Redesigning Engineering Curricula for the 21st Century

Assessing and disseminating a comprehensive model to integrate communication, ethics, leadership, economics, and creativity

Both the public sector and private industry want entry-level engineers to be technically skillful, but they also want these engineers to be competent in a variety of professional practices—communication, ethics, leadership, economics, and creativity (CELEC)—so that they can work as part of teams, manage projects, communicate well, and understand the economic, social and political context of their professional activities. These professional expectations are complicating engineering education.

Engineers handle an ever-growing body of engineering knowledge; many programs are crammed with technical information and leave little room for students to develop professional practices that enable them to become skillful communicators, ethical decision makers, team leaders, creative thinkers, and problem solvers. However, professional practices are essential, even critical, since engineers regularly interact with people in local, national, and international communities and create technical solutions that address complex social and environmental issues. The time crunch in over-packed undergraduate programs challenges us to redefine high-quality engineering education. The time crunch is complicated in four additional ways: a pedagogy that often emphasizes recall rather than contextualized learning with higher-order thinking and problem solving, a faculty that is unsure of effective ways to teach and assess professional practices, assessment that is overly dependent on indirect measures, and a lack of sufficiently detailed and sophisticated assessment research that informs curriculum revision.

The challenges seem enormous. We need to

- create a balanced program that integrates technical skills and professional practices
- provide professional development opportunities that enable faculty to teach effectively in an integrated curriculum
- implement an integrated curriculum that meets diverse student populations
- develop a rigorous assessment program that balances indirect and direct measures
- establish and maintain an active research community with a research agenda that completes a feedback loop to strengthen engineering curricula

Iowa State University has developed and for six years taught a curriculum that addresses the time-crunch problem by integrating professional practices into the technical curriculum—that is, professional practices are contextualized in engineering in ways that reinforce and strengthen students' understanding and their ability to apply that understanding to address engineering problems. Throughout their undergraduate program, students work to master the engineering body of knowledge and simultaneously become skillful communicators, ethical decision makers, team leaders, creative thinkers, and problem solvers.

The PIs propose a five-part, four-year NSF project (Figure 1) that builds on their six years of experience in developing and implementing a fully integrated curriculum. The project has five broad objectives:

- ∞ Create an overall assessment model for integrated curricula
- ∞ Engage in research using the collected assessment data
- ∞ Refine integrated curriculum based on assessment feedback
- ∞ Refine professional development materials based on assessment feedback
- ∞ Disseminate integrated curriculum and assessment models for implementation

This proposed ***Phase 3 Project*** includes all five of the program components in the model of STEM knowledge production and improvement of practice (Figure 1). Is the project likely to have a national impact that changes the infrastructure of engineering education? Yes. It integrates research and teaching, can be sustained by dedicated institutions, can result in highly desirable commercial products, and has been designed by a team with extensive experience with educational publishing and a commitment to innovative pedagogy, assessment, and diversity.

Objectives and Outcomes

The challenges identified above are not unique to Iowa State. Across the country, faculty members are addressing problems related to students' lack of professional performance. Some programs offer linked courses between

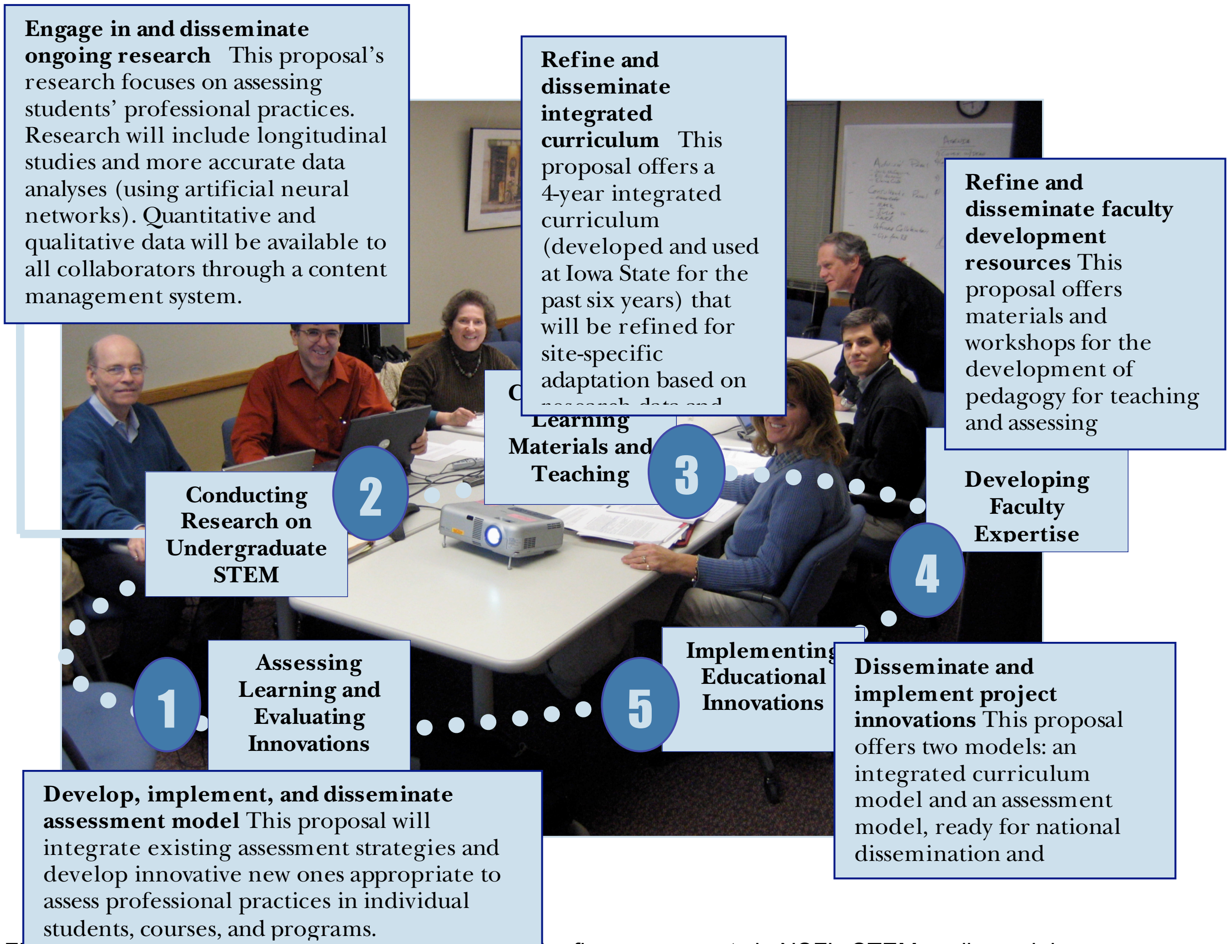

Figure 1. Proposed project's response to each of the five components in NSF's STEM cyclic model

