AC 2007-1192: SOPHOMORE YEAR IN CIVIL AND ENVIRONMENTAL ENGINEERING AT ROWAN UNIVERSITY: INTEGRATION OF COMMUNICATION, MECHANICS AND DESIGN

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Abstract

Engineering clinics are a sequence of project-based learning (PBL) courses taken every semester by all engineering students at Rowan University. The purpose of these courses is to prepare students for aspects of engineering practice, such as solving open-ended problems and contributing to multi-disciplinary teams, which are difficult to teach via traditional blackboard courses. The two four-credit clinics offered during sophomore year (one each semester) have a specific focus on design and communication and are team taught by Engineering and Communication faculty. In these courses, students design teams work on a series of three increasingly complex design projects. This paper describes the sequence of design projects and highlights the integration of communication, and the reinforcement of concepts from traditional mechanics courses (statics, dynamics and solid mechanics) that the students also take during sophomore year. Available assessment data, as well as some ongoing challenges in running multi-disciplinary, PBL-based design courses are discussed.

Introduction

In 2005, Friedman published *The World is Flat: A Brief History of the 21st Century*, where he describes the rapidly changing and highly competitive marketplace that exists today[1]. Friedman makes a strong case for the need to better prepare for this marketplace. However, the engineering and engineering education communities were aware of Friedman's "Flat World" well before the book was published. In the 1990's, it had been observed that engineering graduates needed improvement in real-world skills such as design, teamwork, and communication, as well as a better understanding of how engineering projects fit into bigger pictures[2,3]. These skills are significantly different from the analytical capabilities that had been traditionally emphasized by engineering curriculum[4]. The dichotomy between the needs of industry and the emphasis of engineering curriculum led to implementation of the ABET 2000 A-K criteria[5], which require engineering programs to address many of the real-world needs that have since been identified by Friedman. The new ABET criteria are leading to increased significance of communication and multidisciplinary design in engineering curriculum throughout the United States.

The College of Engineering at Rowan University[6], which graduated its first class in 2000, offers Chemical (ChE), Civil and Environmental (CEE), Electrical and Computer (ECE) and Mechanical (ME) Engineering majors. The hallmark of the engineering program at Rowan University is the multi-disciplinary and project-based engineering clinics sequence[7] which covers all eight semesters of the student's undergraduate curriculum. A typical blackboard and textbook course can be very effective as teaching problem solving and analytical skills – the so-called engineering science curriculum. However, such courses tend to be less effective at developing other skills that are important to engineers. In a typical blackboard course, students usually work on well-posed problems that have unique, or at least verifiable, solutions. When students start a homework assignment, they usually know that the information required to solve the problems is contained in a specific chapter of their textbook. When teams are involved, all the students are in the same class, and typically have the same academic background. The authors submit that project-based learning (PBL) is especially effective at helping the students develop skills at solving open-ended problems, multidisciplinary teamwork and communication. These skills, as well as professionalism and ethics are emphasized throughout the clinics. As students progress throughout the Rowan curriculum, the clinic projects become decidedly more "real-world." Many of the goals of the engineering clinic sequence have since been specifically identified in the ABET 2000 A-K Criteria[5].

The purpose of this paper is to discuss how CEE students at Rowan University are taught design in a multidisciplinary, PBL environment, and to discuss how mechanics and communication are integrated into the design projects. Sophomore Engineering Clinic I and II (SEC I and SEC II) are the innovations that allow this to be accomplished. SEC I and SEC II afford the CEE students at Rowan University an integrated coursework experience for 1) learning and reinforcing material that is directly covered the CEE curriculum, 2) gaining familiarity with material that is not explicitly covered in the CEE curriculum, 3) developing formal communication skills, 4) developing into designers, and 5) acquiring the so-called "soft skills" reflected in ABET 2000 A-K criteria.

