantly, it is necessary to disseminate this information to as many groups as possible. The National Science Foundation should share this information with potential applicants, policy makers, and those organizations with vested interests in engineering education. If more people had access to this information, it would further stimulate discussion on engineering education research and accelerate the pace of engineering education reform.

Appendix A: National Science Foundation

The National Science Foundation (NSF) was created by Congress in 1950 as an independent federal agency with a mission "to promote the progress of science; to advance the national health, prosperity, and welfare; [and] to secure the national defense…" (NSF, 2007). Today it provides 20% of all federally-funded basic research in colleges and universities and is the leading source of funding for mathematics, computer science, and social science research. Its mission is vast and varied, as it touches virtually all scientific research in the United States. There are approximately 1,700 employees at the national headquarters, but through the grants it funds it supports thousands of researchers across the United States as well as in locations such as Antarctica and the many US Territories.

When it was founded in 1950, the National Science Foundation had only enough funds for 28 grants. The first location at 901 16th Street, NW, Washington, DC was roughly the size of a large house. Not only has it grown to giving approximately 10,000 new grants every year, it has also grown in physical size. Presently, the Foundation occupies a substantial block of offices in the Ballston area of North Arlington, Virginia.

After the Soviet Union launched the satellite Sputnik, an emphasis on the technology needed to keep pace in the Space Race led to an increase in budget to well over $100 million. While that pales in comparisons to today's budget of $5.92 billion, it demonstrated the added significance placed on federal funding for scientific research.

The NSF also serves as a forum for communication in the scientific community. As many ideas come through the organization, they are discussed both in terms of intellectual merit and broader impact by NSF staff. The organization has an average of "150 scientists from research institutions on temporary duty." (NSF, 2007) These scientists review grant proposals to ensure they are innovative and are valuable to the academic community.

Each year, a wide variety of projects receive funding. Of the many recipients, one of the most visible is public television. Other projects funded by the NSF are as diverse as the impact of wireless networking on fighting California wildfires, and looking into "A Mathematical Solution for Another Dimension." (NSF, 2007) It both solicits proposals for specific areas of research and accepts unsolicited proposals for grants.

There are 7 major directorates to the National Science Foundation: Biological Sciences; Computer & Information Science & Engineering; Education & Human Resources; Engineering; Geosciences; Mathematical & Physical Sciences; and Social, Behavioral and Economic Sciences. Along with the Office of the Director, Office of the Inspector General, and the National Science Board, there are a total of 10 major branches to the foundation.

The Directorate for Education and Human Resources, where our efforts will be concentrated, is subdivided into 6 divisions: Graduate Education; Research on Learning in Formal and Informal Settings; Undergraduate Education; Experimental Programs to Stimulate Competitive Research; Division of Research, Evaluation, and Communication; and Human Resource Development. We will be working with the Division of Undergraduate Education, whose mission is "To promote excellence in undergraduate science, technology, engineering and mathematics (STEM) education for all students." (NSF, 2007) STEM is a large initiative not only for undergraduate students, but it intends to foster interest from early childhood through post-secondary education.

Within the DUE falls the Course, Curriculum, and Laboratory Improvement (CCLI) program. It "supports efforts to create new learning materials and teaching strategies, develop faculty expertise, implement educational innovations, assess learning and evaluate innovations, and conduct research on STEM teaching and learning." Also, it "provides indirect funding for undergraduate students or focuses on educational developments for this group such as curriculum development, training, or retention." (NSF, 2007) Figure A1 on the following page details how CCLI falls within the organizational structure of the National Science Foundation.