engineering and professional communication programs. For example, Utah State University has created a linked curriculum (Manuel-DuPont 1996), while Texas Tech offers courses encouraging students to think more about ethical and political issues central to their future roles as engineers (Chandler et al. 2001). These efforts demonstrate numerous ways to integrate professional practices into undergraduate engineering. In addition to these efforts, a range of other alternatives exists. The University of North Dakota offers faculty workshops and training, while the University of South Carolina's ECE (Electrical and Computer Engineering) Writing Center, funded by a grant from the Gateway Engineering Education Coalition [NSF Award EEC97-27413], provides tutorial services to undergraduates (Walker 2000). Using another model, an NSF-supported effort at Arizona State University (under the Foundation Coalition's Cooperative Agreement EEC92-21460) prepares students who can think critically about engineering, construct knowledge in teams, and use written and oral communication as a vehicle for problem solving in their collaborative teams (Green and Duerden 1996).

Most relevant to this proposal are the integrated curricula at Colorado State University (Grigg et al. 1996, 2001, 2004) and the US Military Academy at West Point (Bailey, Floersheim, and Ressler 2002). Our proposed project builds on these efforts, but it is distinctive in several ways:

- Integrates professional practices: communication, ethics, leadership, economics, creativity (CELEC)
- Uses communication as the curricular vehicle to link other professional practices
- Includes a broad array of core courses, 12 in all, over the entire undergraduate program
- Focuses on multiple levels of assessment: (1) student performance: individuals and teams, (2) curriculum feedback: assignments, courses, and programs
- Creates a consortium for ongoing conversations about integrated curricula and assessment

One of the distinctive aspects of the objectives and outcomes identified in Table 1 is that they are synergistically linked—that is, no single objective stands alone but all are directly influenced by and, in turn, influenced by other objectives.

Table 1. Objectives and Outcomes for the Proposed Project

Objectives	Outcomes
Create an overall assessment model for integrated curricula	▪ Comprehensive assessment model for integrated curricula ▪ Evaluation by nationally recognized experts ▪ Database of indirect and direct assessment measures for the engineering body of knowledge and each area of professional practice ▪ Strategies for implementing assessment measures, especially refining existing assessment strategies and adapting new ones (e.g., artificial neural networks)
Engage in research using the collected assessment data	▪ Longitudinal research to assess the ways in which students in different curricular models (a) perform overall academically, (b) develop in understanding and performance of professional practices, and (c) perform in the Fundamentals of Engineering (FE) exam (NCEES) ▪ Content management system integral to cyclical research, permitting investigators to collect student work; categorize, rate, and discuss it asynchronously; and then to compile both original examples and assembled metadata for quantitative analysis.
Refine integrated curriculum based on assessment feedback	▪ Revision to integrated curricula based on assessment studies ▪ Written, oral, visual, and electronic activities and assignments (communicating to learn) to increase comprehension and retention as well as use of the engineering body of knowledge (BOK) ▪ Activities and assignments for students from each of the professional practices—communication, ethics, leadership, economics, and creativity (CELEC) ▪ Website for faculty to share materials related to integrated curricula and assessment
Refine professional development materials based on assessment feedback	▪ Consortium for faculty to explore curricular and assessment issues and practices ▪ Ongoing web-based support for faculty consortium ▪ Professional development materials for workshops and the project website ▪ Face-to-face and distance workshops for faculty members
Disseminate models for implementation	▪ Implementation and adaptation of models for integrated curriculum and assessment ▪ Conference presentations and refereed publications (print and electronic) related to various ways the original models have been adapted

Project History

Understanding the two models in this proposal—one for integrated curriculum and one for assessment—requires background about the six years leading up to this proposal. Although Iowa State's Civil, Construction, and Environmental Engineering (CCEE) Industry Advisory Council and employer surveys confirmed that the civil engineering graduates from Iowa State have superb technical skills, students lacked skills in communication, leadership, and practical problem solving. To address these deficiencies and promote additional professional practices, civil engineering faculty enhanced the undergraduate civil engineering curriculum to integrate communication, ethics, leadership, economics, and creativity into 12 civil engineering courses (Table 2). The new courses include topics about issues such as project management (e.g., engineering contracts, estimating, scheduling), professional development, life-long learning, construction management, teambuilding, and business management. These changes have required neither adding credit hours nor reducing the technical focus.

The new integrated courses emphasize written, oral, and visual communication. In each course, students complete about seven communication assignments—including letters, reports, proposals, editorials, visuals and graphical presentations, interviews, and oral reports. The students work in teams and receive training to be effective leaders and team members in more than half of these assignments. These assignments typically focus on integrating topics from non-engineering courses with civil engineering topics. For example, one assignment may involve applying chemistry to an environmental engineering problem or physics to a structures problem. Students quickly engage in civil engineering, which improves their motivation and, hence, retention in the early years.

The integrated curriculum developed at Iowa State is distinctive in that the integration occurs throughout the entire undergraduate program. Many other integrated curricula integrate only the first year or two of the undergraduate program. For example, in Northwestern's integrated program, all engineering freshmen take "Engineering Design

Table 2. Professional Topics Addressed in the Integrated Courses

Freshman	Sophomore & Junior	Senior
CE 101 Introduction to Civil Engineering [Required – 0 cr.] ∞ *Professionalism* ∞ *Communication*	CE 203 Synthesis I [2 cr.] ∞ *Problem solving* ∞ *Communication* ∞ *Teamwork* ∞ *Creativity and aesthetics* ∞ *Economics* ∞ *Critical thinking*	CE 403 Assessment [Required – 0 cr.] ∞ *Problem solving* ∞ *Teamwork* ∞ *Communication* CE 485
CE 104 CE Projects [1 cr.] ∞ *Communication* ∞ *Professional ethics* ∞ *Leadership*	CE 204 Synthesis II [2 cr.] ∞ *Economics* ∞ *Teamwork* ∞ *Problem solving* ∞ *Communication*	CE 453 Highway Design [4 cr.] ∞ *Communication* ∞ *Design* ∞ *Team problem solving* ∞ *Project management* ∞ *Professionalism* ∞ *Public policy* ∞ *Life-long learning*
CE 160 Engineering Problems [3 cr.] ∞ *Communication* ∞ *Problem solving* ∞ *Teamwork*	CE 303 Prof. Issues in CE [2 cr.] ∞ *Communication* ∞ *Leadership and teamwork* ∞ *Business principles* ∞ *Professional ethics* ∞ *Professionalism* ∞ *Public policy*	CE 485 Capstone Design I [2 cr.] ∞ *Communication* ∞ *Design* ∞ *Team problem solving* ∞ *Project management* ∞ *Professionalism* ∞ *Public policy* ∞ *Life-long learning*
CE 170 Graphics [2 cr.] ∞ *Problem solving* ∞ *Communication*	CE 304 Project Management [2 cr.] ∞ *Communication* ∞ *Project management* ∞ *Teamwork* ∞ *Construction* ∞ *Life-long learning*	CE 486 Capstone Design II [3 cr.] ∞ *Communication* ∞ *Design* ∞ *Team problem solving* ∞ *Project management* ∞ *Professionalism* ∞ *Public policy* ∞ *Life-long learning*

