2006-959: THE ROLE OF THE ENGINEERING CLINIC IN PROMOTING AN AGILE ECE LEARNING ENVIRONMENT

Peter Jansson, Rowan University

Ying Tang, Rowan University

Ravi Ramachandran, Rowan University

John Schmalzel, Rowan University

Shreekanth Mandayam, Rowan University

Robert Krchnavek, Rowan University

Linda Head, Rowan University

Robi Polikar, Rowan University

Raul Ordonez, University of Dayton

The Role of the Engineering Clinic in Promoting an Agile ECE Learning Environment

Abstract

To keep up with rapidly advancing technology, numerous innovations to the ECE curriculum, learning methods and pedagogy have been tested, implemented and envisioned. It is safe to say that no single approach will work for all of the diverse ECE technologies and every type of learner. However, a few key innovations appear useful in keeping undergraduate students motivated to learn, resilient to technology evolution and oriented amidst the overload of new information and ECE applications. Engineering clinics, similar to their medical clinic counterparts, provide project-based experiences within the core of an ECE education that enable transformation of the entire curriculum toward an outcomes-oriented, student centered, total quality environment. Clinics and project based learning approaches build skills within the individuals that give them confidence and motivation to continuously self-learn and adapt as the technologies around them give way to new, more effective paradigms. Perhaps more importantly engineering clinic experiences provide numerous opportunities for students to experience the holism of true engineering problem solving approaches and ranges of potential technology solutions. This paper reviews many of the innovations that will enable ECE education to become more effective in the midst of our present plethora of information and technology. Specific benefits from published and unpublished findings from engineering clinic and project-based learning experiences in actual use (Olin, Harvey Mudd, FIT, Drexel, Rose-Holman and Rowan) are summarized and discussed. This paper concludes that creating agile learning environments to graduate engineers that can be rapidly productive in the professional and research worlds is at least enhanced by some degree of clinic and/or project based learning experiences in the ECE curriculum.

Introduction

In the guest editorial for the recent (2003) special issue of the IEEE Transactions on Education devoted to providing visions for the undergraduate ECE curriculum a striking quote is found: “There is no one common vision of ECE education” [1]. It is clear from review of the many fascinating visions presented in that important issue that this was an understatement. The editorial and manuscripts clearly show, however, that a strong convergence exists on defining the challenges facing ECE educators, namely: rapidly advancing technology on numerous fronts (BioX, NanoX, InfoX, Energy and the Environment) [2,3], increasing specialization within the curriculum while problems are growing increasingly multidisciplinary [3,4], an increasing need to densify ECE curriculum content to cover the widening range of important emerging topics and knowledge [4,5], and the need to employ some of these technology innovations and real world content to increase the efficiency with which we educate today's learners [4,6,7]. While we all can agree there is no panacea for the solution of these disparate issues, increasingly institutions are revising their curricula or creating new approaches in attempts to keep current [5,8-13]. Continuous improvement of curricula is surely a desired outcome sought by ABET Engineering Criteria 2000 [14] and it is hopeful that such revision is proactive and anticipatory of technology change [3]. But it has been clearly observed elsewhere that engineering curricula tend to have "tremendous inertia" [5] and that the innovations that are often adopted tend to be incremental as opposed to transformational in nature [15]. This internal resistance must then be overcome by the structure of an ECE program if it is to remain agile, adaptive and responsive to rapid knowledge and hardware obsolescence. Curricula which are infused with project-based and / or engineering clinic experiences by their very nature remain more relevant to contemporary problems and technology solutions than strictly didactic instruction or contrived laboratory problem approaches. Not surprising, students' motivation increases in these settings and their confidence in problem definition, option development and solution grows. As with active learning approaches, the instructor role changes in clinic and project courses from one of talking head to facilitator, guide and resource [2,6]. The structure of an engineering clinic based ECE program is one that requires students to operate at higher orders of abstraction earlier in their education while still requiring a concrete "hands-on, minds-on" engineering solution to the real world problem at hand. These transformative changes are discussed as desirable in most of the papers of future visions of ECE curriculum [1-5] but are actually being provided today in programs that incorporate clinics or project based learning in a significant way [8-13]. This paper will review the need for continuously responsive curricula and successful attempts to revise it described in the literature, provide a brief overview of the methods widely believed to be most effective in engaging and educating today's engineering students, and close with a discussion of how various programs (large and small) across the U.S. are using project or clinic based strategies as a pedagogical structure to successfully satisfy the pressing need to remain relevant to real world issues, technology and challenges (agile curriculum) while implementing active learning methods to motivate students and increase their agility as continuous learners.