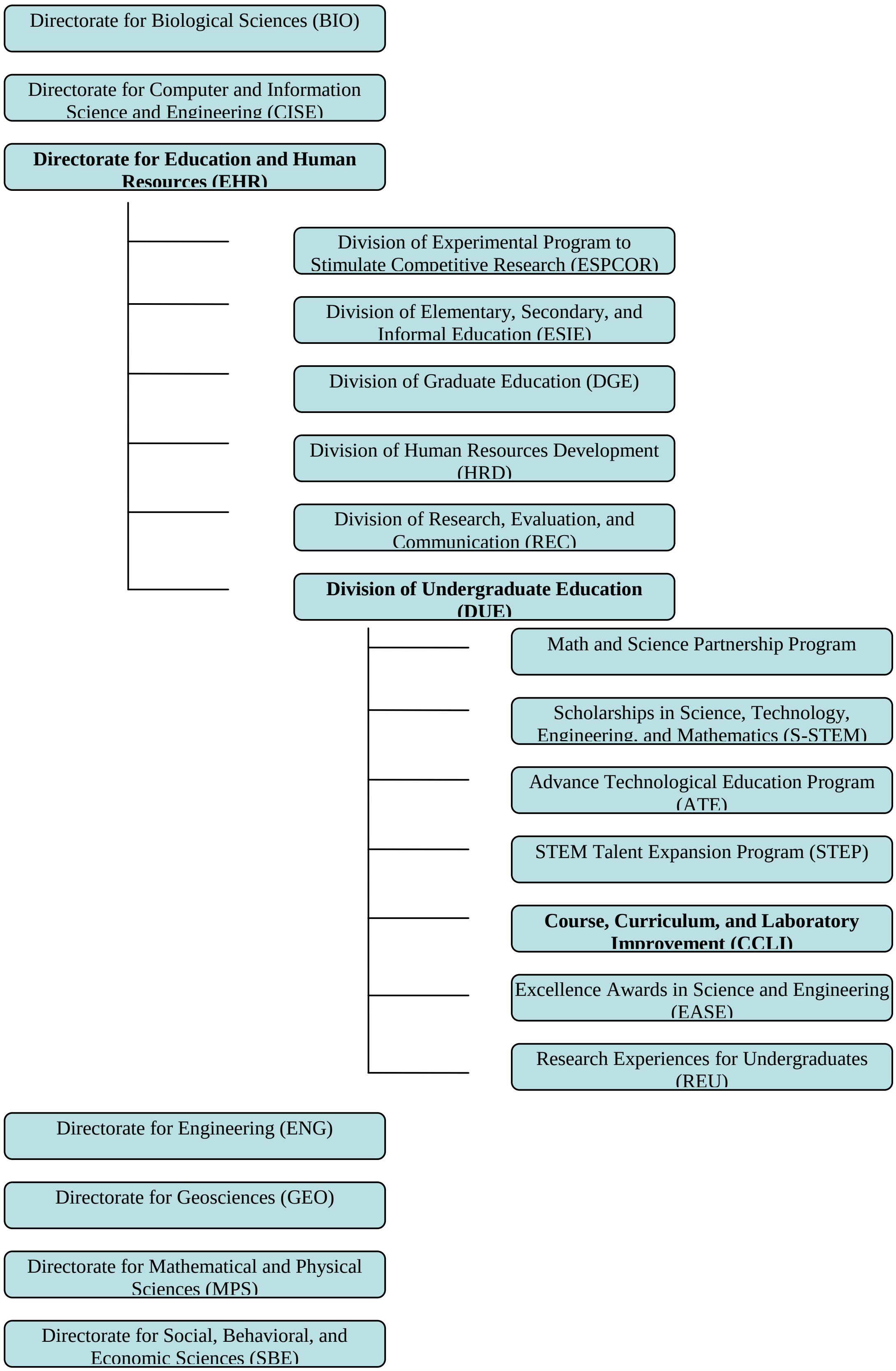

Figure A1 – Organizational Chart of the National Science Foundation

Professors interested in obtaining NSF funding for a project must submit a proposal which is reviewed by both an NSF program officer and a panel of experts. These reviewers will determine if a project possesses an innovative idea that will have the potential to be disseminated beyond the home university. In addition, the panel must feel confident the investigator and the university are competent of performing their stated goals within their budget and time frame. Often, the principal investigator will engage in a correspondence directly with the program officer to refine the proposal during the application phase. Figure A2 below details the flow of proposals during the approval process.