and Communication" in which writing, oral presentation, and teamwork are integrated into their design project work (Hirsh 2006). Other approaches include the successful Cain Project in Engineering and Professional Communication at Rice University, which provides communication support to students in engineering. Examples of other programs that integrate the entire curricula include Colorado State University's integrated program (Grigg et al. 2004) and the University of Oklahoma's "Sooner City" program (Kolar et al. 2000). Even so, the integration at those schools focuses on technical topics such as design, statistics, transportation, and computing. The integrated program at Iowa State includes the integration of professional practices—practices identified as important by a number of organizations including the Accreditation Board for Engineering and Technology (ABET) and the National Society of Professional Engineers (NSPE). In fact, CCEE faculty members were invited to design a curriculum that provides the body of knowledge for Policy Statement 465 (ASCE).

> "The civil engineering integrated curriculum at Iowa State is one of the best additions to the curriculum because it helps prepare CE graduates for their professional career. The CE curriculum is already strong technically; the inclusion of this program rounds out the undergraduate education and prepares graduating engineers for the realities of the workplace."
> – Sandra Larson, Engineering Bureau Chief, Iowa Department of Transportation, 1/20/06

Relation of Objectives to Current Scholarship

The American Society of Civil Engineers has recently defined the body of knowledge that civil engineers are expected to have as they enter the profession (ASCE); other engineering disciplines are engaged in similar efforts, resulting in what is most generally referred to as the engineering *body of knowledge* (BOK). This BOK describes the sum of technical knowledge, applied skills, and professional attitudes and practices within the profession of engineering. The integrated curriculum in this proposed project addresses the profession's call for students to incorporate critical professional practices—communication, ethics, leadership, economics, creativity (CELEC)—

into the engineering BOK.

Most engineering programs do an outstanding job of preparing students with analytic skills and disciplinary knowledge. Further, most universities profess to value a variety of professional practices. However, most research repeatedly shows that few do well in helping students develop these skills. For example, Alexander Astin's landmark study concluded that while most universities profess to value these practices, virtually no self-reported growth occurred in the areas of general knowledge, critical thinking, or interpersonal skills. In fact, growth in communication skills was negatively correlated with engineering and science majors (Kellogg et al. 1998). While many factors have led to the increased attention of engineering educators on professional practices, studies from industrial recruiters—and anecdotal evidence by engineering educators—highlight students' lack of development in their professional practice skills (Ford and Riley 2003).

Communication. More than 20 years ago, 90 percent of technical professionals reported that speaking and writing skills were important to their success. They reported that the amount of time they spent writing increased as their responsibilities increased: Nearly half spent up to 40 percent of their time writing and more than one-quarter spend between 40 and 100 percent of their time writing (Barnum and Fischer 1984; Burnett 2005). More recently, interpersonal skills have been identified as critical for professional success (Robert Half Finance & Accounting 2005). An American Management Association survey identified written and oral communication skills as the highest ranked performance skills for professional success (AMA 2002).

> Clearly, students gain tremendous professional advantages if they write and speak well, work on teams and manage projects effectively, and listen carefully. Their communication needs to be technically complete and accurate, logically organized for the audience, visually appealing, and interesting; it also needs to be mechanically and grammatically conventional, and it must say something worthwhile. Platitudes? No! The National Association of Manufacturers report that 32 percent of entry-level applicants aren't hired because of poor reading or writing skills; 18 percent aren't hired because of poor oral skills (Corporate Concerns, 2003).

One answer to improving students' communication lies in communication-across-the-curriculum (CAC) and communication-in-the-disciplines (CID). Proponents believe that communication engages students in higher-order thinking and, hence, learning. While early CAC/CID studies focused primarily on written instruction in the humanities (Britton et al. 1975; Emig 1977; Flower and Hayes 1980; Fulwiler 1982), later studies suggested convincingly that writing constitutes a powerful path to cognition beyond the humanities (Moore, 1994; Glasgow and Bush, 1995; Radmacher and Latosi-Sawin 1995; Kelly 1995). Integrating communication assignments into engineering courses is increasingly seen as an opportunity to reinforce communication skills of engineering students throughout their undergraduate experience (Andrews 1975; Herrington 1985; Miller and Olds 1994; Seat et al. 2001). Regardless of where these CAC/CID efforts are located in curricula, Griffin (1985) suggests that effective programs follow three guiding principles:

(1) Communication must be practiced and reinforced throughout the curriculum.
(2) Learning occurs in communication processes.
(3) Discourse is central to a university education.

Technical communication researchers have paid increasing attention to communication among engineers and in engineering contexts, including the analysis of document cycling (Paradis et al. 1985), writing in engineering curricula (Herrington 1985), and knowledge/skills transfer issues from the classroom to industry (Katz 1998; Winsor 1996). Over the past dozen years, engineering educators have emphasized the need for improved communication assignments in engineering classes to encourage not only writing proficiency, but also critical thinking and learning course content (Brent and Felder 1992; Olds et al., 1993; Held et al. 1994; Hirt 1995). The status of engineering as a profession will be improved by the increased use of communication. Being an effective communicator, each engineer can then persuasively point to, and articulate for others, the importance and utility of engineering in society. In fact, an engineering curriculum that integrates communication responds forcefully to industry's demand for graduates that possess quality-oriented design and communication abilities; these abilities are vital for our engineering graduates if they are to succeed in today's globally competitive workplace (Barchilon 1996).

In this proposed project, communication is the umbrella for all professional practices—that is, students learn to use written, oral, and visual communication more effectively in relation not only to the engineering body of knowledge but also to ethics, leadership, economics, and creativity.

