Design Integrated in the Mechanical Engineering Curriculum: Assessment of the Engineering Clinics

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At Rowan University, design has been infused into the curriculum through an eight-semester course sequence called the Engineering Clinics. Through this experience, students learn the art and science of design in a multidisciplinary team environment and hone their design skills throughout their 4-year career. This paper describes the objectives of the clinics, types of projects, and how the clinics complement traditional core courses in the curriculum. Impacts and benefits of the clinics on students and faculty are discussed, including retention and graduate study rates comparing Rowan University mechanical engineering students to their peers nationally. An assessment of the clinics is presented based on survey data and accreditation objectives and outcomes. Survey data from students were assessed to determine levels of students' satisfaction and confidence based on the clinics. Results of alumni and employer surveys also provide valuable feedback for assessing and improving the clinics as well as confirmation of the impact of clinics after graduation. Survey data are discussed along with challenges of the clinics at Rowan and adaptability of them at other institutions. Overall, the clinics are a positive and integrated design experience in the curriculum and assist students in achieving the program objectives. [DOI: 10.1115/1.2722788]

Introduction

Engineering education has been undergoing many changes brought about by such factors as society's need for more technically trained individuals, pressure to limit credit hours needed to earn a degree, accreditation criteria [1], industry needs, and a focus on project-based and student-centered learning. Among the many challenges arising from these changes, perhaps the most formidable is the incorporation of more design into the curriculum. Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints [2]. The design process challenges students to synthesize, analyze, evaluate, and apply the engineering skills, knowledge, and tools that they have acquired. While the design skill set is highly valued in engineering graduates, it is also one of the most difficult to learn and teach.

Most mechanical engineering programs currently include a Capstone design course to meet the design needs. Out of 43 peer institutions with nondoctoral engineering programs, which are also listed in U.S. News & World Report rankings [3], only the engineering program at Trinity University in San Antonio, TX, is similar to Rowan with a design course in each of the eight semesters of the engineering curriculum. While numerous institutions have other design courses besides a Capstone design, they were limited to fewer than eight semesters. This was found by reviewing information that was furnished by institutions that responded to an ASEE annual survey, which is available online at the ASEE Engineering College Profiles [4].

While the Capstone experience has benefits, this approach also has some shortcomings. In a one- or two-semester long course, the need to include varied skills such as communications, project management, and teamwork necessarily takes away from the focus on design skills development. Furthermore, many traditional Capstone design courses are not multidisciplinary, which is a valuable experience for preparing students for the workplace. Finally, since the Capstone project occurs at the end of a student's undergraduate career, it does not allow students to continuously apply skills learned in the supporting coursework.

Rowan University and the Engineering Clinics

Rowan University is a comprehensive, state-supported institution with a primary mission of undergraduate education. In 1992, Henry Rowan, a local industrialist, recognized the need for an engineering school in south New Jersey, both to help develop the industrial base of the region and to stimulate its economic growth. In order to do so, he made a $100 million gift to then Glassboro State College with the sole stipulation that a high-quality engineering program be created. The College of Engineering at Rowan University was created and still consists of four academic programs: Chemical Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, and Mechanical Engineering. The first class of engineering students entered in the fall of 1996 and graduated in spring 2000.

The Engineering College at Rowan is committed to innovative methods of learning to best prepare students for a rapidly changing and highly competitive marketplace. Key objectives of the curriculum include the following:

- Creating multidisciplinary experiences through collaborative laboratories and coursework;
- Incorporating state-of-the-art technologies throughout the curricula;
- Creating continuous opportunities for technical writing and communication; and
- Emphasizing hands-on, open-ended problem solving, including undergraduate research.

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Table 1 Overall structure of the eight-semester Engineering Clinics sequence at Rowan University

Year	Clinic theme (Fall)	Clinic theme (Spring)
Freshman	Engineering measurements	Competitive assessment and reverse engineering
Sophomore	Multidisciplinary project and technical writing	Multidisciplinary project and public speaking
Junior/Senior	Capstone Design or Research Project, one or two semesters	

In order to meet these objectives and foster competencies in engineering science and design, the common Engineering clinic sequence throughout the programs of study was developed and implemented with the inception of the College of Engineering at Rowan. The Engineering clinics infuse design into the curriculum through an eight-semester, required course sequence in which students learn the art and science of design in a multidisciplinary team environment. Students in the Engineering clinics practice a wide range of engineering skills while honing their design skills throughout the 4-year curriculum [5]. In this regard, the clinics have followed the national trend of integrating design into the curriculum at an early stage [6–10] and allowed for students to design and construct working devices and to generate documentation. However, simply placing students into a project based setting such as the Engineering clinic sequence does not necessarily alter their calculation-oriented thinking [11]. The clinics address this by not only requiring significant design components from the freshman through the senior years, but through utilizing reverse engineering practices [12,13], parametric design methodologies [11], and converging–diverging design frameworks [2] to give structure to the process of approaching and solving design problems.