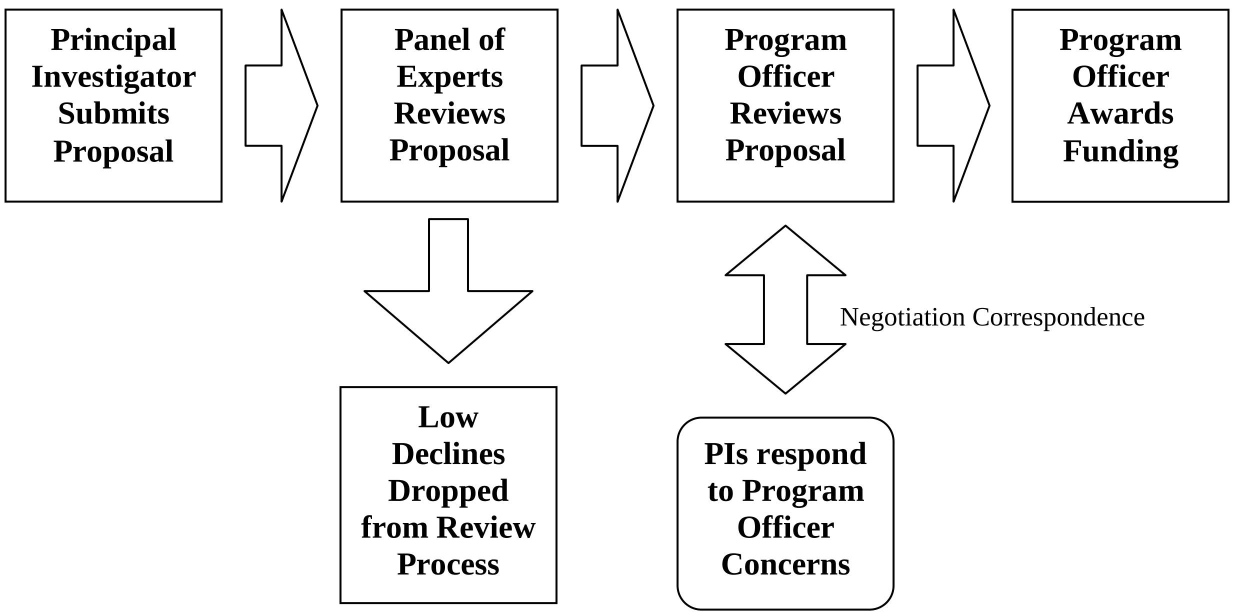

Figure A2 – Flow chart of proposals through the National Science Foundation

Along with funding research projects and furthering the interest of children and young adults in math and science, the NSF also has programs for women and minorities both in and out of the undergraduate environment. It has ongoing research projects on "Gender in Science and Engineering" (GSE) and "Women, Minorities and Persons with Disabilities." A determined effort is being made to broaden the demographic of the minds doing the research.

The work done by the National Science Foundation greatly affects everyday life in the United States. It is attempting to foster new scientists through children's programs, create life-changing technology, and generally better the lives of the US population and in turn those of the other citizens of the world. It also betters the life of the college undergraduate through the grants it provides to our universities for research. These grants provide research opportunities that have the potential to bring more prestige to our universities, in turn attracting higher quality professors and students and enhancing the academic environment.

Appendix B: Engineering Education Coalitions

Coalition	Participating Institutions	Major Contributions
Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) http://echo.ecsel.psu.edu/ 1990–2001	City College of the City University of New York Howard University Massachusetts Institute of Technology Morgan State University Pennsylvania State University University of Maryland University of Washington	First-year engineering design courses Assessments of innovative pedagogical approaches
Synthesis http://www.synthesis.org 1990–2001	California Polytechnic State University at San Luis Obispo Cornell University Hampton University Iowa State University Southern University Stanford University Tuskegee University University of California at Berkeley	Artifact dissection NEEDS (National Engineering Education Delivery System)
Southeastern University and College Coalition for Engineering Education (SUCCEED) http://www.succeednow.org 1992–2003	Clemson University Florida A&M University - Florida State University Georgia Institute of Technology North Carolina Agricultural and Technical State University North Carolina State University University of North Carolina Charlotte University of Florida Virginia Polytechnic Institute and State University	Multidisciplinary capstone design courses SUCCEED longitudinal student database