Changing Curriculum for a Changing ECE Environment

Motivations to change curriculum within ECE stem from many sources: obsolescence, relevance, flexibility, emerging technology, need for more interdisciplinary studies, inadequate student preparation for professional endeavors, and ABET to name but a few [2,5]. All these motivations can be summed in the goal of many ECE programs such as Rowan's "To create effective engineers" [16]. As times and technology change, the curriculum must evolve with it, ideally anticipating this change, or the result is students are ill-prepared to shoulder the responsibilities and expectations of the graduate engineer in our market based society. While it is clear from our brief and recent history that what is taught in our field will be directly relevant to the dominating technologies in the market, there will also remain a necessity to teach core fundamentals and provide a true educational experience which is broad enough to produce well rounded, responsible and participating citizens [3]. In its infancy, electrical engineering was dominated by commercial concerns for expanding reliable electrical grids across the industrializing world, and much of the education was focused on power systems. In today's curriculum, most undergraduate institutions do not have any requirements that students learn power system fundamentals (generation, transmission or distribution) as such topics are left far behind when we ushered in the high-tech information age. Relevance has placed communications and other data and signal processing courses into the positions of requirements for any current graduate of ECE. Many schools have now migrated away from independent EE and CE curricula to a single ECE, like Carnegie Mellon to "explicitly recognize evolutionary trends in the discipline and industry to emphasize the commonality across EE and CE, and not the differences" [5]. As electric power issues such as reliability, distributed generation, large scale renewable energy technologies (wind, solar, etc.), electric energy storage, and power electronics technology integration become more important in the market place, this ECE integration which has dominated today's information centric paradigm may prove inferior to some new curriculum elements that better prepare our graduate engineers to be effective. Others have observed that only a handful of universities have significantly changed their undergraduate curricula during the past 30 years, the same period during which the field of electrical engineering has seen its greatest shake-ups [17]. We have learned from our brief history, however, that we can evolve if we so choose and remain relevant. We have also learned that change requires massive effort to overcome inertia and it is ultimately successful technology (the marketplace) that drives the changes to curriculum in agile ECE programs.

Challenges of Teaching Engineering Students in the 21st Century

Today's student is the most technologically immersed of any previous generation. They are efficient at text messaging, web surfing, emailing and simultaneously downloading music from their broad-band connected personal digital assistant and capable of integrating systems and software packages that their professors have often had little time to be exposed to themselves. The challenges facing the instructor are staggering. Fortunately, these same systems can be used by teachers to increase course relevance, interest, content [4] and can serve as exemplars of the benefits ECEs bring to modern society. The students entering an ECE program come with the high hopes that they will be able to become a master of all these neat technologies by the time they leave. It is that hope and desire that can be channeled through active learning into course pedagogical changes that help students retain the most relevant components of their educational experience. Unfortunately, today's students also come with some of the record lowest preparations in mathematics, science and reading [5] often placing greater responsibility on the ECE instructor to provide remedial aid. It is widely agreed that students read only what they believe is required from the texts to solve homework or other assignments and do not use that learning aid in the manner for which it was intended. We have learned from many studies that students retain only a tiny fraction of what they hear, a larger but still small fraction of what they see, and a more substantial fraction of what they actually do with their hands and minds in an active learning exercise [3,6,18]. Yet, as late as today, it is widely known that the "talking head" and blackboard (or whiteboard) approach is still in widespread use among our peers. While we know this is the surest way to lose a group of teenagers, the practice somehow survives. Incorporating active learning activities such as learning moments, one-minute quizzes, group problem solving and the like will engage each student in a way that requires they do more than look and listen. They must speak, write, think, and otherwise actively engage in their own learning during the lecture period and/or laboratory. Traditionally we have considered laboratories as the appropriate time for students to demonstrate that what they heard and saw can now be applied and directed to their minds and hands through the designed, structured and well-thought out exercise we have embodied in the lab. Unfortunately, if the student was not fully connected to the lecture portion of the course, their performance in lab will only confuse and not reinforce the learning outcomes intended. Our experience at Rowan where students have participated since their freshman year in project based, clinic experiences is that the laboratory challenge must be significant, relevant to the concepts being taught and real-world in nature or it runs the risk of not seriously engaging the students. Whatever active learning methods you employ, students must be engaged during the lecture period if we are to have hope that the content we have to share during that period will be absorbed and understood.