The learning objectives of the Engineering clinics are that the students will be able to:

- Demonstrate an expanded knowledge of the general practices and the profession of engineering through immersion in an engineering project environment;
- Demonstrate an ability to work effectively in multidisciplinary teams;
- Demonstrate acquisition of new technology skills through use or development of appropriate hardware, software, and/or instrumentation;
- Demonstrate understanding of business and entrepreneurial skills by developing business, marketing, and venture plans, or other approved instrument;
- Demonstrate effective use of project- and personnel-management techniques;
- Integrate engineering professionalism and ethics in their work and as it relates to the context of engineering technology in society;
- Demonstrate improved communication skills, including written, oral, and multimedia;
- Conduct a patent search and write a patent disclosure for novel work; and
- Integrate engineering professionalism, ethics, and the environment in their work and as it relates to the context of engineering in society.

The clinics are taken by all Engineering students, not only those students in Mechanical Engineering; and all engineering faculty are involved in the clinics. The clinic sequence and its themes are summarized in Table 1. The themes are the connecting link for each term and skill sets are incrementally introduced throughout the sequence. This incremental approach to teaching design and research has been shown to be beneficial [14].

The purpose of this paper is to describe and assess the Engineering clinics at Rowan University. Each year of the clinics is described and shows how elements of design are integrated compactly into the 4 years of the undergraduate curriculum. Impacts and benefits of the clinics for both students and faculty are discussed. The clinics are assessed through analysis of survey data from students, alumni, and employers in order to report that the clinics contribute to students meeting program goals and accreditation criteria. These data along with the ABET self-study data illustrate that students achieve program outcomes and learning objectives through the clinic experience and provide necessary feedback to improve the clinics. Finally a discussion of these data, challenges of the clinics, and the adaptation of the clinics at other institutions are presented.

Freshman Engineering Clinic. The Freshman clinic consists of a 50 min lecture class and a 2 h and 40 min laboratory focused on engineering measurements in the fall and reverse engineering in the spring. Students from all four disciplines are mixed in six sections of the course. Each section is taught by one faculty member; and historically one of six faculty is from Mechanical Engineering. In the fall semester of the freshmen year, students learn and practice basic engineering skills, such as problem solving, teamwork fundamentals, engineering measurements and computer tools, and survival skills such as note and exam taking. Students work on a series of multidisciplinary projects throughout the term and learn engineering skills in the context of these projects. This course serves as a launch pad for the design curriculum to introduce students to unifying engineering science principles. With the engineering measurements theme, students learn how to take measurements, plot and analyze data, write reports, and explain engineering and physical phenomena.

In a recent offering of the Freshmen clinic, the project selected was the construction of LEGO Mindstorm robotic cars. This project was chosen since it easily incorporated content from multiple disciplines through such concepts as gears, mechanisms, materials, computer programming, dimensioning, and tolerance. The project naturally lent itself to the development of teamwork, open-ended problem solving, and communications skills, as the students were placed into two-person teams of different disciplines and presented with challenges to various competitions, including a final obstacle course.

In the second semester, an intense study of engineering design occurs through reverse engineering (“dissection”) and competitive assessment (instrumentation, testing and side-by-side comparison of technical performance for the purpose of improvement) of a consumer product or process. In this manner, students are introduced to design by studying both good and poor designs of other engineers. This exercise also serves to demonstrate to students the importance of working in multidisciplinary teams to design a product and allows the students to determine how scientific principles, materials, manufacturing, cost, safety, environment, and intellectual property impact product design. Other professional skill topics included in this semester are communication skills, teamwork, and engineering ethics.

In Spring 2005, the Freshmen Clinic II project led by Mechanical Engineering faculty involved the design and engineering of soccer helmets. This project allowed the students to first reverse engineer a variety of helmets to gain insight into their design and construction. Students then evaluated current research concerning the effectiveness of these helmets in preventing head injury. After understanding the current state of the art, student teams then went about designing their own experiments which addressed the shortcomings found in previous experimental studies. These student designed experiments that involved everything from instrumented crash test dummies to impact rails. Armed with extensive data on acceleration of the head, deflection of the neck, damage to the helmet, and rebound of the ball, student teams were able to evaluate each helmet for effectiveness in preventing injury, minimal intrusiveness toward the player during game play, and durability.

Sophomore Engineering Clinic. The Sophomore clinic is focused on integrating engineering design with significant communication components; writing in the fall semester and public speaking in the spring semester. The students spend 2 h and 40 min in a single engineering lab period and 50 min in each of three communications periods per week. The course is team taught by faculty from multiple departments within the College of Engineering and the College of Communication and again the sections are mixed such that teams have four to five students from the different disciplines. Assignments and grading are integrated through both communications- and engineering-specific sections, a trend which is gaining national acceptance [15–17].

The Sophomore clinic course consists of design projects that traditionally have components tied to the Mechanical Engineering curriculum and thus serve as a laboratory component for core courses in the mechanics stem [18]. Mechanical Engineering students take the two semesters of Sophomore clinic concurrently with statics, dynamics, and solid mechanics over the course of the academic year and prior to electronic networks, which is a course in circuit analysis. In the Sophomore clinic, the projects contain elements of design and computer aided drawing; marketing; economics; structural, life-cycle and environmental analysis; prototyping; and testing and are integrated with communications courses.