Gateway http://www.gatewaycoalition.org 1992–2003	Columbia University Cooper Union Drexel University New Jersey Institute of Technology Ohio State University Polytechnic University University of South Carolina	First-year engineering curricula Multimedia modules
Foundation http://www.foundationcoalition.org 1993–2004	Arizona State University Maricopa Community College District Rose-Hulman Institute of Technology Texas A&M University Texas A&M University Kingsville Texas Women's University University of Alabama University of Massachusetts Dartmouth University of Wisconsin Madison	First two years of engineering curricula Engineering science concept inventory assessment instruments
Greenfield http://www.greenfield-coalition.org 1994–2005	Lawrence Technological University Lehigh University Michigan State University University of Detroit Mercy Wayne State University	Learning objects Manufacturing curricula

Figure A3 – Engineering Education Coalitions Membership and Major Accomplishments (from Educating…, 85)

Appendix C: ABET Organizations

ABET Member Societies

American Academy of Environmental Engineers (AAEE)
American Congress on Surveying and Mapping (ACSM)
American Institute of Aeronautics and Astronautics (AIAA)
American Institute of Chemical Engineers (AIChE)
American Industrial Hygiene Association (AIHA)
American Nuclear Society (ANS)
American Society of Agricultural and Biological Engineers (ASABE)
American Society of Civil Engineers (ASCE)
American Society for Engineering Education (ASEE)
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
American Society of Mechanical Engineers (ASME)
American Society of Safety Engineers (ASSE)
Biomedical Engineering Society (BMES)
Computing Sciences Accreditation Board (CSAB)
Health Physics Society (HPS)
Institute of Electrical and Electronics Engineers (IEEE)
Institute of Industrial Engineers (IIE)
The Instrumentation, Systems, and Automation Society (ISA)
National Council of Examiners for Engineering and Surveying (NCEES)
National Institute of Ceramic Engineers (NICE)
National Society of Professional Engineers (NSPE)
Society of Automotive Engineers (SAE)
Society of Manufacturing Engineers (SME)
Society for Mining, Metallurgy, and Exploration, Inc. (SME-AIME)
Society of Naval Architects and Marine Engineers (SNAME)
Society of Petroleum Engineers (SPE)
The Minerals, Metals, and Materials Society (TMS)

Associate Member Societies

Materials Research Society (MRS)

(ABET 2007)

Appendix D: Objective Characteristics

Dates

- Application date (mm/dd/yyyy)
- Date awarded (mm/dd/yyyy)
- Date project completed (mm/dd/yyyy)

Project Level

- Phase (code)
- Standard or continuing grant
- Collaborative project (Yes, No)

Budget and Term

- Award value (dollar amount)
- Award term (months)
- Percent awarded as PI's salary (percent)
- Percent awarded as senior personnel salary (percent)
- Percent awarded as other personnel wages (percent)
- Percent awarded as materials or supplies (percent)
- Percent awarded as equipment (percent)
- Percent awarded as dissemination costs (percent)
- Percent awarded as travel costs (percent)
- Funding from outside the NSF (dollar amount)

Academic Focus

- Academic discipline (code)

Principal Investigators

- Area of degree (code)
- Level of degree (code)
- Experience since Ph.D. (year of award – year of degree)
- Number of senior personnel (number)
- Number of previous NSF awards (number)
- Number of previous declines (number)
- Academic rank of faculty (Assistant Professor, Associate Professor, Professor)

Institutions Involved

- Public or private
- 4-year or 2-year
- Highest degree offered (code)
- State (US Postal Service abbreviations)

- Geographic region (New England, Mid-Atlantic, South, Midwest, Southwest, West)
- Number of institutions involved (number)

People

- Number of undergraduate students (number)
- Number of graduate students (number)
- Number of faculty (number)
- Number of pre-college students involved (number)

Appendix E: Subjective Characteristics

Codes used to rate proposals can be found in Appendix F.