An Agile Curricular Structure: Project-Based / Engineering Clinics

Perhaps one of the most significant innovations in engineering education in the past decade has been the creation of a more agile curricular structure through the replacement of some number of "taught" modules or courses with project-based or engineering clinic experiences. While not unique to Rowan, where all of these authors presently teach or recently have taught, it was a unique component of the vision which established this engineering college in 1996. Numerous schools have some varying degrees of project-based or clinic experience requirements. Some from their initial curriculum design (Olin and Rowan), and many through curricular innovation (Harvey Mudd, Drexel and Rose-Holman) to name some noteworthy leaders. More than any other innovations in curriculum that we have reviewed, the clinic or project-based educational approach merges the needs to keep the curriculum connected and relevant to changing technology, contemporary research and industrial problems with the needs of today's learners to be engaged in active learning exercises. The clinic experiences engage students early on in the higher order and integrative thinking that we hope they have experienced in their undergraduate education. Table 1 below highlights some of the key clinic and/or project based ECE/EE curricula described in the literature and on the college websites.

Table 1 -Engineering Clinic or Project-Based Modules in EE/ECE Curricula

College/University*[Ref]** ***Degree(s) granted – credits	***Number of Courses***	***Credits % of total***	***Course Name / Year(s) Offered for the Degree(s) Requirements***
Drexel University [9,11] BSEE, BSCE – 181 Credits	~6	20 (11%)	Engineering Design Lab [12 cr - Freshman] Senior Design [8 cr - Sr]
Harvey Mudd College [13,19] BSE – 128 Credits	4	12 (9%)	Frosh Project [3 cr - Freshman] Clinic [3 cr /Jr, 6 cr /Sr]
Olin College [12,20] BSECE – 128 Credits	>7	27 (21%)	Engineering Design Nature [~3 cr - Freshman] Eng. Des. / Collab. Des. [4 cr each - Soph] Capstone Design Projects [16 cr Senior] Plus: Unifying Projects for Each Two Subjects
Rose-Hulman Inst Tech [4,21] BSEE, BSCE – 194 credits	5	20 (10%)	Analysis & Design of Eng. Sys. [4 cr. - Soph] Principles of Design [4 cr - Jr] Engineering Design I/II [12 cr - Senior]
Rowan University [22,23] BSECE – 128 Credits	12	24 (19%)	Freshman Clinic I/II [2 cr each] Sophomore Clinic I/II [4 cr each] Junior/Senior Clinic [4 cr /Jr, 4 cr /Sr] Eng. Clinic Consultant [2 cr /Jr & Sr]

From a high of 27 credits in a 128 credit hour curriculum (21%) to a low of 12 (9%) for those institutions above with clinic (project) based courses, it is clear that there is a growing commitment to this approach. Olin, perhaps the most aggressive, is reporting that between 20% and 60% of all student time in courses is devoted to project based experiences. Both Olin and Rowan appear to be the only institutions offering a BSECE degree that includes clinic experience in all levels of the undergraduate curriculum (Freshman through Senior year). A closer look at each of the programs for the institutions above follows:

The cooperative program at Drexel is well known as is the 5-year curriculum encompassing a total of approximately 180 credit hours. The senior (capstone) design element of the curriculum has been part of the degree program for a long period of time.

The innovation of introducing the Frosh project has been reported to be a significant retention tool for engineering students, including female and minorities [11]. This course is credited with that success due to the early introduction of extensive hands-on learning. The professors at Drexel believe that coupling this experiential learning with engineering design, and higher use of technology has increased student motivation for learning the mathematical and scientific foundations of engineering. The introduction of this course began in 1992 with 140 students participating. Since that time, through the Gateway Coalition of participating institutions, freshman year enrollment in this freshman design experience grew to nearly 3900 in 2002. Even though it is only a 3 credit course in a curriculum of 181, the analysis indicates that this minor curricular change increased graduation rates over 15% overall, and higher (20-25%) in women and minorities [11].

Harvey Mudd has the longest history of incorporating clinic experiences into the curriculum. Since the mid 1960s, over 1400 undergraduate engineering students have taken a series of required courses in which junior, senior and master's students work on interdisciplinary teams to complete design and research projects that have been proposed by industry. The founders built their engineering clinic model on the "clinical" experience at medical school (i.e., students learn the practice of medicine by working with real patients and real diseases under the supervision of an attending physician). At Harvey Mudd, the engineering clinic provides real project assignments that expose students to the art and practice of engineering. The real goal of the engineering profession is to solve real problems for real clients. At Harvey Mudd students have worked on over 800 projects, from over 200 companies [19]. Project areas include a host of multidisciplinary challenges (electrical, environmental, mechanical engineering as well as biomedical, chemical and computer engineering). Though the range of projects can be wide, all projects must have a well-defined goal with a scope that enables successful completion of key goals within the semester. The engineering clinic is a hallmark of the Harvey Mudd College curriculum. The institution considers it one of its most successful innovations in engineering education [19]. It was the inspiration for the development of the Rowan University model and has been replicated at other institutions. Harvey Mudd continues to rank second overall and third in EE/ECE specialties based upon the Engineering Dean's reputation assessments reported by the US News and World Report.