Ethics. Engineering ethics has become increasingly important, so central in the public eye that the History Channel has a series about engineering disasters, which involve questions of ethics. While the public recalls the Kansas City

Hyatt Regency Hotel walkways, Challenger, Columbia, and, most recently, the New Orleans levees, engineering students need less hype and more substance related to actual cases. Numerous authoritative sources exist for such study: National Society of Professional Engineers' *Code of Ethics* (NSPE 1987); National Institute of Engineering Ethics (NIEE); Online Ethics Center for Engineering and Science at Case Western Reserve University (Online 2006). In addition, NSF-sponsored projects (e.g., Pritchard 1992; Rabins et al.) provide a wealth of case information that can be integrated into courses. Students at Iowa State are encouraged to provide actual ethics examples that have occurred at their own institution and in local organizations. These examples are followed by discussions of consequences to whistle blowers as a result of following professional standards for reporting violations of professional conduct.

An integrated curriculum gives students an opportunity to consider the ethical ramifications of violating professional standards. Like all professional practices in the integrated curriculum, ethics is not layered on top of students' technical work; instead, ethics is a part of students' foundational decision-making. Equally important, because communication is the vehicle for applying ethics, students become skillful in explaining their reasoning and decision-making.

Leadership. By the very nature of their work, engineers need to be leaders. They influence others, from project team members to citizens attending a public hearing (Bowman and Farr 2000). Engineers must be able to convince others of the credibility of their concepts, designs, and plans. In engineering classrooms, the emphasis is typically on the technical aspects of a project, instead of effective leadership.

> The engineering profession needs to recognize that engineers can build the future through a wide range of leadership roles in industry, government, and academia—not just through technical jobs. – National Academy of Engineering, May 2004

Effective leadership and team skills draw on research-based strategies (e.g., Burnett 2005; Foundation Coalition) as well as best practices (e.g., Bowen 2003). Some successful programs include Leadership Rice, which focuses on leadership skills for all students (not only for engineers), and Women in Engineering Leadership Institute (WELI), which focuses on leadership skills for women engineers (not only for students). Efforts at integrating leadership are underway at some institutions—for example, University of Utah's Center for Engineering Leadership, part of the interdisciplinary CLEAR Program (Communication, Leadership, Ethics, And Research) between the College of Humanities and the College of Engineering.

Equally important and included in our concept of leadership is teamwork. Engineering is seldom practiced in isolation, and students need to experience early in their undergraduate program that teams, particularly multi-disciplinary ones, accomplish much more than individuals. Much of the integrated program encourages teamwork in communication, ethics, leadership, economics, and creativity (CELEC). Domination by a single person in a group is discouraged; all team members are encouraged to lead in their assigned or chosen roles. What is distinctive in this proposed project is that the principles and practices of leadership and teamwork are explicitly explored, not just assumed.

Economics. Engineering economics is the application of decision-making steps to determine optimal allocation of resources. This topic is integrated into engineering education by utilizing workplace scenarios and analyzing actual engineering alternatives. Integration with other professional practices occurs in numerous courses. For example, in Iowa State's integrated curriculum, critical thinking is applied to evaluate the non-technical aspects of engineering alternatives and communication skills are used to defend optimal choices.

Many important elements are applied during the decision-making process. First, students must recognize the problem, so goals can be formulated and the relevant data assembled. Next, feasible alternatives are identified and criteria selected to determine the optimal alternative. This information can be used to construct models to predict the outcomes of alternatives. Finally, an audit ensures the outcome is realistic.

Creativity. *"Engineers are not creative"* (Edward de Bono, Personal Communication 1998). The possible accuracy of this assertion could be the result of years of instruction in prescribed methodology, design guidelines, and standard practices. Too much creativity could be risky, and many consulting engineers are reluctant to experiment with new processes or equipment without a proven track record. Furthermore, a notion exists that creativity is an inherited gift and cannot be learned.

Some consider creativity essential to engineering. Donald Christiansen, former editor of *IEEE Spectrum*, suggests that "the proclivity to invent without necessarily thinking of the process as invention" makes a good engineer (2002). Interesting research about creativity in engineering is ongoing: some of it suggests "the possibility that certain kinds of problems (routine problems) may actually inhibit creativity" (Cropley 2005), but other work suggests that even if creative approaches are introduced and encouraged, students show "little likelihood that such [creative behaviors] will persist unless they are further developed by appropriate follow-up activities" (Cropley and Cropley n.d., 24).

The integrated program at Iowa State teaches various creative problem-solving techniques (adapted from de Bono, 1993), such as illogical provocation, conceptualization, random inputs, creative pausing, and parallel thinking for group problem solving. The program encourages creativity throughout the entire undergraduate curriculum, not just as an isolated activity in one or two classes. These problem-solving techniques help produce engineers who are more attentive to the variety of approaches available to solve unusual problems (Stouffer, Russell, and Oliva 2004).

Example Students are asked to find a solution to breaking drill bits used to make holes to connect concrete panels used in construction of inner walls. The general engineering approach would be to find solutions in material selection or drill mechanisms. A more creative conceptualizing approach would be to realize that what we need are holes, not drills. Holes could be cast into the panels, or panels could be designed to clip together. Even more creative would be to cast the walls on site without joints or redesign towards an open space concept without inner walls.

Assessment

While Iowa State's integrated curriculum is on the leading edge of pedagogy and curriculum, the programmatic assessment has been largely indirect and anecdotal rather than serving as a "process that focuses on student learning, a process that involves reviewing and reflecting on practice" (Palomba and Banta 1999, 1) and involves the "systematic collection, review, and use of information about educational programs undertaken for the purpose of improving student learning and development" (Palomba and Banta 1999, 4). Thus, this project's first objective is to create an overall assessment model for integrated curricula, which includes the following three tasks:

(1) Provide multiple levels of appropriate assessment resources—for individual students and student teams, assignment and assignment sequences, courses, and programs.
(2) Increase the amount of direct assessment, especially in relation to professional practices.
(3) Use innovative tools to organize and analyze data.

Assessment Resources. Many assessment tools are available. The problem—for students who want to become skillful at self-assessment, for faculty members who want to assess assignments and courses, and for program administrators—is picking the appropriate tool for the particular task. A number of resources summarize useful assessment strategies. For example, a recent issue of *Engineering Education* (January 2005) identifies the assessment methods typically used and suggests additional ones that have promise. Similarly, the University of Michigan's College of Engineering has created a useful online *Assessment Handbook* (Michigan) that provides information a range of direct and indirect assessment strategies. This proposed project will compile an extensive online catalogue of direct and indirect assessment strategies and provide clear guidelines for selecting appropriate assessment strategies in relation to specified objectives and outcomes.

Direct and Indirect Assessment. The assessment model will balance direct and indirect assessment strategies (also called measures, instruments, tools, or methods), which at many institutions means increasing the percentage of direct assessment strategies.

Direct assessment of learning occurs through conventional tests or a considerable array of actual performances as shown in the box to the right. During their entire undergraduate experience in Iowa State's integrated curriculum, students will complete virtually all of these direct assessment measures.