Academic Focus

- Academic concentration (code)
- Course level (code)
- Majors or non-major engineers or non-majors
- Single discipline or multi-disciplinary
- One course or multiple courses or no courses affected

Goals of Research or Development

- Curriculum development/improvement (Yes, No)
- Pedagogy development (Yes, No)
- Materials development (Yes, No)
- University faculty development (Yes, No)
- Development of assessment tools (Yes, No)
- Research (Yes, No)
- K-12 community outreach/education (Yes, No)
- Dissemination to other universities (Yes, No)
- Addresses underrepresented populations (Yes, No)
    - Addresses women (Yes, No)
    - Addresses minorities (Yes, No)
    - Addresses persons with disabilities (Yes, No)

Materials Development

- Software development (Yes, No)
- Uses professional software (Yes, No)
- Remote laboratory (Yes, No)
- Online tutorial (Yes, No)
- Simulation (Yes, No)
- Laboratory manual (Yes, No)
- Visualization tool (Yes, No)
- Set of experiments (Yes, No)
- Instructor’s manual (Yes, No)
- Games (Yes, No)
- Kit (Yes, No)
- Case study (Yes, No)
- Laboratory tool (Yes, No)
- Textbook (Yes, No)
- Workbook (Yes, No)
- Video (Yes, No)
- Modules (Yes, No)

- Other (Yes, No)

Faculty Development

- Materials dissemination (Yes, No)
- Conference (Yes, No)
- Workshop (Yes, No)
- Other (Yes, No)

Pedagogy Development

- Active learning (Yes, No)
- Lecture development (Yes, No)
- Discussion development (Yes, No)
- Laboratory development (Yes, No)
- Collaborative learning (Yes, No)
- Peer-led learning (Yes, No)
- Co-operative education (Yes, No)
- Distance learning (Yes, No)
- Other (Yes, No)

Professional Skills Development

- Ethics (Yes, No)
- Teaming (Yes, No)
- Design (Yes, No)
- Problem solving (Yes, No)
- Economics and business (Yes, No)
- Communication (Yes, No)

Evaluation

- Formative or summative or both
- Pre- and post-tests (Yes, No)
- Student surveys (Yes, No)
- Faculty surveys (Yes, No)
- Student focus groups (Yes, No)
- Student interviews (Yes, No)
- Expert evaluation specialists (Yes, No)
- University evaluator (Yes, No)
- Other (Yes, No)

Dissemination

- Website (Yes, No)
- Conferences (Yes, No)
- Journals (Yes, No)
- Mailings/e-mailings (Yes, No)

- Specialty and collaborative groups (Yes, No)
- Seminars (Yes, No)
- Workshops (Yes, No)
- Other (Yes, No)

Appendix F: Codes Used to Rate Proposals

Phase:

1	Phase 1
2	Phase 2
3	Phase 3
A&I	Adaptation and Implementation
ND	National Dissemination
ASA	Assessment of Student Achievement
EMD	Educational Materials Development

Academic Discipline and Area of Degree:

31	Computer Science
32	Computer Engineering
33	Information Science and Systems
34	Software Engineering
35	Computing – Other
42	Geology
51	Engineering - Aeronautical/Astronautical
53	Engineering – Chemical
54	Engineering – Civil
55	Engineering – Electrical
56	Engineering - Mechanical
57	Engineering – Materials
58	Engineering - Engineering Technology
59	Engineering – Other
71	Psychology – Biological
72	Psychology – Social
73	Psychology – Cognitive
91	Assessment / Research
99	Interdisciplinary
0	Other

Level of Degree and Highest Degree Offered:

A	Associate
B	Bachelor
M	Master
D	Ph.D.
U	Unknown

Course Level:

UP	Upper-level Undergrad (Junior + Senior)
LO	Lower-level Undergrad (Freshman + Sophomore + introductory course)
BO	Undergrad (Upper-level and Lower-Level)

Appendix G: Interview Questions for Program Directors

1. What do you see as the direction of CCLI programs?
    a. What types of programs do you see CCLI funding in the future?
    b. Have you noticed any trends in the proposals you review?