Sophomore curriculum for CEE students

The courses taken in the freshman year are common to all four engineering disciplines offered at Rowan, except for some flexibility in computer science courses. In the sophomore year, engineering students begin to take courses geared specifically toward their majors. Courses typically taken by sophomore CEE students are listed in Table 1. The Math for Engineering Analysis I and II sequence was developed by the Mathematics Department specifically for engineering students. This eight credit sequence covers topics that are drawn from the Calculus III, Linear Algebra, and Differential Equations courses offered at Rowan University. Advanced College Chemistry II is a continuation of Advanced College Chemistry I, which is taken in the freshman year. Engineers take this chemistry class along with physics and chemistry majors. Surveying and Engineering Graphics is a CEE course that is split between traditional surveying and CAD. Statics and Dynamics are both half-semester courses, and CEE students are mixed with ME students. Solid Mechanics is a full semester course. Sophomore Engineering Clinic I and II are discussed in greater detail in the next section.

Table 1. Typical Courses for Sophomore CEE Students

Fall Sophomore Year		Spring Sophomore Year	
Sophomore Eng. Clinic I	(4 cr.)	Sophomore Eng. Clinic II	(4 cr.)
Math for Eng. Analysis I	(4 cr.)	Math for Eng. Analysis II	(4 cr.)
Adv. College Chemistry II	(4 cr.)	Surveying and Eng. Graphics	(3 cr.)
Statics	(2 cr.)	Statistics	(3 cr.)
Dynamics	(2 cr.)	Solid Mechanics	(2 cr.)

Design Philosophy

Design is perhaps the most distinguishing feature of the engineering profession. However, most of the effort toward educating undergraduate engineering students is focused on analysis and engineering science, starting with well-posed problems and leading to unique correct answers. Design, on the other hand, is inherently ill-posed and open-ended[8]. Dym, *et al.*, suggest that this dichotomy is a fundamental contributor to the difficulty that engineering graduates have with design[4].

Numerous texts for design courses are currently available[9-12]. In general, these texts describe an overall process for design, as well as provide valuable tools to manage the design process. For example, the text by Eide, *et al.*[12], which is used for Freshman Engineering Clinic at Rowan University, describes a design process as consisting of the ten steps listed in Table 2.

Table 2. Ten-Step Design Process, after Eide, *et al.*[12]

1.	Identification of a need
2.	Problem definition
3.	Search
4.	Constraints
5.	Criteria
6.	Alternative solutions
7.	Analysis
8.	Decision
9.	Specification
10.	Communication

The text presents a flow diagram to illustrate how a real design team might proceed from concept, to preliminary design, to detail design. The design process flow diagram identifies certain steps throughout the process where the design is optimized, and certain steps where the design is evaluated. At each evaluation, a team might design to revisit earlier design decisions. This complex, iterative process reflects real design. However, the exact design process will depend on both the nature of the project and the design team itself—there is no correct number of iterations that can be specified *a priori* to ensure an acceptable design. As a result, students do not have a “recipe” they can follow to proceed through the design process. At best, they have a framework to which they can map their own process. Faculty teaching Sophomore Engineering Clinic in the past had observed that students had difficulty successfully navigating the design process[13,14]. While students were successful in analyzing a final truss design and building artifacts, there was little evidence of a well thought-out design process. For example, many teams tried to maximize the weight that a crane they were designing could lift—regardless of cost—despite being told their grade would be determined based largely on strength to cost ratio. These teams are not considering their criteria. Also, many teams did not appear to perform any calculations when choosing between various options, apparently submitting to the will of the most forceful personality in the group. These teams waited until after their decision to perform analyses. The open-ended and ill-posed nature of design, coupled with the students’ comfort and expertise with well-posed analytical problems, made it difficult for the faculty to teach, and the students to grasp, the process of design.