Examples of direct assessment include evaluation of a variety of written, oral, and visual artifacts: in-class activities and assignments; objective and open-ended quiz and exam questions; individual and team presentations; academic and internship documents (e.g., problem sets, work logs, correspondence, journals, proposals, research reports, manuals, instructions, websites, brochures, presentation projections, and brochures); workplace client and campus projects; exit exams; print/e-portfolios.

Indirect assessment, in contrast, is based on perceptions, recollections, opinions, and reflections about learning, not on actual performance; thus, it is subject to a range of affective influences and, perhaps, to faulty recall. The box to the right shows frequently used indirect strategies.

Examples of indirect assessment include a variety of print and electronic surveys; reflections; focus group feedback; database information (e.g., GPA, FE exam); self-assessments; feedback from internship supervisors, employers, faculty; industry surveys; advisory council feedback; exit surveys and interviews.

In addition, several approaches borrowed from descriptive research are valuable additions to assessment resources in engineering. For example, ethnographic observations of engineering culture (Winsor 1996) and rhetorical analyses of collaborative/team interactions (Burnett 1996) can provide insights that lead to stronger curricula. Similarly, longitudinal research (Fishman et al. 2005; Sternglass 1997) contextualizes individual classes as well as programs.

Innovative Tools. This proposed project is distinctive in bringing innovative tools to assessment: a content management system (CMS) and knowledge-extraction tools.

- This proposed project will manage the massive amount of assessment data with a content management system designed for this project. Content management is a category for a set of processes and technologies that facilitate data collection, organization, and dissemination among collaborators using a variety of formats. Web interfaces will be used to collect and interact with data, ranging from ASCII text to stylized graphical data, to minimize intrusion into students' educational experiences. Content management systems tend to be compatible and easily integrated with learning management systems (e.g., BlackBoard, WebCT).
- This proposed project will extend the usual repertoire of indirect assessment measures by using innovative and powerful data analysis and knowledge-extraction tools such as artificial neural networks (ANNs; e.g., Weckman et al. 2001) and other computational intelligence techniques in assessing the collected data. Using such tools will help identify relationships and correlations between different data sets and input parameters and will result in descriptive models.

Research

This proposed project has one, complex, overarching research question:

> Throughout their undergraduate engineering program, how do students (a) perform overall academically, (b) develop in understanding and performance of professional practices, including communication, ethics, leadership, economics, and creativity, and (c) perform in their FE exam if they have participated fully in one of these curricular models: no integrated curriculum, first-year integrated curriculum, selected aspect of an integrated curriculum, and full integrated curriculum?

In addition, the project is also interested in these two subordinate research questions:

> Throughout their undergraduate experience, how do students demonstrate improvement in their ability to self-assess their engineering performance and their professional practices?
>
> What methods work effectively for assessing professional practices—communication, ethics, leadership, economics, and creativity?

Additional research questions will evolve through ongoing discussions among the PIs, Advisory Panel, consultants, and participants from other universities and colleges.

This proposed project addresses these questions by using a content management system and software (such as QSR's N6) designed specifically for analyzing large amounts of qualitative data—such as students' documents and videos of their presentations. Assessment will include examining text, annotating and coding it, searching for patterns, building data-based explanations, and creating quantitative as well as descriptive models. The content management system to be used in this study will be integral to our cyclical research method, permitting investigators to collect examples of student work, to categorize, rate, and discuss this work asynchronously, and then to compile both the original examples and the assembled metadata for quantitative analysis. The system will enable rapid searches through large quantities of student work. Researchers on this project will also use artificial neural networks and other computational intelligence techniques to identify relationships and correlations between data sets—for example, relationships between GPA or FE exam scores and other data gathered from students such as learning style surveys, career focus surveys, communication process questionnaires, and self- and peer-feedback.

Since this proposed project will generate enormous amounts of data, the expertise of Iowa State's Research Institute for Studies in Education (RISE) will provide consultation in quantitative and qualitative research design and methodology, survey development and entry, program and project evaluation, and, most important from the project's perspective, statistical data analysis. RISE is a national leader in scientific-based educational research. Recent RISE partners have included the National Science Foundation, the US Department of Education, K-12 districts and schools world-wide, the W. K. Kellogg Foundation, and the Pew Foundation.

Faculty Development

The faculty development effort for this project involves three synergistically linked strategies that involve exploration of a range of issues related to developing, implementing, and assessing integrated curricula.

Workshops. Three types of workshops will be offered to audiences with different purposes and interests. Workshops will be offered in face to face, in video-conference, and/or teleconference formats.

- *Introductory workshops* will enable project PIs and other personnel from ISU to share innovative concepts and strategies about teaching and assessing the engineering BOK and professional practices.
- *Regional workshops* will bring together faculty for discussions related to data collection. These workshops will be feasible because of the existing network established by the Local Technical Assistance Program (LTAP). LTAP is a program within the Federal Highway Administration that provides a national distribution network for training and taps into centers that are very successful in conducting educational sessions across the country (NLTAPA). Iowa's LTAP unit at Iowa State, directed by one of the project's senior personnel, gives this project access to LTAP experience in arranging regional workshops.
- *Dissemination workshops* will be primarily for institutions interested in exchanging and discussing assessment data for refining both the curricular and assessment models.

Website. This project will establish a network among participating universities and colleges via a website. During the development phase in the first two years of the project, the site would not be open to the public; however, once the website has been established and developed, it will be open for public information and input.

Consortium for Engineering & Professional Practices. A consortium of participating schools will be formed (these participating schools are discussed in the proposal section about Participant Interest). The purpose of this consortium is networking, gathering information, and disseminating data. This consortium will provide visibility and recognition of the project's activities. Even more important, it will provide a forum for substantive discussions and a receptive arena for testing ideas related to integrated curricula and assessment.

Plan of Work

The project's plan of work (Table 3) spans four years, involving collaboration with our Advisory Panel, Consultants' Panel, and participants from 16 universities and colleges from the US and Canada.