2. What is your overall strategy for funding grants? Do you consider certain projects more heavily based solely on their focus?

3. If there were a profile describing the nature of CCLI Awards, what information should it have?
    a. What types of information would be valuable to your work, particularly the decision-making process? (or, would have been useful if interviewee is no longer employed at NSF)
        i. What would you like to know about PIs?
        ii. What would you like to know about the other people working on the projects?
        iii. What would you like to know about the instructional approach advocated?
        iv. What would you like to know about the institutions sponsored?
        v. What would you like to know about budgetary information?
        vi. What would you like to know about project evaluation?
        vii. What would you like to know about project dissemination?
        viii. What would you like to know about the academic areas of research?
        ix. What would you like to know about the level of the course funded, i.e. core, elective, for non-majors?
    b. What other types of information would you be curious about?

Appendix H: Interview Questions for Principal Investigators

1. What do you feel is the direction of engineering education?
2. How did you learn about the CCLI funding program?
    a. Why did you choose to pursue funding through this avenue?
3. Imagine you had a profile of the CCLI program that you could use as you were building or developing your next project.
    b. If you were developing a new project that you hoped to get CCLI funding for, what types of information would be valuable to you?
    c. If you were writing a proposal for a project you've already developed, what types of information would be helpful in making your proposal more competitive?
4. What would you like to know about the instructional approaches of funded CCLI grants?
5. What would you like to know about the evaluation methods of funded CCLI grants?
6. What would you like to know about the dissemination efforts of funded CCLI grants?
7. What would you like to know about the academic areas of research of funded CCLI grants?
8. What other types of information would you be curious about?

Appendix I: Interview Questions for Legislators

1. How is the need for STEM Education perceived on Capitol Hill?

2. What has led to this feeling of need for STEM Education?

3. What do you see as the focus of STEM funding programs?

4. What are future goals of STEM legislation, especially regarding undergraduate programs?

5. Why are science and technology so important when it comes to global competitiveness?

Appendix J: Interview Questions for ASEE, NAE, and ABET

1. In what direction do you think engineering education is heading?

2. Do you feel that ABET 2000 has impacted research on engineering education? If so, then how?

3. What stance does ASEE/NAE/ABET hold about the future of engineering education research?

4. What is the role of faculty development in engineering education reform?

5. What is the role of curriculum development in engineering education reform?

6. From your understanding of the engineering education research being performed, do you feel like there is a sufficient balance between faculty development and curriculum development focus?

7. If there were a profile of CCLI grants, what information would be useful to you?

    a. What are you interested in knowing about the type of research and development being conducted?

    b. What are you interested in knowing about the types of institutions doing the research?

    c. What are you interested in knowing about dissemination efforts?

Appendix K: Breakdown of Database for Subjective Characteristic Analysis

Sampled Projects	Phase 1	Phase II	Collaborative
2006	21	12	13
2007	49	15	20
	70	27	33
Total Projects		97	
Collaborative Considerations			
Total Collaborative Awards	33		
Total Collaborative Projects	12		
Total Unique Projects	97		

Appendix L: List of States by Region

New England:
Connecticut
Maine
Massachusetts
New Hampshire
Rhode Island
Vermont

South:
Alabama
Arkansas
Florida
Georgia
Kentucky
Louisiana
Mississippi
North Carolina
South Carolina
Tennessee
Virginia
West Virginia

Southwest:
Arizona
New Mexico
Oklahoma
Texas

Mid-Atlantic:
Delaware
Maryland
New Jersey
New York
Pennsylvania
Washington D.C.