In recent fall semesters students designed, built, analyzed, and tested truss systems in a project named the Hoistinator. Some requirements are that the system should lift loads between 420 and 1400 lbs a distance of 36 in., using a maximum of 150 in.^{3} of aluminum and 50 in.^{3} of plastic as construction materials. Additionally, each team designed and built a digital timing circuit to determine the exact time required to lift the weight. Students were not allowed to test their cranes before the final, graded competition which forced them to rely on statics and failure calculations that were learned in statics and solid mechanics courses. The teams improved their professional skills by conducting life-cycle and present worth analyses, and they were rewarded for economic and environmentally friendly designs. The fall semester is team taught by engineering and writing arts faculty. Writing is integrated into the course through technical memos, proposals, and reports that the students write within the context of the project.

Similarly the second (spring) semester course is team taught by engineering and communication studies faculty. The goal of the public speaking component is to enable students to effectively participate in oral communication, particularly technical presentations, which are related to the semester-long project. Past projects in the Sophomore clinic have included the design and construction of golf ball launchers, two degree of freedom cranes, and small motorized vehicles. In these projects, the students expand their knowledge on topics covered in dynamics and electrical networks. For example, in the golf ball launcher project, students constructed devices that used a spring to drive a plunger which impacted a golf ball. They analyzed the impulse imparted to the golf ball by converting the energy stored in the spring-driven system into a resultant harmonic motion of the plunger which is then converted into an impulse to the golf ball. These second semester projects also often include the wiring of LED displays and counting circuits, and the design of power circuitry to make the connection with the electrical networks course.

Junior/Senior Engineering Clinic. In the final four semesters of a student's career, the clinics continue with the format of multidisciplinary teamwork with the added dimensions of semester- or year-long projects and the inclusion of both Junior- and Senior-level students in 3–5 member teams. In Mechanical Engineering guiding principles for the Junior/Senior clinic are "design, analyze, build, and test." Each multidisciplinary team works closely with one to two professors, often from two different disciplines, who act as project managers to advise the team.

The Junior/Senior clinic projects have been inspired by a mix of industry-sponsored activities, professors' research activities, professional society competitions, service learning activities, and entrepreneurial projects inspired by student or faculty ideas. Industrial and government partners and sponsors vary from regional, such as the Navy, FAA, Coriell, and Carlisle; national (Dura-bar, Chicago, IL), or international (Continental Tire, Germany). Faculty research activities are another source of projects. Many research projects involve design of an experimental test bed that fits well into the structure of the Junior/Senior clinic. Research grants from federal and state government agencies such as the NSF, NASA, NJDOT, and the NJ High-tech Workforce Grant supply the funding for the bulk of these types of projects. Examples of student design competitions that are projects in the Junior/Senior clinic are the SAE Mini-Baja, ASME design contest, ASME indoor aerial robotics contest, and NASA reduced gravity student flight opportunities program. Student competitions provide excellent opportunities for putting coursework into practice, which is one of the main goals of the Junior/Senior clinic. These experiences also give students the opportunity to observe other designs at the competition and reflect on the design process. Service-learning projects, which are gaining popularity in engineering curricula [19,20], are conducted in the clinic. Two examples are to provide of relief in the Gulf Region after Hurricane Katrina and an international project to provide safe access to potable water through the Engineers without Borders organization. Finally, students are invited each semester to submit proposals to develop their own original inventions through our innovative Venture Capital Fund [21]. This is an exciting and unique opportunity for our students to find a need and develop a product. Since its inception, over 20 entrepreneurial projects have been funded, which have led to further funding from the National Collegiate Inventors and Innovators Alliance (NCIIA) and the development of several small businesses and products that are patented or patent pending.

The Junior/Senior clinic projects are typically centered on a multidisciplinary technical problem, product, or process. Deliverables for each of the projects include a midsemester design review presentation, final design presentation, final design report, and prototype or product. Presentations include an introduction, project goals and objectives, design development and calculations, summary of progress, and future work. Midterm presentations are evaluated by at least two faculty members, and final presentations are evaluated for technical and communication merits by faculty and peer students. The final reports contain similar elements as the presentations and also must include a technological impact statement that addresses societal, economic, and environmental impacts; sustainability; manufacturability; and health and safety.

Impact of Engineering Clinics

The clinics result in numerous benefits for students and student learning as well as for faculty. In Freshmen Clinic I, students are introduced to Rowan University and the College of Engineering, taught survival skills and work on hands-on, multidisciplinary activities, which spark their interest in engineering, and work with students from the other disciplines. In Spring, the students develop critical thinking skills and are exposed to the multidisciplinary nature of most products and processes through competitive assessment. Not only do the Freshmen clinics begin to prepare the students with engineering skills, but they also promote high levels of retention into the sophomore year.