Table 3. Plan of Work for Years 1-4 of the Proposed Project

Year 1	**Curriculum** ■ Provide instructions for using analytical tools developed by project PIs to aid in identifying a program's current level of integration of professional practices ■ Articulate the integrated curriculum for adaptation by other departments and institutions. For each professional practice area, include the theoretical foundation, definitions and rationale, models for activities and assignments, and strategies for assessment ■ Design and develop, and regularly update an interactive project website that will serve as a clearinghouse for curriculum, professional development, and assessment materials **Professional Development** ■ Engage in project team development (e.g., attend courses in creativity) ■ Collect, describe, and provide print and video examples of successful, engaging, student-centered pedagogy for integrating professional practices into engineering classes ■ Update and create additional professional development materials and workshops for face-to-face and distant presentations for (a) each area of professional practice and (b) assessment strategies ■ Establish a professional forum of faculty members involved in integrated curricula for on-line discussions and sharing of materials **Implementation** ■ Invite participating departments and institutions to conduct an analysis of their program's current

	level of integration of professional practices, guided by the project's PIs ▪ Invite participating departments and institutions to identify nature and level of implementation (e.g., a decision to integrate only communication or to completely revise the curriculum) ▪ Organize and direct the Consultants' Panel to develop the assessment model ▪ Organize and direct the Advisory Panel to provide regular guidance, evaluate the direction of the work, and assist in dissemination **Assessment and Research** ▪ Collect, describe, and provide examples of current assessment strategies used by project faculty and faculty from other institutions ▪ Adapt and create additional assessment strategies for each area of professional practice ▪ Use artificial neural networks to create assessment baselines drawing on data such as students' GPA, FE exam scores, employers' feedback, percent of students employed ▪ Design and establish the content management system (CMS) ▪ Input existing engineering assessment data into the CMS
Year 2	**Curriculum** ▪ Solicit feedback about adaptation of the generic version of the integrated curriculum to meet the needs of specific departments and institutions ▪ Update the project website **Professional Development and Implementation** ▪ Solicit guidance from Advisory Panel about areas of development and implementation ▪ Present faculty development workshops to faculty interested in the integrated curriculum: (a) on-site at interested institutions, (b) at regional sites bringing together faculty from several institutions, (c) at Iowa State with faculty from ISU and other institutions, and (d) with distance technology, originating from ISU and involving other institutions ▪ Continue the professional forum of faculty with on-line discussions and sharing of materials ▪ Implement aspects of the integrated curriculum at interested institutions **Assessment and Research** ▪ Direct the Consultants' Panel to refine the assessment techniques and model ▪ Collect indirect and direct assessment data and create assessment databases ▪ Analyze data in order to answer the project's research questions
Year 3	**Curriculum** ▪ Solicit feedback about adaptation and implementation of the integrated curriculum ▪ Update the project website **Professional Development and Implementation** ▪ Solicit guidance from the Advisory Panel (as in Year 2) ▪ Present professional development workshops in four settings (as in Year 2) ▪ Continue the professional forum of faculty with on-line discussions and sharing of materials ▪ Implement aspects of the integrated curriculum at interested institutions **Assessment and Research** ▪ Direct the Consultants' Panel to refine the assessment techniques and model ▪ Collect indirect and direct assessment measures and create assessment databases ▪ Input all Year 3 assessment data from Iowa State and other schools into the CMS ▪ Analyze data in order to answer the project's research questions
Year 4	**Curriculum** ▪ Solicit feedback about adaptation and implementation of the integrated curriculum ▪ Update the project website **Professional Development and Implementation** ▪ Solicit guidance from the Advisory Panel ▪ Continue the professional forum of faulty involved in integrated curricula ▪ Present conference presentations and submit refereed articles about the role of professional development in the implementation of an integrated curriculum ▪ Sponsor a culminating integrated curriculum conference for all participants ▪ Implement aspects of the integrated curriculum at interested institutions **Assessment and Research** ▪ Direct the Consultants' Panel to refine the assessment model ▪ Collect indirect and direct assessment measures and create assessment databases ▪ Input all Year 4 assessment data from Iowa State and other schools into the CMS ▪ Analyze data in order to answer the project's research questions

National Dissemination

The project's dissemination plan, which follows the advice in Ely and Huberman (1994), seeks to disseminate the models for an integrated curriculum and its assessment to engineering schools, especially those in Table 4, so that they can improve the teaching of professional practices. The dissemination plan exploits previous findings regarding dissemination. An effective strategy involves disseminating *awareness*, *knowledge*, and *use* (Sharp and McLaughlin 1997, Fincher 2000).

- The PIs have begun disseminating awareness by assembling a list of schools (Table 4) with which to collaborate on this project. Further efforts will include conference presentations and seminars, and PI Kushner, Dean of Iowa State's College of Engineering, will notify other engineering deans about our project (e.g., by distributing electronic media), as in Carpinelli and Perna (2002).
- Disseminating knowledge involves teaching faculty at other schools about the merits of the integrated curriculum model via *active dissemination* to identified collaborators, such as workshops and conference presentations, and *passive dissemination* to future users, such as journal articles and the project website (e.g., Fincher 2000).
- To meet the challenges of disseminating use—allowing the audience to adapt models to their needs and measuring the effectiveness—the PIs will (1) develop and disseminate not only the integrated curriculum model but also the assessment model for determining its effectiveness, (2) build faculty expertise in teaching an integrated curriculum, and (3) work with participants to adapt Iowa State's curriculum and assessment models to local needs, which will vary with the type of institution. Disseminating the project's models will include working with individual faculty members, which represents a bottom-up approach, identified as crucial for the success of dissemination (Louis and Jones 2001).

Dissemination will include active and passive techniques, similar to those in other NSF-supported efforts (e.g., SUCCEED, Ohland and Anderson 2000). In particular, the deliverables of the project will be

- Conference presentations
- Publications in refereed print and electronic journals
- Workshops for faculty members interested in integration and assessment issues
- Website with professional development options as well as research information
- Content management system (CMS) developed for this project and available to researchers interested in curriculum and assessment

These means will be used to disseminate findings about assessment in engineering programs, project research, principles and practices of integrated curricula, adaptations of the integrated curriculum model, and professional development of engineering faculty to teach an integrated curriculum.

The purpose of disseminating the results from this study will be, in large part, to demonstrate that the integration and assessment of professional practices into engineering education can be done with (1) specific techniques that do not require unreasonable effort by faculty and (2) demonstrable effect on students' engineering BOK and professional practices.

While such findings can be reported in peer-reviewed publications, a generally more effective approach is to provide electronic publication of the overviews of findings, with links to detailed examples that demonstrate to readers the techniques necessary for integrating professional practices into engineering curricula. The CMS for this study will facilitate exactly this sort of two-tiered reporting of results: textual overviews of research results, with links to detailed examples available, should readers choose to explore further.

Participant Interest

Faculty members from 16 institutions (Table 4) across North America are interested in this project in order to (1) discuss issues related to engineering curricula that integrate professional practices, (2) implement part or all of the integrated curriculum model, (3) implement part or all of the assessment model, (4) participate in faculty development opportunities, (5) gain access to assessment data that will be in the CMS, (6) add assessment data from their own institution to the CMS, and (7) participate in research with colleagues from other institutions. Faculty members from other institutions will also be welcome to participate. Resources are available in the budget to support faculty development and data collection. Letters indicating participant interest in this proposed project appear in Supplementary Documents.