The curriculum at the Franklin W. Olin College of Engineering in Massachusetts is one of the newest on the scene for the BSECE degree. The goal of the curriculum is to make sure that each student is taught their courses in integrated blocks of dual subject areas with a strong project element. It is the vision of the structure that as students move further through the curriculum more and more of their education can be accomplished by projects as coursework becomes a diminishing component as their foundations are strongly laid [12]. The projects in the early years are intended to provide unity between the two subject matters (which can often contain theory and mathematics) with the real world of everyday technology and problems that need solving. The foundation years (Freshman and Sophomore) culminate in a large interdisciplinary design project attacked by student teams. The curriculum focuses Junior engineering students toward specialization and leads to what is termed "realization" in the Senior year capstone design project. It is the intent of the Senior project to provide as close to a real world experience as practical within the academic environment by taking advantage of a corporate project or research project challenge. The Olin innovation appears to take advantage of the benefits of the early (Freshman) design experience pioneered by Drexel and the Gateway Coalition and supplemented with Harvey Mudd type clinic experiences in the Sophomore and Senior levels. The linking of two subjects with a unifying project is perhaps unmatched anywhere else in a BSECE or BSEE curriculum and represents a significant innovation.

The curriculum at Rose-Hulman is covered in four years of study. During the freshman year the foundations of engineering (sciences and mathematics) are laid, in the sophomore year the engineering sciences that provide key technical knowledge for all disciplines of engineering are taught with the introduction of the first project based experience -Analysis & Design of Engineering Systems [4 credits in their 194 credit experience] to all engineering majors [4]. During the junior year, the students concentrate on topics in electrical engineering (dealing "with movement of either energy or information from one place to another via a vague “substance” called electricity”[21]). to provide a breadth across the whole field of ECE. They also enroll in Principles of Design (4 credits) which is another project based experience. Each student is then exposed to a major team-based design project (Engineering Design I/II) in their senior and final year consisting of 12 credits form their curriculum. In total, over 10% of the engineering students’ academic courses have been specifically project-based or focused. Rose-Hulman continues to rank first overall and first in EE/ECE specialties based upon the Engineering Dean’s reputation assessments reported by the US News and World Report.

Rowan University’s engineering programs are the direct result of the endowment that Henry and Betty Rowan made in 1992. The Rowan engineering challenge was the creation of quality programs to develop engineers who could compete in a progressively global economy. Four engineering disciplines (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical) were started in 1995; the first undergraduate class enrolled in 1996; the first engineering building was completed in 1998; and the first graduates left Rowan in 2000. Accreditation under ABET [14] Criteria 2000 was granted to all four engineering programs in 2001. The opportunity to create new engineering programs is rare—most educators spend their careers making the best of incremental curriculum innovation at established institutions. There are many well-known problems such as those cataloged by the ASEE report, “Engineering for a Changing World” [24]. It was clear that engineering education needed to do a much better job of demonstrating the relevance of materials taught and more actively involve students in the learning process so that they can *do*. However, it is a far different matter to transform engineering education to an outcomes-oriented, student-centered, total-quality environment.
This was the initial Rowan context at the start of the curriculum development effort. It was also clear that merely squeezing in a few new courses into a traditional curriculum would not solve the problems; the entire curriculum content and structure needed reexamination and reengineering. Serendipitously, ABET had just published Criteria 2000, which outlined a new process for evaluating programs. First, desired outcomes needed to be defined, then diagnostic measures taken in order to assess progress toward those desired outcomes**.** Only then should modifications to the process be made. This

process of continuous improvement defines a quality engineering education environment. The curriculum we developed from these motivations contains a combination of course, structure, and environmental elements. Furthermore, the structure of the ECE program presages the ability to adapt to continuing challenges such as the “future curriculum” challenge issued by NECEDHA and the IEEE Education Society. How can ECE education be retooled for the year 2013 so as to better prepare for the new challenges inherent in exploding technological developments and the pressing need to work at the intersections between disciplines? We are struck by the similarity to the original goals and objectives of the Rowan engineering programs. The remainder of the paper briefly reviews the curriculum development at Rowan and explores the unique mechanisms that support future agility within an ECE curriculum. The detail is provided so that this experience may facilitate curriculum innovation at other institutions.