Data from Institutional Research at Rowan University for Mechanical Engineering students entering between Fall 1999 and Fall 2004 are shown in Table 2. The number of students enrolling in Mechanical Engineering as freshmen from 1999 to 2001 does not include the students from those entering classes who transferred into Mechanical Engineering from General Engineering. At

Table 2 First year retention of mechanical engineering students enrolling between 1999 and 2004

Fall enrollment year	Number of students declaring mechanical engineering	Number of students returning after freshman year	Retention (%)
1999	15	10	67
2000	25	21	84
2001	12	10	83
2002	46	37	80
2003	29	23	79
2004	28	22	84

Table 3 Rowan ME graduates pursuing S&E graduate studies since Fall 2000

Graduation year	Number of students pursuing S&E graduate studies	Total number of students graduating	Percentage of students pursuing S&E graduate studies (%)
2000	6	28	21
2001	5	17	29
2002	9	22	41
2003	11	24	46
2004	13	42	31
2005	5	27	19
2006	12	25	48

Rowan, General Engineering was not a degree program, but a category for students who had not declared an engineering major. In Fall 2002, the General Engineering category was dropped, and students from then on were required to declare a major as incoming freshmen. Note that the percentage of students dropping out between freshmen and sophomore years is typically less than 20%, as retention rates are 67–84%. These rates are lower than estimates of loss rates of 30% in science and engineering (S&E), based on a longitudinal study by the Center for Institutional Data Analysis and Exchange (C-IDEA 2000) at the University of Oklahoma [22] and the NSF [23].

Hands-on activities and teamwork in the Freshman and Sophomore clinics prepare students for the open-ended real-world projects of Junior/Senior clinic. The writing and speaking experiences in Sophomore clinic help students prepare for the reports, papers, resumes, and presentations that are also important aspects of Junior/Senior clinic.

In the Junior/Senior clinics, students further hone their skills through engineering practice. Students engage in valuable technical and professional experiences that give them advantages when applying for internships, scholarships, graduate school, and jobs after graduation. Rowan undergraduates can often point to conference presentations, journal publications, engineering reports, design and fabrication experience, or field work as evidence of their exceptional preparation. Students working on industry sponsored projects have often received internship or full-time job offers with the sponsoring company based on their experience and contacts. Students who participate in entrepreneurial projects, have the opportunity to experience the patent-granting process firsthand. Students who engage in service learning activities, address community needs, see their impact through key elements of reciprocity and reflection, and take on engineering management roles.

Based on our experiences and discussions, the Engineering clinics have had a positive impact on faculty development as well. During the startup phase of the engineering program at Rowan, 32 faculty members were hired over a 5 year period, the majority of which were early-career, tenure-track junior faculty members who responded to the challenges associated with starting an innovative new undergraduate engineering program. One challenge for faculty members at non-Ph.D. granting institutions is the need to maintain a level of scholarly activity necessary to stay current in their field of study and to remain competitive for career growth opportunities. We have found that the Junior/Senior Engineering clinic, in concert with a modest full-time Master's program, has been highly effective as a means for engineering faculty members to maintain their scholarly activity. The design, build, and test approach is not only effective for student learning, it has also been shown to be effective for providing experimental hardware for scholarly pursuits. Since all engineering faculty members supervise two Junior/Senior clinic teams per semester as part of their normal course load, a research program can potentially have access to up to eight undergraduate students per semester from four engineering disciplines. Since each student is expected to work at least 10 h/week on their clinic project, the total amount of effort from these teams is approximately 2500 person hours per year for each year of a research project.

In addition to the benefits on design education, the Engineering clinics have been highly effective in allowing undergraduate students to perform quality research as evidenced by the number of journal and conference papers written by Rowan Engineering faculty members with undergraduate co-authors. Indeed, the overwhelming majority of all of research done in the engineering program has been conducted through the use of multidisciplinary teams of undergraduate students working alongside masters students in the clinic setting. This vertical integration has allowed the Masters students to take an advisory role and allowed the undergraduates to be mentored in graduate research. Most often, the Clinic teams are involved in the design and building of experimental equipment or hardware for research, and then students may conduct research in the clinic or as part of an undergraduate research experience. In many cases, our own undergraduates stay for a Masters degree and get their start through working on a project in the clinic. The impact of undergraduate design and research at Rowan on the greater educational community can be measured by the high percentage of graduates from the program who go on to graduate study. Typically between 20% and 40% of a graduating engineering class will go on to graduate study at some of the nation's top graduate schools, which in recent years have included UC-Berkeley, Drexel, Penn State, Princeton, Stanford, University of Michigan, University of Texas, and Virginia Tech.

Table 3 shows the number and percentage of Rowan graduating seniors continuing on to full-time graduate school in engineering. According to 2006 statistics from the NSF, approximately 12% of those who graduate with a bachelor's degree in science and engineering (S&E) continue in S&E graduate studies [23]. Thus, Rowan graduates are more likely than their peers nationally to pursue graduate studies. We believe that this can be attributed to their hands-on education and technical and professional skills acquired through the clinics, undergraduate research opportunities, and working closing with faculty and Masters students.

Assessment

Various data were used in order to assess the clinics. Student survey data were used to determine student satisfaction and self-confidence, which reinforce the strengths of the clinics and verification of students meeting clinic objectives. ABET self-study was used to develop and measure student outcomes related to the clinics. Alumni survey data were used to determine if the students believed that they had achieved the goals of the program and ABET outcomes as well as to determine how important the clinic experience was in their careers. Finally, employer survey data were used as an external assessment to determine if the students achieved the outcomes from the clinics.