Table 4. Participant Interest

School	Participants
Colorado State Univ.	Tom Siller, Associate Dean, Academic Affairs
Des Moines Area Comm. Coll.	James W. Stick, Jr., Dean of Sciences and Humanities
Drake Univ.	Lawrence P. Staunton, Chairman, Department of Physics and Astronomy
Georgia Institute of Technology	Laurence J. Jacobs, Professor and Associate Chair for Undergraduate Programs, School of Civil and Environmental Engineering
Kirkwood Community College	Bob Driggs, Dean, Mathematics and Science; Mario Meza, Pre-Engrg. Coordin.
N. Carolina A&T State Univ.	W. Mark McGinley, Prof., Dept. of Civil, Archit., Agricult., and Envir. Engrg.
Penn State Univ.	Andrew Scanlon, Prof. and Head, Department of Civil and Environmental Engrg.
Texas Southern University	Oscar H. Criner, Professor and Chair, Department of Computer Science
Univ. of Arkansas–Little Rock	Cynthia Nahrwold, Assoc. Prof., Graduate Coordin., Dept. of Rhetoric & Writing
Univ. of California, Santa Barbara	Karen Lunsford, Assistant Professor of Writing, Writing Program Susan H. McLeod, Professor of Writing, Director, Writing Program
Univ. of Illinois	David Lange, Prof./Assoc. Head, Depart. of Civil and Environmental Engrg.
Univ. of Minnesota	Lee-Ann Kastman Breuch, Associate Professor, Department of Rhetoric John Gulliver, Joseph T. and Rose S. Ling Prof. and Head, Dept. of Civil Engrg.
Univ. of Toronto	Robert Irish, Director, Engrg. Communication Program Will Cluett, Prof. and Chair of Engrg. Science Peter Weiss and Dr. Katherine Tiede, Engrg. Communication Program Lisa Romkey, Engrg. Education Lecturer in Engrg. Science
Univ. of Wisconsin, Madison	Jeffrey Russell, Professor and Chair, Civil and Environmental Engineering
US Military Academy at West Point (USMA)	Allen C. Estes, Colonel and Director, Civil Engrg. Division, Department of Civil and Mechanical Engrg.
Virginia Technological Univ.	James Dubinsky, Assoc. Prof. and Dir. of Professional Writing, Dept. of English Marie Paretti and Linda McNair, Department of Engrg. Education—Co-Directors of MSE/ESM Engrg. Communications Program

Project Management

This proposed project sees all five components as synergistically and recursively integrated. Equally important, the PIs involved on the project (six of them pictured in Figure 1) are dedicated teachers, active researchers, and successful practitioners who integrate research and leading-edge practice in their teaching—and the proposed project reflects that integration in the nature and scope of the work. The PIs have demonstrable experience in infusing students' academic work not only with reality and rigor but also with energy and excitement.

Major curricular initiatives—particularly ones focusing on professional practices and assessment— frequently meet resistance because professional practices are both difficult to teach and difficult to assess. This proposed project takes the approach that professional practices can be effectively integrated with technical content in ways that increase students' learning of the engineering body of knowledge (extending *communicating to learn*, borrowed from communication-across-the curriculum efforts). In addition, the project provides faculty development opportunities and resources that increase the confidence that faculty members have in integrating and assessing professional practices. This project also has an increased likelihood of success because the PIs have been working together for six years as the Curriculum Integration Committee in the Department of Civil, Construction, and Environmental Engineering at Iowa State University—with colleagues from the Department of English as members for that entire period as well. A summary of their responsibilities is presented in Table 5; additional information is available in the Budget Justification. The Plan of Work (Table 4) shows additional details.

Table 5. Project Management

Position	Primary Project Responsibility
Advisory Panel	National and regional experts from industry and two-year, four-year colleges and universities who provide guidance, evaluate the direction of the proposed work, and help in disseminating the model to other schools ▪ Jack McGuire—Director, Engineering Technology Development at Boeing ▪ Bill Anderson—Exec. Director of Council of Engrg. and Scientific Specialty Boards ▪ Elaine Craft—Director, SC ATE Center of Excellence and National Resource Center for Engineering Technology Education, and President of SCAT, Inc. ▪ PLUS two additional individuals from the list of participants
Consultants' Panel	Experts who provide specialized information to guide the project assessment and research. This panel will assist in developing the assessment model, which will include data collection and analysis with traditional and non-traditional tools for course, programmatic, and institutional assessment. Experts serving on the Consultants Panel include ▪ Julia Williams—Executive Director, Office of Institutional Research Planning and Assessment at Rose-Hulman ▪ Geoffrey Sauer—Director, Studio for New Media, Iowa State University ▪ Mack Shelley, Director of Iowa State RISE Program, will contribute approximately 20 hours per year for the project. His expertise project assessment will provide guidance for the RISE postdoc who will provide statistical quantitative and qualitative support. ▪ Geoffrey Sauer—Director of the Iowa State Studio for New Media will design and develop the CMS for the project, train project personnel in its use and maintenance, and coordinate its use for assessment and research (also a co-PI)
PI/Co-PIs	Each PI/Co-PI will be responsible for ▪ working on teaching, professional development, and assessment of professional practices ▪ coordinating activities with participating schools ▪ serving as author or co-author of research reports, journal articles, and conference presentations In addition, the PIs will contribute to the project based on their expertise, experience, interests, and administrative assignments. ▪ PI Porter will manage the project, providing overall administration of personnel and budget. ▪ Co-PI Kushner will serving as liaison with other institutions and coordinate communication amongst the administrative personnel in the community colleges and the 3+2 program. ▪ Co-PI Walton will coordinate the integrated curriculum model team ▪ Co-PI Burnett will coordinate assessment and research for the project. ▪ Co-PI Ceylan will coordinate the artificial neural network assessment ▪ Co-PI van Leeuwen and co-PI Rehmann will coordinate participants in the project
Other Professionals	▪ Duane Smith, Associate Director of Outreach for the Center for Transportation Research and Education (CTRE) at Iowa State, will coordinate distance conferences and facilities arrangements for the dissemination workshops. ▪ Mary Goodwin, Coordinator for Undergraduate Programs in the College of Engineering at Iowa State, will assist with data collection and provide program assistance for workshops. In addition, she will have responsibility for the administrative coordination of area community colleges. ▪ A program coordinator will assist with managing the massive amounts of data to be collected, organized, and analyzed and well as with the logistical coordination of the CELEC curricula, including, but not limited to travel coordination, workshop arrangements, and various other administrative support.
Post-Doc	Assist Mack Shelley with the RISE Program's commitment to the project.
Graduate Students	The commitment of the graduate students to this project will include collaborating in collecting data and entering it into the CMS. They will participate in analyzing, and interpreting data and then co-authoring reports, journal articles, and conference presentations. ▪ One PhD student in engineering education ▪ Two ½-time PhD students in Rhetoric & Professional Communication (RPC) ▪ One ½-time MA student in Rhetoric, Composition, & Professional Communication (RCPC) ▪ One ½-time MS student in CCEE
Undergrad. Student	The undergraduate student will assist with the project implementation and assessment and provide clerical support.