The four engineering programs worked together to develop a unified set of goals for the college in response to the mission statement of developing a high-quality engineering program whose graduates would be ready for industry. Each program then augmented the college-wide goals with discipline-specific goals. The ECE program goals are summarized in Table 2. The overarching program goal is to create effective Electrical and Computer Engineers. Example assessment tools are also cited for each objective that supports the ECE program goal. The structure of the curriculum is shown in Figure 1. Many of the course titles imply content that is familiar in typical ECE programs; for example, Digital I is a first-course in logic design, and Network I is a first course in circuit analysis. General Education courses are chosen to satisfy a broad range of topics, examples of which are Literature, Microeconomics (μEcon) and a Writing Intensive (WI) component. Electives are typically ECE courses; Technology Focus Electives are expected to be multidisciplinary engineering courses. The CS elective is usually chosen from Software Engineering, Operating Systems and Programming Languages. The core content of the curriculum includes both Electrical and Computer Engineering as a combined degree

Table 2. ECE Program Objectives.

Objective	ATTRIBUTES	ASSESSMENT
Cultivate capable communicators	• Writing skills • Oral skills • Multimedia skills	• Informal and formal work • Self-assessment • Seminar presentations
Develop agile technologists	• Tool (computer/equipment) users and tool makers • Adapts to & learns new technologies (life-long learning)	• Course work • Project work and scope • Employer feedback • Seminar presentations
Instill entrepreneurial spirit	• Entrepreneurial attitude • Understands business process • Calculated risk taking	• Employer (Employee) feedback Intrapreneurial • Business acumen • Scope/diversity of projects
Facilitate multidisciplinary discourse	• Work in multidisciplinary teams • Contribute to out-of-discipline design projects • Communication across disciplines	• Multidisciplinary design project work • Out-of-discipline evaluation
Sensitize to contemporary issues	• Professional issues • Ethics • Societal concerns • Impact of engineering decisions	• Total project scope • Interpretation and interaction • Professional societies • Outside activities
Impart essential ECE knowledge	• Breadth and depth in math, foundations, systems, computing • Aware of the state-of-the-art • Product design (function & form) • System design • ABET accreditable	• Exams (written, oral) • Project work • Employer feedback • ABET accreditation

FIRST YEAR

Freshman Engineering Clinic I	2	Freshman Engineering Clinic II	2
Composition I	3	Computer Science & Programming	4
Calculus I	4	Calculus II	4
Advanced College Chemistry I	4	Physics I	4
General Education I	3	General Education II	3
Total Units	**16**	Total Units	**17**

SECOND YEAR

Sophomore Engineering Clinic I w/ Composition II	4	Sophomore Engineering Clinic II w/ Public Speaking	4
Engineering Analysis I	4	Engineering Analysis II	4
Physics II	4	Statics	2
Network I	2	Dynamics	2
Network II	2	Digital I	2
		Electronics I	2
Total Units	**16**	Total Units	**16**

THIRD YEAR

Junior Engineering Clinic I	2	Junior Engineering Clinic II	2
Clinic Consultant	1	Clinic Consultant	1
Systems & Control I	3	Data Structures for Engineers	3
Engineering Electromagnetics I	2	Digital Signal Processing	3
Engineering Electromagnetics II	2	Communication	4
Digital II: Microprocessors	2	Electronics II: VLSI Design	3
General Education III (μEcon)	3		
Total Units	**15**	Total Units	**16**

FOURTH YEAR

Senior Engineering Clinic I	2	Senior Engineering Clinic II (WI)	2
Clinic Consultant	1	Clinic Consultant	1
Computer Arch. I: Introduction	2	Seminar: Engineering Frontiers	1
Computer Arch. II: Specialized	2	Elective	3
CS Elective	3	Technology Focus Elective	3
Elective	3	General Education IV	3
Technology Focus Elective	3	General Education V	3
Total Units	**16**	Total Units	**16**

Total Credits: 128

Figure 1: ELECTRICAL & COMPUTER ENGINEERING PROGRAM

All four engineering programs share an *Engineering Clinic* component, which was originally included as an upper-division course. This was at the suggestion of one of the members of the Rowan Advisory Board from Harvey Mudd where their Clinic includes the frosh project experience and the more commonly named *capstone*- or *senior-design* course in the final year. As we began to wrestle with our program goals and considered the potential inherent in the broader clinic concept, the possibilities suggested by a multidisciplinary team-based project environment prompted the transformation of the Engineering Clinic sequence into an eight-semester sequence of laboratory-based instruction that is a core component of all four programs. And we appropriated the philosophy of the Clinic as practiced in medical education: Medical (Engineering) students working on real patients (problems) in a real setting (lab) with real equipment under the watchful mentorship of an experienced physician (engineer).