Table 4 Attitudes toward engineering clinic by mechanical engineering majors by year of survey (% agreeing or strongly agreeing with statement)

Attitude statement	Date of survey: Spring 2002	Spring 2003	Spring 2004	Spring 2005	Spring 2006
Overall the engineering clinic experience is beneficial to engineering majors	93.8	86.6	80.4	86.1	80.9
Clinic serves to unify engineering students in same class but different majors	83.3	74.1	78.4	78.5	67.5
Clinic provides realistic experiences like in the work world	84.4	74.8	73.8	67.7	68.4
Clinic projects provide useful hands-on experience in engineering	92.8	88.9	86.0	89.2	65.3
Clinic enables me to connect things from different disciplines I wouldn't otherwise do	83.3	74.8	78.4	78.5	67.5
Working in assigned teams with classmates helps me understand class material	66.7	69.8	54.7	61.7	52.2
Clinic experience makes me more positive about working in groups/teams	70.1	55.9	53.8	59.6	56.0
Teamwork slows down learning process in clinic	13.4	10.2	4.6	7.5	12.2
In clinic a lot of time is spent learning material/approaches irrelevant to my major	38.6	35.5	35.5	32.2	40.4
In group/team assignments, not everyone does fair share	58.8	65.3	64.5	62.8	58.9
Too much work expected in clinic for amount of credit given	74.0	77.1	74.4	59.1	64.0
(n)	(97)	(127)	(107)	(93)	(91)

Student Surveys. Rowan engineering students have participated in a semi-annual survey, at the beginning and end of each academic year, for the last 5 years in order to assess their engineering self-confidence, satisfaction with the program, and plans for their future in engineering. It should be noted that these surveys were and administered by a social scientist outside of engineering with minimal engineering nput. These surveys and study findings can be found in Hartman and Hartman, 2004 [24]. Some results of this work were previously reported for all Rowan Engineering students [27], whereas the following results and analysis are of Mechanical Engineering students' data. Students' responses to Engineering Clinics, measured at the end of each academic year, have been overwhelmingly positive, as Table 4 shows. Each year over 80% of the mechanical engineering majors agreed or strongly agreed that overall the Engineering clinic experience is beneficial; 70–80% agreed or strongly agreed that the clinics unify engineering students from different majors; 68–84% agreed or strongly agreed that the clinics provide realistic experiences, like in the work world; close to 90% in most of the years agreed or strongly agreed that clinic projects provide useful hands-on experience in engineering; and 70–80% agreed or strongly agreed that the clinic helps them to connect things from different disciplines. Nearly two-thirds thought that working with students in other majors in the clinic was a beneficial learning experience.

The clinic directly contributed to their orientation to group work. Over half of the students claim that the clinic experience made them more positive about group work, and less than 10% claimed that it made them less positive. Between 50% and 60% agreed or strongly agreed that working in assigned teams, as they do in the clinic, helped them to understand class material. Less than 15% thought that teamwork slowed down the learning process.

On the other hand, they expressed some ambivalence about the amount of work that was required in the clinic for the credit given; about a third of the students thought that a lot of time was spent learning approaches not relevant to their major; and over half had complaints that in groups not everyone did their fair share. Table 4 also shows that the evaluation of the clinic has lowered slightly in some areas in the most recent year of the survey. While this is disappointing, the clinics will continue to be monitored and improved and results for cohorts of students by class will be probed. Clearly room for improvement exists, but the benefits are well worth the effort.

Because the survey has been repeated for several years, we also can look at the development of the students as they progress through the program. Looking at the cohort who entered the Mechanical Engineering major in Fall of 2001, and following this cohort through the Spring of 2005, when most of this cohort graduated in the most recent graduating class, we can trace the development of their self-confidence as related to their major and the competencies emphasized in the clinics (Table 5). About half enter as first-year Mechanical Engineering majors agreeing or strongly agreeing that they are mechanically inclined or technically inclined. After a year in the program, nearly 90% agree or

Table 5 Engineering self-confidence of mechanical engineering majors by year in school (Fall 2001 cohort; Fall, 2001 through Spring, 2005 survey responses) (% agreeing or strongly agreeing with statement)

Year in school	First semester	Second semester	Sophomore	Junior	Senior
	Survey date				
Self-Confidence Statement	Fall, 2001	Spring, 2002	Spring, 2003	Spring, 2004	Spring, 2005
I consider myself mechanically inclined	54.4	88.1	90.9	92.3	85.0
I am good at designing things	68.2	84.7	86.4	80.8	80.0
I consider myself technically inclined	54.5	88.2	90.9	88.5	85.0
I am competent in skills required for my major	86.4	70.6	95.4	96.1	85.0
(n)	(22)	(17)	(22)	(26)	(20)