Midwest:
Illinois
Indiana
Iowa
Kansas
Michigan
Minnesota
Missouri
Nebraska
North Dakota
Ohio
South Dakota
Wisconsin

West:
Colorado
California
Idaho
Montana
Nevada
Oregon
Utah
Washington
Wyoming

Other: Alaska, Hawaii, Puerto Rico

Adapted from:
U.S. Diplomatic Mission to Germany. (2006) Retrieved November 29, 2007 from http://usa.usembassy.de/travel-regions.htm

Glossary of Terms and Acronyms

A&I: Adaptation and Implementation
ABET: Accreditation Board for Engineering and Technology
ACC: Academic Competitiveness Council
ASA: Assessment of Student Achievement
ASEE: American Society for Engineering Education
Assessment: projects which aim to "design tools to measure the effectiveness of new materials and instructional methods, (2) develop and share valid and reliable tests of STEM knowledge, (3) collect, synthesize, and interpret information about student reasoning, practical skills, interests, or other valued outcomes, and (4) apply new and existing tools to conduct broad-based evaluations of educational programs or practices if they span multiple institutions and are of general interest" (CCLI, 6).
Award: A proposal which has been recommended by a program director and granted funding. Each award has a unique entry in the NSF Awards database.
CCD: Course, Curriculum, and Development
CCLI: Course, Curriculum, and Laboratory Improvement
Characteristic: a feature of a proposal
Collaborative Project: a project financed by multiple awards, each to a different university or institution, but with a common focus
Curriculum Development: projects that revise, enhance, or create new curricula
DD: Division Director
DOE: Department of Education
DUE: Division of Undergraduate Education
EC2000: Engineering Criteria 2000
EEC: Engineering Education Coalition
EERC: Engineering Education Research Colloquies
EMD: Educational Materials Development
Faculty Development: projects that "design and implement methods that enable faculty to gain […] expertise. Projects should provide professional development for a diverse group of faculty so that new materials and teaching strategies can be widely implemented" (CCLI, 6).
Group Dissemination: Any dissemination where results are distributed to members of an organization, association, corporation, or other group or dissemination to universities within a research collaborative
Kit: a collection of laboratory supplies and/or instructional matter that can be easily transported for use inside or outside the classroom
Laboratory Tool: any device designed to assist in a laboratory environment
Mailings: Any dissemination where results are mass-mailed or mass-emailed to any list
Materials Development: projects that "develop new learning materials and tools, or […] revise or enhance existing educational materials […] based on prior results" (CCLI, 6).
Modules: any independent set of lessons that can be easily added to a course
NAE: National Academy of Engineering
ND: National Dissemination
NSB: National Science Board
NSF: National Science Foundation

On-Line Tutorial: any resource available via the internet for the purpose of instruction
PD: Program Director
Pedagogy Development: projects that "develop […] or create new and innovative teaching methods and strategies […or] revise or enhance existing […] teaching strategies, based on prior results" (CCLI, 6).
Phase 1: a CCLI project with a budget of up to $150,000 ($200,000 when four-year colleges collaborate with two-year colleges) and a term of 1-3 years. Phase 1 projects are proof-of-concept projects.
Phase 2: a CCLI project with a total budget of up to $500,000 and a term of 2-4 years. Phase 2 projects are expansions on smaller-scale innovations and implementations.
Phase 3: a CCLI project with a total budget of up to $2,000,000 and a term of 3-5 years. Phase 3 projects are comprehensive, national dissemination efforts.
PI: Principal Investigator
Program Director: a National Science Foundation employee responsible for (among other things) reviewing proposals and recommending funding
Principal Investigator: the lead researcher or developer for a project
Project: a unique research or development initiative, financed by one or more awards.
Remote Lab: any project that develops a laboratory experience that can be accessed from offsite
Research: projects that "(1) develop and revise models of how undergraduates STEM students learn and (2) explore how effective teaching strategies and curricula enhance learning" (CCLI, 6).
Simulation: any representation or model of a system that requires user interaction
Software Development: any project that creates a new software application
STEM: Science, Technology, Engineering, and Mathematics
Uses Professional Software: any project that uses a professionally developed and widely distributed software
Value: a description of a characteristic for a given proposal
Visualization Tool: any representation or model of a system that allows a user to understand a process with minimal user interaction

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