The perceived shortcomings of previous Sophomore Engineering Clinic offerings, combined with a review of design literature recently published by Dym, *et al*.[4] and an earlier text published by Dym[8], inspired the authors to synthesize and, importantly, explicitly state a model for design. Once a model for design was explicitly stated, the opportunity to improve the design content in SEC I became apparent. A fundamental change was a goal of developing designers with insight into the various kinds of knowledge and thinking that design entails. The hypothesis is that this insight helps the students to navigate the complex design process.

Two specific aspects of design thinking have directly informed recent modifications to SEC I. First is the concept that effective design teams are adept at alternating between distinct phases of convergent and divergent thinking. Dym, *et al.*, discuss two distinct types of questions and types of thinking: convergent and divergent[4]. In convergent thinking, the "questioner attempts to converge on, and reveal 'facts.'" In divergent thinking, the "questioner intends to diverge from facts to the possibilities that can be created from them." Convergent questions deal with knowledge, while divergent questions deal with concepts. Dym, *et al.*, then describe design thinking as "a series of continuous transformations from the concept domain to the knowledge domain." [4]

In the assignments for written deliverables for the design projects in SEC I, students are asked to discuss which of their design activities are convergent thinking and which are divergent thinking. The authors feel that providing the students with specific language to describe the design process allows the students to better grasp design concepts. Since transitioning from convergent thinking to divergent thinking is an essential aspect of real-world design processes, a strong understanding of these concepts is essential to the students becoming effective designers.

The second important design concept is the taxonomy of mechanical design problems originally presented by Dixon, *et al.* and summarized by Dym[8]. Dixon defined 7 states of knowledge that are possible throughout a design process. These knowledge states are listed in Table 3. Complexity of design problems (not necessarily the difficulty of design problems) is quantified by the difference between the initial state of knowledge and the final state of knowledge, which must be lower on the table than the starting state. For example, parametric design starts with knowledge of artifact type and leads to determination of all the parameters to completely define a specific artifact instance. This taxonomy was specifically developed for mechanical design. However, the authors argue that the basic concept can be extended to include design of processes as well. For students to have the best chance to improve their design skills in a logical and rational manner, it is important that a design project have the appropriate degree of complexity.

Table 3. States of Knowledge in Dixon's Taxonomy

Perceived Need
Function
Physical Phenomena
Embodiment (or Concept)
Artifact Type
Artifact Instance
Feasibility

Sophomore Engineering Clinic I and II

SEC I and SEC II are a two-semester sequence of courses that has been developed by faculty members from the College of Engineering and the College of Communication at Rowan University. All of the nominally 120 students from the four engineering disciplines offered at Rowan (ChE, CEE, ECE and ME) take Sophomore Engineering Clinic each semester. The courses include two hour-and-fifteen minute communication classes (writing in the fall, public speaking in the spring) with approximately 20 students per class, as well as one two-hours-and-thirty minute lab period each week. The clinic sequence is consistent with the growing national trend of integrating design into the early years of the curriculum[15-17]. The main goals are to develop communication and design skills, while continuing to foster real-world skills that are central to the engineering clinic series. Since a significant aspect of the real-world design process involves communication with customers and team members, an integrated course in design and communication makes pedagogical sense and has been adopted at other programs as well[18-20].

In the fall semester (SEC I), the students are split into two different lab sections, each with approximately 60 students. Student teams work on a four-week rocket design project[14], followed by a ten-week crane design project[13]. In the spring semester (SEC II), all 120 students are in a single design lab section, but are allowed to choose between two distinct projects. In 2006, one project was an electro-mechanical based project, while for the second project, student teams were tasked with designing improvements to the operation or systems of buildings on campus, with the goal of reducing greenhouse gas emissions that result from their operation[21]. A schematic diagram illustrating the content of the two-course sequence is shown in Figure 1. For this paper, the experience of students who chose the greenhouse gas reduction project in SEC II will be discussed because this project has been described in detail in the literature and most CEE students chose this project. Brief descriptions of the three projects are given below.