Table 6 Contribution of the engineering clinics to the 12 program outcomes

	Program Outcomes: Solve problems using mathematics, science and engineering knowledge	Design a system, component or process	Be knowledgeable of contemporary issues	Work effectively in multidisciplinary teams	Communicate effectively	Be bold and creative problem solvers	Apply entrepreneurial skills	Apply broad scientific, mathematical and analytical knowledge	Identify, formulate and solve engineering problems	Understand the need for professional and ethical responsibility	Understand and consider the consequences of engineering solutions on society	Recognize that learning is a continuous process
Freshman Clinic I	A		E	A	A	A		A	A	E	A	
Freshman Clinic II	A	A	E	A	A	E	A	A	A	A	E	E
Sophomore Clinic I	A	A	E	A	A	A	E	A	A	A		E
Sophomore Clinic II	A	A	E	A	A	A	A	A	A	A		E
Junior Clinic I	A	A	E	A	A	A	E	A	A	A	E	E
Junior Clinic II	A	A	E	A	A	A	E	A	A	A	E	E
Senior Clinic I	A	A	E	A	A	A	A	A	A	A	A	A
Senior Clinic II	A	A	E	A	A	A	E	A	A	A	A	A

Program Goals

1) Create well-rounded engineers who possess theoretical and practical skills and understand the significance of humanities and social sciences

2) Produce graduates who have the necessary teamwork and leadership skills to excel in multidisciplinary team environments

3) Develop innovative and creative thinking with an understanding of entrepreneurship

4) Develop science, mathematics, analytical, computational and experimental skills and apply them to formulate and solve engineering problems

5) Instill in students and appreciation of the impact of engineering solutions in a global and societal context, including the broad implications of professional ethics

6) Develop the flexibility to adapt to changing technology and an understanding of the need for continuous improvement and lifelong learning

strongly agree that they are mechanically or technically inclined, and this percentage remains until the end of their fourth year as seniors. Similarly, their confidence that they are good at designing things rises from 68% to 80%. A more general feeling of competence in the skills required for their major rises from 70.6% after their first year in the major to 85–90% in the remaining years. While other factors such as faculty teaching styles, student self-motivation, and other external student experiences may be attributed to these results, the clinics do have a major role to play in this building of engineering self-confidence since the students spend so much time "practicing" engineering in the clinics.

ABET Self-Study. Further evidence of the strength of the clinics in the Mechanical Engineering program can be found in part of our ABET self-study. Program goals and objectives were formulated around the ABET a–k criteria [26], ASME program criteria [27], and the ambitions of the faculty, which led to a set of 12 program outcomes. Table 6 shows the Engineering clinics and their contributions toward achieving these 12 outcomes, which also map to six program goals. While some outcomes achieved in a course are assessed in the course (through graded assignments, for example), others simply provide students in the course with an exposure. The differences are denoted with an "A" for assessed

Table 7 Outcomes, assessment criteria, and results related to the clinics

Outcome	Assessment criteria	Results	Comments
Be able to design a system, component, or process	• 90% of sophomore ME design, build and test an electromechanical device	• >90% achieved	• Criterion met
	• 100% "satisfactory" and 80% "good" or better on technical merit of J/S Clinic oral presentation	• Fall 2005 96% "satisf." or better, 77% "good" or better Spring 2006 97% "satisf." or better, 79% "good"	• Criterion NOT met completely in either semester, but close in both semesters
	• 100% of ME J/S Clinic projects have major design component	• 100% of projects had major design	• Criterion met
Be knowledgeable of contemporary issues and Understand and consider the consequences of engineering solutions on society	• 100% of ME J/S Clinic include societal impact statement	• 100% satisfied in spring 2006 semester	• Criterion met
Work effectively in multidisciplinary teams	• 100% of ME students will be part of multidisciplinary J/S Clinic project	• 100% of graduating seniors; 88% of juniors	• Criterion met for seniors; likely to be met for juniors next year
	• 75% of ME J/S Clinic teams will be multidisciplinary	• 64% in Fall 2004, 19% in Spring 2005; 77% in Fall 2005, 57% in Spring 2006	• Criterion NOT met in either of two most recent academic years
	• 100% of sophomore ME students on multidisciplinary project	• 100% in Fall 2005 and Spring 2006	• Criterion met
	• 100% "satisfactory" & 70% "very good" or better on peer assessment in J/S Clinic survey	• 96.5% "satisfactory" or better, 94.3% "very good" or better	• Criterion partially met
Be effective communicators	• 100% "satisfactory" & 80% "good" or better on quality of presentation in J/S Clinic oral presentation	• Fall 2005: 98% "satisf." or better, 65% "good" or better Spring 2006: 98% "satisf." or better, 78% "good" or better	• Criterion NOT met completely in either semester, but close in both semesters
	• 100% will pass Soph Clinic I & II	• 100% passed	• Criterion met
	• 100% of ME J/S Clinic to include oral presentation, final report	• 100% completed these deliverables	• Criterion met
Be bold and creative problem solvers	• At least two ME J/S Clinic projects per semester will be student originated	• 1 in Fall 2005 3 in Spring 2006	• Criterion NOT met in Fall 2005 but met in Spring 2006
	• 90% of ME sophomores will develop e-m device in Clinic	• >90% achieved	• Criterion met
	• 100% of ME freshmen will complete Freshman Clinic I	•100% completed	• Criterion met
Have entrepreneurial skills	• At least two ME J/S Clinic projects per semester will be student originated	• 1 in Fall 2005 3 in Spring 2006	• Criterion NOT met in Fall 2005 but met in Spring 2006
	• 90% of ME sophomores will develop commercial e-m device and do patent search in Clinic	• >90% achieved	• Criterion met
	• At least two ME J/S Clinic project per year will include proposal to agency	• 2 in 2005–2006 academic year	• Criterion met
Possess and apply broad scientific, mathematical and analytical knowledge to identify, formulate and solve engineering problems	• 100% "satisfactory" and 80% "good" or better on technical merit of J/S Clinic oral presentation	• Fall 2005: 96% "satisf." or better, 77% "good" or better Spring 2006: 97% "satisf." or better, 79% "good"	• Criterion NOT met completely in either semester, but close in both semesters
	• 90% of sophomores will use 3D modeling in Clinic II	• >90% achieved	• Criterion met
Possess a recognition of the need for and an ability to engage in life-long learning	• 15% of ME seniors will pursue graduate studies full time	• 2005: 20% (5 out of 25) 2006: 50% (12 out of 24)	• Criterion met
	• At least 2 student presentations per year at professional society meeting	• 6 presentations made in 2005–2006	• Criterion met