Clinics provide the structure needed to deliver many of the hallmarks intended to define the Rowan engineering experience:

- Hands-on/Minds-on instruction
- Treatment of integrated topics
- Teamwork
- Effective communication
- Multidisciplinary experience
- Entrepreneurship

The Clinic sequence has several general themes dependent on level:

- Freshman Clinic I: Measurements and the culture of engineering
- Freshman Clinic II: Competitive assessment (reverse engineering)
- Sophomore Clinic I: Multidisciplinary design
- Sophomore Clinic II: Structured design project
- Junior Clinic I, II: Small system design projects
- Senior Clinic I & II: More complex system design project

The Freshman and Sophomore Clinics share some similarities to Introduction to Engineering courses found at many universities; however, we emphasize a multidisciplinary experience. Each course section rotates through laboratory instruction in all four disciplines. Greater detail of the Freshman and Sophomore Clinic experience can be found in numerous papers written by the instructors of those courses during the pas few years [22, 25-36]. Upper-division (junior and senior) Clinics are project driven, with multidisciplinary projects and industry sponsorship as objectives. Some Clinics include module-based instruction to cover additional discipline-specific topics, Rowan vision elements, and to provide project-related instruction. Examples of the Junior and Senior Clinic experiences have been reported elsewhere [37-39].

Instilling entrepreneurial spirit is an important goal of all the Rowan engineering programs. We have developed three elements to foster entrepreneurism in the Junior/Senior Clinic. There is a Rowan Engineering Venture Capital Fund [40, 41] that students can apply to if they believe they have a product concept that is novel based on market and patent surveys. Successful proposals may receive funding up to $2,500. A second mechanism is the creation of “microbusinesses” [42]. Students organize a company-like structure within the Clinic to provide engineering services at a cost to clients. Example services include mechanical design and fabrication, electronic circuit design and fabrication, software development, etc. A third venue for examining entrepreneurism is to bring in outside speakers who address important elements such as developing a business plan, the role of other professionals in a business, etc. The Clinics provide the key vehicle for achieving multidisciplinarity [43]. We seek to broaden participation in Clinic projects to include as many other disciplines as possible. ECE students are actively managed during their junior and senior years to ensure that they sign up for at least one Clinic project sponsored by a different discipline. Future plans call for expansion to include students from disciplines outside engineering such as Computer Science, Biochemistry, and Business, to name a few.

Another of the unique features of this program is “Engineering Clinic Consultant”. These one-credit courses occur in all four semesters of the junior and senior years. The Clinic Consultant was spawned by the College’s decision to reduce the total Junior and Senior Engineering Clinic credits from 12 to 8, returning four credits to each department. The ABET planning that we were simultaneously engaged in was fortuitous; we had been searching for ways to provide additional curriculum feedback mechanisms, particularly methods to feedforward as opposed to the normal feedback processes that are often the only methods available. Creation of the Clinic Consultant provided a novel means of correcting deficiencies identified in a previous course—students in a follow-on Clinic Consultant could be selectively targeted to ensure they received additional instruction in a deficient topic [44].

The Consultant course has a number of other objectives. One is to create opportunities for students to experience a consultant experience. This requires that students identify and market their skills to a potential client. The client can be internal, such as another discipline's clinic project, or it can be an external business or individual with an engineering need. This component of the Clinic Consultant course directly supports the objective of providing students with entrepreneurial experience. Another role of Clinic Consultant is to provide juniors with the opportunity to learn new skills under the guidance of a senior; for example, printed circuit board layout and fabrication, network administration, developing PERL scripts, etc. An added benefit of this component is that it further emphasizes the importance of maintaining the ECE culture of productivity. A final use of the Consultant course is to serve as a forum to bring in outside speakers who can address issues of professionalism, entrepreneurship, and other topics.

Rowan Engineering's first class graduated in May 2000. Of the 100 students who entered in 1996, 85 graduated in four years. Our first ABET accreditation visit occurred in October 2000; we were evaluated under the EC 2000 criteria and achieved accreditation. A number of critical components of the Rowan approach to ECE education became evident, notably the 8 semester clinic sequence.