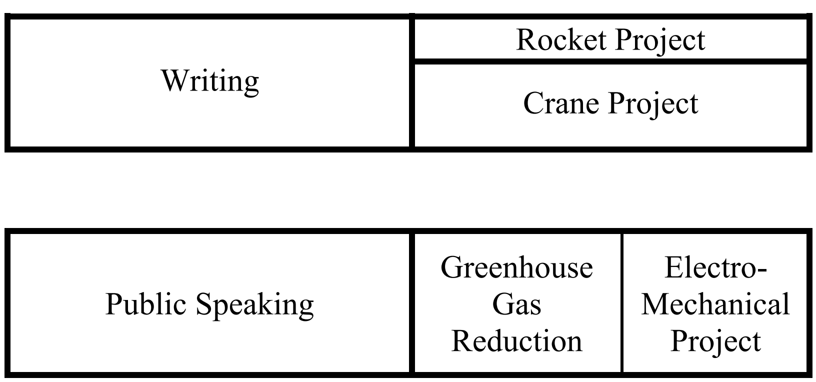

Figure 1. Schematic figure of topics for Sophomore Clinic sequence.

The first design project in SEC I is the bottle rocket project. In the bottle rocket project, students use 0.25 inch thick foam board, duct tape, a 2 liter soda bottle, modeling clay and water to design rockets that can be launched from a nozzle by using pressurized air. This concept has been used at other universities to teach core engineering principles[22], and NASA has proposed standards and lesson plans to use for grade 5-12 students[23]. The rocket project was originally run at Rowan as a one-lab period ice-breaker, which was not included in the students' grades. However, in 2005 this was expanded to a four-week project as part of the changes in SEC I. In the current incarnation, student teams design rockets in the first lab period, limited only by the materials and set air pressure, and are charged with designing a rocket that can fly as far as possible. In the second lab period, students are given a new, but highly constrained design challenge, and have three weeks to develop their designs. Student teams are asked to decide on a single family of wings (their choice) that is characterized by a single parameter—for example, triangular wings with a fixed aspect ratio, but variable size. The teams are limited to using exactly three wings belonging to the chosen family, mounted 120^{o} apart, and placing the modeling clay in a mass at the front of the bottle. A schematic figure of a rocket is shown in Figure 2. By varying the single parameter to describe the wing, the mass of clay, and the mass of water put in the rocket, students have a three-dimensional design space. Students use experimental data from tests, as well as basic physical models (the so-called rocket equation to predict the impulse given to the rocket, particle dynamics to model flight path, etc.) to converge on their optimized design.

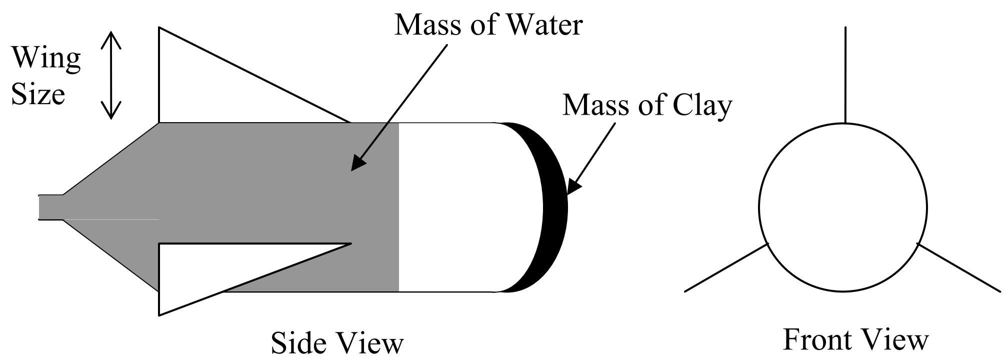

Figure 2. Schematic figure of bottle rocket with three parameters identified.