outcome, and with "E" for exposure to outcome. While all of the courses in the Mechanical Engineering curriculum contribute in some way, Engineering clinics contribute heavily to meeting all 12 program outcomes and are the focus of this discussion.

Table 7 shows many of the assessment criteria related to the clinics and the most recent results and comments related to the outcomes. The faculty has set the assessment criteria high. In general, the criteria were achieved or nearly met, which is positive regarding the clinics. Few criteria that were not met were those based on the quality of the technical merit and oral presentation skills of the student work in the clinic. Since only a small percentage of students did not meet the requirements set by the faculty, these data show that most students did achieve the desired outcomes by meeting or exceeding course requirements. Another criterion that was not met involved the percentage of multidisciplinary projects. This criterion has been a challenge due the nature of the projects that are available each term and balancing student assignment on projects based on student interests and availability. Finally, two outcomes that are measured by the criterion of student originated projects are not met. While students are encouraged to initiate their own projects, it is not always possible. Collaborations with the College of Business and an entrepreneurial program at Rowan may increase the number of student projects. The results, both positive and negative, will continue to serve as a guide in administering and improving the program.

Alumni and Employer Surveys. We believe that the outcomes persist beyond graduation based on alumni survey data. Twenty nine mechanical engineering alumni out of 156 completed the alumni survey in 2006, the results of which are quite positive. When asked "How well did your program prepare you for your career?" the response averaged 4.37 out of a scale of 1= "not very well" to 5= "very well," with only one response rating a 3 (the lowest rating given). When we queried the alumni regarding the ABET a–k outcomes, the average rating of the 11 outcomes ranged from a low of 3.90 to 4.62 (again on a 1–5 scale), with all but two of outcomes rated at an average of greater than 4.0. The two that were rated below 4.0 relate to "h. the broad education necessary to understand the impact of engineering solutions in a global, environmental, and societal context," and "j. knowledge of contemporary issues relevant to engineering." Twenty seven of the responses to the request "List the strengths of your engineering program" contained one or more of the following: explicitly stating clinics or implicitly referring to clinics by stating features such as: hands-on experience, teamwork, multidisciplinary, and communication skills as shown in Table 8. These data show that not only were the objectives of the clinic met, but that the students believe that the clinics and skills they learned in the clinics are important in their careers after graduation.

Survey data from internship employers provide sound evidence of the impact of clinics and the engineering program on the students and are another value source of feedback for assessment. Internship surveys have a five point rating scale of 1, 2, 3=average, 4=good, and 5=very good. Employers were asked to rate students regarding various skills and the results have been exemplary. Regarding students' abilities to solve problems using mathematics, science, and engineering knowledge, in 2003 100% were rated "average" or better and 94% "good" or better. This improved in 2004 such at 100% were rated "good" or better. When asked about students' abilities to work effectively in multidisciplinary teams, 83% in 2003 and 92% in 2004 were rated "good" or better. In 2003, 89% were "good" or better in verbal communication and 80% were "good" or better in written communication. Similarly in 2004, 90% for verbal and 86% for written were good or better.

Table 8 Items reported by alumni as strengths of the engineering program and frequencies of responses

Elements in response to the request "List the strengths of your engineering program"	Frequency
Clinic or clinic projects	8
Hands-on experience	8
Teamwork or multidisciplinary teamwork	9
Project management	2
Communication skills (writing and/or presentations)	6
Industry collaborations/relationships	1

Discussion

The clinic program was designed from its inception in 1996 with the ABET EC2000 in mind and a strong focus on design, thus the clinics cannot be compared with a previous curriculum. Further, the clinics are required for all students, thus a control group cannot be used to assess the effectiveness of the clinics. Still, the clinics do provide much information about the success of the program and students achieving program objectives, which are discussed in terms of student, alumni, and employer survey data, as well as the ABET self-study of program objectives and outcomes.