Intellectual Merit

The proposed work will *advance knowledge and understanding* of implementation and assessment (which rely heavily on dissemination) of integrated curricula. Assessment strategies will include both direct and indirect measures, as recommended by Huba and Freed (2000). The use of traditional assessment methods as well as artificial neural networks (e.g., Weckman et al. 2001) will allow the assessment (and improvement) not only of the curricula but also of the assessment methods themselves. For example, because artificial neural networks can explore many relationships between variables, they can expose the key relationships and show whether traditional methods address them. Answers to the research questions about the effectiveness of various types of programs at improving professional practices will suggest improvements to integrated curricula at research universities, engineering colleges, and community colleges. Working with faculty at other schools through workshops will reveal ways to "abrogate ownership" (Fincher 2000) and adapt the integrated curriculum model to local conditions.

The *qualifications of the project team* include participation on the Curriculum Integration Committee in the Department of CCEE at Iowa State University; experience with teaching an integrated curriculum; experience with assessment; and ability to disseminate the project findings widely. Teams with longevity tend to have a higher likelihood of engaging in productive processes and generating successful products, and the members of the Integration Committee—which now includes PIs Porter, Ceylan, Walton, van Leeuwen, Rehmann, and Burnett—have been working together for the six years that CCEE has had an integrated curriculum. Also, five of the PIs have taught one or more courses in the integrated curriculum. PI Burnett brings experience with teaching and assessing professional practices, while PI Sauer brings experience with content management systems. The consultants' panel, which includes Professors Julia Williams of Rose-Hulman and Mack Shelley of RISE at Iowa State, will assist with traditional assessment methods, while PI Ceylan will use his expertise in artificial neural networks to help generate new methods. Dissemination of the project findings will be aided by PI Kushner, Dean of College of Engineering, who can increase awareness among other engineering deans across the country (as in Carpinelli and Perna 2002), and the Advisory Panel members, who can disseminate results through academia and industry.

Broader Impacts

The proposed work *promotes teaching, training, and learning* in several ways. Most important, the assessment and dissemination strategies focus on improving engineering education in general and the teaching of professional practices in particular in engineering programs throughout the nation. The project also involves educating a postdoctoral researcher from RISE and five graduate students at Iowa State: a Ph.D. student and an M.S. student in civil engineering and two Ph.D. students and an M.A. student in rhetoric and professional communication. The project includes professional development for project personnel, including software training and attendance at classes in de Bono creativity and at the Rose-Hulman Assessment Conference. Much of the effort in dissemination will focus on training faculty at other schools in developing, implementing, and assessing an integrated curriculum.

The project *broadens the participation of underrepresented groups* in multiple ways. We start with equity in our own project and classrooms. Attention to diversity is, in fact, infused throughout the integrated curriculum, not as an extra layer but as a foundational element. For example, faculty members construct teams that represent a range of technical backgrounds as well as gender, ethnic, and racial diversity. Such an approach prepares students for the concurrent teams that many of them will join in the engineering workplace where they will seldom get to select their own team members. The colleagues and institutions invited to participate in the project represent geographic, demographic, and institutional diversity (Table 4); all are concerned with integrating professional practices into their curricula and assessing students' understanding and use of the engineering body of knowledge and their performances in professional practices. Comparing assessment results from various schools and observing the ways in which different types of schools adapt the basic model of an integrated curriculum to their conditions will allow the integrated curriculum and assessment models to be generalized to different types of schools. The dissemination strategies will also *enhance the infrastructure for research and education* by promoting the integrated curriculum and an assessment model for improving educational practices in US colleges and universities.

Much of the proposed work aims to *disseminate results broadly* through journal articles, conference presentations, a website, and workshops at other schools (especially those connected to the LTAP program) and conferences such as those sponsored by the American Society for Engineering Education and Rose-Hulman. The Advisory Panel will also help disseminate the project results throughout both academia and industry. The proposed work will *provide benefits to society* by helping colleges and universities produce engineers and scientists with the knowledge of technical information and professional practices needed to meet society's needs for the 21st century.

Results from Prior NSF Support

PI Porter, Award CMS-9812745, Workshop on Research in FRP Composites in Concrete Construction, $26,876, 1/15/04–12/30/05 This workshop held in San Francisco identified priority areas of needed research for the use of FRP in concrete structures. Forty-eight experts from four countries attended, in the associated fields representing government, academe, and industry. Presentations have been made at American Concrete Institute (ACI) national meetings to summarize the workshop results. The PI is disseminating the results ACI committees 440 and 440-D, which he currently co-chairs. Important findings for this sponsored workshop were the topics and priorities for needed future research for FRP in concrete. Two publications and several oral presentations have resulted from this NSF support. A new sub-committee in ACI 440 has been formed about the utilization of the FRP reinforcement in masonry structures. The PI of this proposed work is also active in this new subcommittee, which also has potential applications of this proposed work.

PI Rehmann, Award OCE 99-77208, Molecular Diffusivity Effects on Mixing in a Diffusively-Stable Turbulent Flow, $167,000, 1/1/00–12/13/02 Experiments revealed the conditions for differential diffusion of salt and temperature in a diffusively stable, turbulent flow, the dependence of the mixing efficiency on the density ratio, and the conditions for layer formation. Rapid distortion theory (RDT) allows the relevance of direct numerical simulations of oceanic differential diffusion to be assessed. The project produced in four journal articles, two conference papers, and seven other conference talks. The project has involved training of five graduate students—two of whom used the projects for their M.S. theses—and one undergraduate and a collaboration with Professor Hideshi Hanazaki of Kyoto University.

PI Kushner, Award CTS03-15353/CTS05-20368, Atmospheric Pressure Plasma Processing of Polymers: Plasma Dynamics and Nanoscale Plasma Surface Interactions, $324,000, 07/01/03-06/30/06 The use of atmospheric pressure plasmas to functionalize polymers was computationally investigated, with the goal of innovating techniques whereby commodity processes, such a corona discharges, can be applied to fabricate high value materials such as porous beads for viral drug delivery. This project has involved training of three PhD and two MS students. Publications acknowledging NSF support include 24 journal articles in print, accepted or submitted, 26 invited conference and symposia presentations, and 31 contributed conference presentations.