The main point of this project is to provide a simple design experience that allows an emphasis on convergent thinking. At the start of the second week, the rocket design is known except for the three parameters (wing size, mass of water, and mass of clay). This is the *artifact type* in Dixon's taxonomy. These three parameters are determined during the design process, allowing the *artifact instance* to be known and the final rocket to be built. The process of moving from *artifact type* to *artifact instance* is *parametric design*. After the final launch, students are led in a group discussion about how some wing families fundamentally led to better distances than others. In real design problems, this leads to new cycles of diverging-converging thought. Students are also asked for other ideas for propelling soda bottles, to suggest that divergent thinking can occur at earlier stages in the design process. The students are graded on this project entirely based on individual reports they write about the design process.

The second project is the crane or "Hoistinator" project. The crane project had been run as a thirteen-week project as part of SEC I for several years at Rowan University. The original version of the project was described by Constans, *et al.*[24]. In 2005, the current version was introduced[13]. Now, student teams have ten weeks to design and construct a truss made of aluminum and plastic bars that the students attach to an existing I-beam. A schematic figure of a truss is shown in Figure 3. A three-horsepower motor, a cable, and a series of pulleys are used to lift weights. Student teams are allowed three chances to lift weights, ranging from 280 to 1400 pounds. The greatest weight that is successfully lifted is counted. The students are graded based on an explicit performance equation that is varied slightly each year but is largely driven by strength to cost ratio.

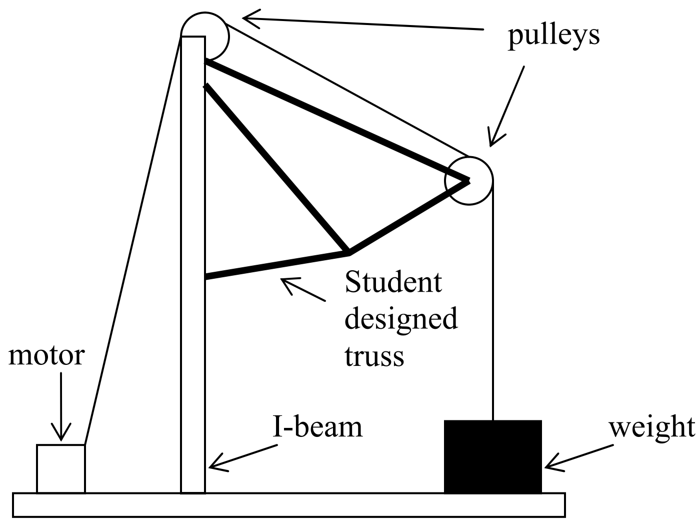

Figure 3. Schematic figure of a crane.

For this project, the initial state of knowledge is that their solution will be a truss, which is the *embodiment* or *concept* in Dixon's taxonomy. Like the bottle rocket project, the final state of knowledge is the *artifact instance*. This project is more complex than the bottle rocket, as the state of knowledge moves two steps, rather than one. In a more concrete sense, the number and connectivity of elements as well as location of nodes must be determined before member material and cross sections can be specified. The students turn in two progress reports as well as a final report. In addition to the writing, 20% of the students' grades are based on the performance ratio of their truss.

The third project that students are given is the greenhouse gas reduction project[21]. As run in 2005 and 2006, student teams are assigned to investigate one of three aspects of a specific building on campus: the heating, ventilation and air-conditioning system (HVAC); the electrical system; or the potential for a roof-mounted photovoltaic system. The objective of each team is to design cost-effective improvements to the building systems or operation that reduce the amount of greenhouse gases that are released as a result of operation of their building. In 2004, student teams were charged with investigating all three aspects of their building. The scope of this project was reduced to make a more reasonable workload for the students.