The student survey data provided the faculty with valuable feedback regarding the clinics. Students' attitudes regarding overall benefits of the clinic experience and that the clinics provide for realistic, hands-on experiences that allow students to make connections between different disciplines have been overwhelmingly positive as previously noted. These are evidence that the clinics are an important part of helping the students achieve the objectives of the program. Similarly, the large percentage of students rating themselves highly in terms of their self-confidence over their four years in engineering is important in their persistence and retention in engineering.

While there are many strengths in the clinics, improvements can be made. Two areas for improvement noted by students are in the areas of teamwork and relevance to major. Dr. Christine Johnston of the Rowan University Center for the Advancement of Learning developed the interactive learning model that uses metacognition to promote learning and the Let Me Learn process to help students better understand themselves as learners [28]. She and her colleagues have assisted the Rowan Engineering faculty in using this process with students particularly in the formation of teams and facilitated learning activities with students to help them deal with team dynamics and conflict resolution. Also, improvements in the peer evaluation process may improve teamwork and student accountability. In terms of relevance, perhaps students do not always realize that skills relevant to their major are more than the technical concepts. Faculty should be sure to convey to students the importance of having depth in their chosen field, breadth of other subjects, and how these are relevant and are interwoven when practicing engineering.

Finally, while the majority of results are positive, Table 4 does show some declines in the most recent year of the student survey. These must be probed further and future data will provide information to determine if a trend exists. The clinics continue to be monitored and future studies will allow assessment of changes made to specific semesters of the clinic to be made. While the declines are discouraging, this study of survey data has provided the faculty with feedback to improve the clinics as well as other parts of the curriculum. This information would not have otherwise been gleaned, thus stressing the importance of continuous evaluation and assessment of any curriculum.

The ABET self-study allows the faculty to maintain and improve the undergraduate experience. This is important, since all of the objectives are linked to one or more of the clinic courses and serve as a check that the curriculum has the key elements desired in the program. The faculty set high standards that were met or nearly met as previously mentioned. Survey data from alumni and employers show that not only were the objectives of the clinic and the program met, but that the students found that skills learned in clinics, such as their ability to solve problems, design, communicate, and work in teams, remained important in their careers after graduation.

While the clinics have been positive for the students, challenges have also arisen. Compared with other institutions, the Mechanical Engineering curriculum is compact in terms of the core courses. Many core courses in the Mechanical Engineering major are three or four semester or quarter hours, while at Rowan many of these courses are two credit hours. A challenge exists to balance coverage of technical material and incorporate the wide variety of skills encompassed in practicing engineering and design in the clinics. As previously mentioned, most Mechanical Engineering programs currently include a one or two semester Capstone design experience. However, due to its very nature, the Engineering clinic at Rowan can be much more time intensive for both stu-

Table 9 Engineering clinic student to faculty ratios

Course	Semester credit load	Typical no. of students	ME faculty	Student/faculty ratio	Students/total faculty credit load
Freshmen clinic	2	25	1	25:1	12.5:1
Sophomore clinic	4	25	2	12.5:1	3.1:1
Junior/Senior clinic	2	50	8	6.3:1	3.1:1

dents and faculty. For this reason, scalability at larger institutions would require careful planning to keep degree requirements and faculty work loads at reasonable levels. Table 9 shows the approximate relationship, for a typical fall or spring semester, of students to faculty for clinic courses in the Mechanical Engineering department.

Team teaching in the sophomore level can be time intensive, but also allows faculty from the various engineering disciplines, communications, and the writing arts to divide duties. The low student to faculty ratios, particularly in the Junior/Senior clinic, may make scale up difficult. For example, an institution with a combined Junior/Senior student population of 100 students would require an additional 32 credits of faculty teaching load per semester to implement the Junior/Senior clinic course. The actual number will be much less than this as the Engineering clinic would replace an institution's Capstone design course. Teaching assistants or graduate students could assist in advising Junior/Senior clinic teams and alleviate the strain on resources due to the low ratio of students to faculty. The Engineering clinic's overwhelmingly positive impact on students, as outlined in this study, is worth the effort and this model may be adaptable at other institutions. Components of this model, such as teaching technical communications in the context of engineering design or having more semesters of a capstone experience as done in the Junior/Senior clinics, could be easily adapted at other institutions and provide beneficial design experience to students.

Conclusions

The Engineering clinics represent a paradigm for seamless incorporation of design throughout the 4-year curriculum. In addition to focusing on student-centered, hands- and minds-on learning, the clinics are multidisciplinary; allow for continuous practice and development of communications, teamwork and design skills; involve our constituencies; and easily incorporate the professional skill topics such as societal considerations, ethics, and entrepreneurial skills. The Engineering clinics sequence has been a beneficial experience for students and faculty as discussed and has contributed to high rates of retention and large percentages of students pursuing graduate studies in engineering. Survey data from students, alumni, and employers have provided valuable information in assessing confidence, teamwork, and abilities of the students, confirm the positive contributions of the clinics, and provide evidence that students met the outcomes and objectives of the program and the clinics. While challenges exist, the results reflect a positive overall design experience in the clinics, well worth the effort, and provide useful feedback in order to improve the program or allow others to adapt it. Future work includes probing recent declines in students' attitudes based on the self-reported student survey data. Improvements will be made and the effects of these changes will be assessed.

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