Clinic Challenges: Hands on *versus.* Minds on

Among the issues that arise during the development and execution of project-based or clinic infused curricula is the creative tension between the initial concept of trying to create the "best" student for industry *versus.* developing students who would be ready for follow-on graduate work. These competitive views were captured in the "hands on" *versus* "minds on" dichotomy. If "hands on" is over-emphasized, programs run the risk of being too technology-skills oriented; if "minds on" was the primary emphasis, we risk producing students without sufficient practical skills. Even today, this trade-off remains one of the most hotly discussed within the ECE program, with every curriculum review always returning to this point. However, the pleasant surprise to faculty holding either viewpoint in the Rowan experience has been the graduate placement outcomes. We have placed students in both graduate programs and industry with balanced success. We believe that one of the key contributors to the remarkably high number of our graduates who go directly to graduate school is the multiple opportunities afforded to students to become involved in sponsored research projects. At any given time, approximately half of the nearly 60 Clinic projects offered each semester are derived in some measure from faculty sponsored research. Thus, even if a student doesn't select a project based on personal research interests, they are still very likely to end up participating in a research-based project. This active involvement serves to demystify the research and development enterprise; students learn first-hand that they can conduct research. Also, for their part, faculty get a chance to develop and inspire students to participate in their research. As students near graduation, there is a very active recruitment of the most capable students. After seeing the exodus of our brightest students to the best graduate schools in the country, there was an abrupt about-face and we now recruit our students just as strenuously as our competition. In any case, we want to achieve a balance of students who do go elsewhere with a sufficient number who stay to sustain and grow our own graduate program. About 30 percent of our students go on to graduate school and the top 10 percent go to the top schools in the country.

When comparing graduates from different programs, employers most often cite *confidence* as the key attribute that the Rowan graduate has in abundance. They often go on to add others such as the ability to network and work with others, but confidence is the one most often brought up first. The large number of design project experiences and the frequency of oral presentations combine to yield a young engineer who is not afraid to stand at the podium and pitch his/her views. Faculty sometimes joke about the tendency of our students to first—and last—cast everything they do in terms of PowerPoint slides, but it is also the reality of getting ready for the inevitable project meetings, design reviews, and final project presentations that will occur throughout the semester. The importance of communication skills is emphasized through the curriculum, but it gets a serious jumpstart in the Sophomore Clinic where the required three-credit composition and the second 3-credit public speaking courses are both integrated within the Clinic [34,35]. Students are taught the simple lesson that to engineer is to write and speak well.

Clinic Success

The Engineering Clinic is the key curricular innovation that we developed as the solution to providing students with meaningful *multidisciplinary discourse* and *teamwork* opportunities. Working on the *cultivation of capable communicators* could—and was—addressed throughout the curriculum, but the Clinics afforded yet another obvious opportunity. Similarly, we captured the need to prepare our students to respond to the challenges of life-long learning and continuous renewal as developing *agile technologists*. Again, pressure is maintained on our courses to keep them as relevant to the state-of-the-art as possible. The Engineering Clinics afford a ready mechanism to ensure that our students are continually immersed with relevant problems representing the state-of-the-art from sponsoring industries and from faculty research. Reaching out to our stakeholders as part of the infusion of continuous external assessment by our partners is yet another opportunity addressed by the Clinics. Potential sponsors are quick to point out weaknesses in your program, particularly when they form the basis for non-support and non-hire decisions. That form of real-time feedback on the perceived value of the curriculum to a critical stakeholder is invaluable.

Summary and Conclusions

Engineering clinics, adopted by various institutions, provide valuable research and design project-based experiences within the core of a diverse ECE education. Students experience the real-life nature of multidisciplinary engineering problems and are actively involved in solving such problems by applying and augmenting the knowledge gained by coursework. Students learn the value of teamwork, oral and written communication skills, entrepreneurship and the agility for life-long learning. The clinic experience is highly useful for students aiming to either proceed to graduate school or take up a job in industry upon completion of the undergraduate degree. The clinic is also useful in keeping the ECE courses up to date and in configuring new technical electives.The next step at

Rowan is to broaden the clinic base to include students and projects from business, computer science and physical and life science. This will further enhance multidisciplinary discourse.

Acknowledgements

The authors wish to acknowledge the vision and commitment of Mr. and Mrs. Henry Rowan, who made the Rowan Engineering programs possible. We thank the founding dean, Dr. James H. Tracey, who made Henry Rowan's vision a reality. We salute all of our students, but most of all those who joined our program in the beginning when the entire curriculum was nothing but a promise and Rowan Hall was only a stack of drawings. We thank the many companies and agencies that have invested in our program to help it flourish, in particular, the National Science Foundation. Entrepreneurship activities have also been generously funded through the National Collegiate Inventors and Innovators Alliance.