For this project, the initial state of knowledge is the *function* of the design, *e.g.*, reduce the electricity used by a given building. The desired final state of knowledge is *artifact* *instance*, *e.g.*, replace 60 T-12 bulbs with T-8 bulbs in the first floor hallway. To develop an appropriate design, students must determine how the building operates, what data must be collected, where opportunities for improvement in the building are, and which commercially available products might be helpful. Finally, the information must be synthesized to allow the students (and, ultimately facilities management) to evaluate which of their suggestions are practical. Student teams make two presentations throughout the semester, as well as hand in two drafts of their final report. These deliverables account for 20% of the students' grades in SEC II.

Integration of Communication

A significant portion of the students' grades depends on communication deliverables in both SEC I and II. A list of the communication deliverables for SEC I and SEC II, as well as the weighting on the final grade, are given in Tables 4 and 5, respectively. Deliverables that are specifically related to the design project are denoted by bold font.

In SEC I, each of the reports that are specifically related to the design project are graded by three faculty members: one communication faculty and two engineering faculty. In SEC II, student teams give two presentations and write two reports that are specifically related to their designs. The presentations are graded by three engineering faculty, and the design reports are graded by a single engineering faculty, with checks by a second faculty member to ensure consistent grading standards between faculty.

Table 4. Sophomore Clinic I Communication Deliverables[†]

Deliverable	% of grade
Rocket report (individual)	**10**
White paper (individual)	15
Crane progress report 1 (team)	**10**
Crane progress report 2 (individual)	**10**
Final report (team)	**20**
Resume (individual)	5

Table 5. Sophomore Clinic II Communication Deliverables[†]

Deliverable	% of grade
Speech of introduction (individual)	P/F
Informative speech (individual)	10
Technical speech (individual)	20
Persuasive speech (individual)	25
Design Reports (team)	**10**
Design Presentations (team)	**10**

[†] Bold denotes deliverables that are related directly to design project.

Integration of technical concepts in design projects

Project-based learning courses provide the opportunity to reinforce core sophomore level curriculum topics, introduce topics that will be covered in greater detail in future courses, and expose students to subject matter that they would not otherwise be exposed to. Tables 6 – 8 list chapters in the texts used to teach Statics, Dynamics and Solid Mechanics courses, respectively, at Rowan in the 2005-2006 academic year. The exception to this is buckling, which is shaded. Due to the limited amount of time available in a two-credit course, buckling, denoted by the shaded cells, is shifted to a steel design course, instead of being taught in Solid Mechanics. Subjects that are covered by each of the three design projects are identified by an "x" in column 1, 2 or 3, for the rocket, crane, and greenhouse gas reduction project, respectively. Figure 9 lists a number of subjects that are covered by one or more of the projects that are not normally part of the CEE curriculum. Based on these tables, it is clear that a significant number of technical topics can be covered in two semesters of design projects. Since none of the Mechanics courses are pre-requisites for SEC I or SEC II, any specific technical subjects needed are covered by specific lectures.

Table 6. Statics

	Project		
1	2	3	Subject
			Vectors
X	X		Forces
	X		Moments
	X		Equilibrium
	X		Trusses
X			Centers of Mass
			Friction

Table 7. Dynamics

	Project		
1	2	3	Subject
X			Motion of a Point
X	X		Force, Mass, Acceleration
			Planar Kinematics
			Planar Dynamics
X			Energy Methods

Table 8. Solid Mechanics

	Project		
1	2	3	Subject
	X		Stress and Strain
	X		Axial Deformation
			Torsion
		X	Equilibrium of Beams
		X	Stresses in Beams
		X	Deflection of Beams
	X		Buckling

Table 9. Additional Topics

Project 1	Project 2	Project 3	Subject
X			Ideal Gas Law
	X	X	Circuit Analysis
		X	Heat Transfer
X		X	Mass Balance
		X	Thermodynamics
X			Flow through Nozzles
		X	Building Codes
		X	Building Systems
		X	Engineering Drawings

Discussion

The engineering clinics sequence at Rowan University was developed to better prepare engineering graduates for what has since been described as the "Flat World." SEC I and II are especially charged with developing design and communication skills. Recently, changes were made to the design aspect of SEC I and II. Specifically, divergent and convergent thinking are explicitly discussed and the design projects were modified to allow a series of three increasingly complex design projects. The previously existing framework of concurrent design and communication education set in a team-based, multidisciplinary PBL environment was maintained.

Since transitioning between divergent and convergent thinking is an essential aspect of design, helping students to distinguish between these types of thought is a significant aspect of teaching design. The complexity of the design projects may be thought of as increasing throughout the three project sequence in three distinct ways. First, the duration of the projects increases from 4 weeks, to 10 weeks, to 14 weeks. Second, the number of convergent-divergent thought cycles increases. Finally, the projects increase in complexity as measured by the difference between initial and final states of knowledge in Dixon's taxonomy. The authors found these metrics for complexity useful when expanding the rocket project, re-defining the scope of the crane project, and re-evaluating the scope of the greenhouse gas reduction project. These metrics will also be useful when determining the scope of future projects for SEC I and SEC II. The two-pronged approach to teaching design has greatly helped the faculty present design in a manner that allows students to develop their design skills in a more rational manner.

Assessment of Clinics

Assessing the objectives of the engineering clinic sequence is difficult[25]. The clinics have been part of the Rowan engineering experience from inception, and all engineering students take the clinics, so there are no control data available. However, there is evidence that suggests the engineering clinics in general, and the recent changes to Sophomore Engineering Clinic I in particular, are effective ways to educate engineers.

Hartman and Hartman have been performing a study of the retention rates in the College of Engineering at Rowan University[26]. In general, they have found that retention rates for

Rowan engineering students are relatively high. Furthermore, they find that women have the same or higher retention rates than men. Hartman and Hartman contrast these data with other studies, which have shown significant gender gaps in retention rates. While improved retention rates for females was not necessarily an explicit goal when developing the clinic sequence, it is a commonly espoused benefit of PBL.

A potential weakness of PBL is that time and resources that are taken away from traditional blackboard classes might lead to a decrease in the analytical capability of engineering graduates. However, the authors feel that PBL is an effective way to teach engineering, and well worth the lost blackboard time. First, engineers in general tend to have analytical skills sufficient to meet the needs of industry. Dym, *et al.*, argue that analytical skill is the strength of engineering curriculum[4]. Todd, *et al.*, cite a list of 16 weaknesses in recent engineering graduates that were perceived by employers[3]. None of these mention weak analytical skills. Indeed, one cited weakness was that recent graduates were "all wanting to be analysts." There are relatively few, if any, instances of employers criticizing recent graduates' analytical skills, as reported in the recent literature. This can be contrasted with numerous examples of employers citing the need for improved "real world" skills, which led to the changes made in the ABET 2000 criteria[2]. Second, recent engineering graduates from Rowan University appear to have sufficient analytical skills. Rowan student have had reasonable success passing the fundamentals of engineering exam, despite the credit hours devoted to PBL in the curriculum. In the past four years, approximately 80% of the graduating CEE students have taken the exam, with 85% of these students passing the exam. These rates appear to be comparable to national averages. Informal discussions with the industrial advisory board for the CEE program suggest that employers are pleased with the analytical skills of recent Rowan graduates.

Assessment of student course evaluations of SEC I, as well as student design deliverables in SEC I and II, suggest that the current model for teaching design is effective. The revised model was first run in the 2005-2006 academic year. Results from student course evaluations in 2005 SEC I compared favorably to the 2004 SEC I course evaluations. For example, to the statement that "this course assisted me in developing multidisciplinary engineering design skills," student response (on a scale of 1 = strong disagree to 5 = strong agree) improved from a 3.70 in 2004 to a 4.06 in 2005. Results of the actual trusses, as based on the 2004 criteria, improved from a mean score of 8.63 in 2004 to a mean score of 14.99 in 2005, despite the 2005 cohort having ten instead of thirteen weeks to design, and not designing for the exact 2004 criteria. Finally, improvements were shown to carry through to SEC II. Final reports from SEC II in 2005 and SEC II in 2006 were assessed using rubrics that have been previously published[27]. These rubrics were designed to assess work with respect to specific learning outcomes, including the ABET A-K objectives. The resulting data showed that the 2006 cohort's final reports were better in every respect than the 2005 cohort, despite the fact that SEC II was largely unchanged from 2005 to 2006. These assessments are described in detail by Dahm, *et al.*[28].

Ongoing Challenges

One of the main challenges in developing design projects for Sophomore Engineering Clinic I and II is to have projects that are truly multi-disciplinary. While it is not necessary (and perhaps not possible) to choose a project that all students are deeply interested in, it is desirable to have a project to which students from all disciplines are able to contribute. As a result, not all projects that will be run will have the strong ties to specific course material that the crane project has. For example, the greenhouse gas reduction project does not have the strong and obvious ties to mechanics that the crane project has. Instead, the specific subject matter that is involved in this project is tied more closely to building systems, and more fundamental concepts in thermodynamics and circuits, which are not explicitly covered in the CEE curriculum. Learning these additional skills, and learning how to learn these additional skills, are also valuable benefits of PBL. At least one CEE student found an internship with an engineering company using skills honed specifically during the greenhouse gas reduction project.

One temptation that PBL presents is to move specific technical aspects of the curriculum into the projects. The authors feel that the objective for developing projects must be to find appropriate challenges that all disciplines can contribute to, while meeting the pedagogical requirements of teaching design. By itself, this is a difficult challenge. Therefore, while content specific to a project can, and should, be taught within the context of PBL, it is essential that the design projects are not given any additional curriculum charges beyond design and communication.

The format of SEC II, where two different design projects run concurrently, gives more flexibility to accommodate the backgrounds of students from the four different majors. However, there is a cost associated with this approach because the design project cannot be discussed in the communication classes in SEC II to the extent that the projects are discussed in SEC I. Furthermore, the nature of public speaking makes it difficult to incorporate the design project into the communication deliverables. While it is acceptable for an entire class of twenty students to turn in a written report on the same topic, an entire class of twenty students giving presentations to the class on the same topic is not acceptable. The effect of these factors can be observed by studying the communication deliverables listed in Tables 4 and 5. Fully 50% of a student's grade in SEC I depends on communication deliverables that are directly tied to the design project, whereas only 20% of a student's grade in SEC II depends on communication deliverables that are directly tied to the design project. One of the goals of the faculty is to increase the degree of integration between the design project and SEC II.

Summary and Conclusions

The engineering clinics are an essential part of the Rowan University engineering curriculum. These courses were designed to address aspects of real world engineering that has since been included in the ABET 2000 criteria, and discussed in Freidman's popular *The World is Flat*. The clinics feature team-based multidisciplinary engineering projects that become increasingly "real world" as students progress through the four-year curriculum.

Sophomore Engineering Clinic I and II are an essential part of the sophomore curriculum for CEE students at Rowan University. These courses integrate concepts from communication, design, and mechanics. Design is both an essential and difficult subject to teach, and recent changes to SEC I have improved the design content in the course.

While it is perhaps true that creativity cannot be taught, the faculty are striving to develop an appropriate learning environment that helps ensure that students are not overwhelmed by the complexity of open-ended problems, or by their well-honed analytical abilities. The authors have found two design concepts to be especially useful in this regard. First, divergent and convergent thinking is specifically addressed to help students distinguish these two distinct aspects of the design process. Second, the students undertake three increasingly complex projects throughout the year. This approach has been shown to be successful in improving student designs and their perception of SEC I, as well as having lasting effect on various ABET A-K learning objectives, as demonstrated by assessment of SEC II deliverables.

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