References

[1] S.M. Goodnick, "A Vision for ECE Education in 2013 and Beyond," Guest Editorial, *IEEE Trans. Educ.,* vol. 46, no.4, p. 405, Nov 2003

[2] D.L. Evans et al., "ECE Curriculum in 2013 and Beyond: Vision for a Metropolitan Public Research University," *IEEE Trans. Educ.,* vol. 46, no.4, pp. 420-428, Nov 2003

[3] S.C. Hu, "A Wholesome ECE Education," *IEEE Trans. Educ.,* vol. 46, no.4, pp. 444-451, Nov 2003

[4] F.C. Berry et al., "The Future of Electrical and Computer Engineering Education," *IEEE Trans. Educ.,* vol. 46, no.4, pp. 467-476, Nov 2003

[5] S.W. Director et al., "Reengineering the Curriculum: Design and analysis of a new undergraduate electrical and computer engineering degree at Carnegie Mellon University," Proc. IEEE, vol. 83, pp. 1246-1269, Sep 1995

[6] J.T. Bernhard, "Challenges and Strategies for Electrical Engineering Education," ASEE / IEEE 1997 Frontiers in Education Conference, Session S4A, pp. 1459-1462

[7] M. Nahvi, "Developing Freshman-Year Experience in Electrical Engineering: Primary Functions and Possible Features," Cal Poly

[8] B. Farbrother, "New approach to electrical and computer engineering programs at Rose-Holman Institute of Technology," presented at the 1997 ASEE Annu. Conf. Milwaukee, WI, June 1997, Session 2432

[9] K. Scoles and N. Bilgutay, "ECE 21: A new curriculum in electrical and computer engineering," Proc. 29th Annu. Frontiers in Education Conf., vol. 2, San Juan, Puerto Rico, Nov. 1999, pp. 12b5-10 – 12b5-14, Session 12b5

[10] J.L. Schmalzel et al., “Composing a new ECE program: The first five years,” Proc. 31st Annu. Frontiers in Education Conf., vol. 2, Reno, NV, Oct. 2001, pp. F3B-1 – F3B5, Session F3B
[11] E. Fromm, “Innovations that Changed the Engineering Educational Environment,” *Global J. of Engng. Educ*., vol. 7 no. 2, pp. 173-178
[12] S.E. Kerns et al., “Designing from a Blank Slate- The Development of the Initial Olin College Curriculum”
[13] A. Bright, “Student, Faculty and Liaison Roles in the Engineering Clinic Program at Harvey Mudd College,”
[14] The Accreditation Board for Engineering and Technology, *Engineering Criteria 2000*, ***www.abet.org/eac/eac2000.html***, Oct 29, 1998. Available: Online
[15] P.M. Jansson, “An Empirical Approach to Invention and Technology Innovation in Electricity,” PhD Dissertation - University of Cambridge, Feb 2003
[16] rowan ece goals on college of engineering website
[17] D. Munson, “Elements of a New Electrical Engineering Curriculum at Illinois: A Shift from Circuits to Signal Processing.” IEEE 1995.
[18] R.M. Felder et al., “The future of engineering education: II. Teaching methods that work,” *Chem. Eng. Educ.,* vol. 34, no. 1, pp. 26-39, 2000
[19] ***http://www.eng.hmc.edu/clinic.php?sidebar=clinic*** Available: Online
[20] ***http://www.olin.edu/academics/curriculum.asp*** Available: Online
http://www.olin.edu/academics/pdf/CurriculumYrs1_41.pdf Available: Online
[21] ***http://www.rose-hulman.edu/Catalogue05-06/program-ece.htm*** Available: Online
[22] J.L. Schmalzel, A.J. Marchese, J. Mariappan, and S.A. Mandayam, “The engineering Clinic: A four-year design sequence,” *2nd An. Conf. of Nat. Collegiate Inventors and Innovators Alliance*, Washington, D.C., March 13-15, 1998.
[23] ***http://www.rowan.edu/catalogs/pdf/rowanundergrad04.pdf*** Available: Online
[24] Engineering Deans Roundtable, “Engineering for a changing world,” American Society for Engineering Education, Washington, D.C.
[25] R.P. Hesketh, *et al*, “Introducing freshmen to engineering through measurements,” *Proc. ASEE Middle Atlantic Section Spring 1998 Reg. Conf.*, April 25.
[26] K. Jahan, *et al*, “Engineering measurements and instrumentation for a freshman class,” *Proc. 1998 ASEE Nat. Conf.*, Seattle, WA, June 28 – July 1.
[27] J. L. Schmalzel, *et al*, “An interdisciplinary design sequence for sophomore engineering,” *Proc. 1998 ASEE Nat. Conf.*, Seattle, WA, June 28 – July 1.
[28] J.L. Schmalzel, A.J. Marchese, and R.P. Hesketh, “What’s brewing in the Clinic?” *HP Engineering Educator*, 2:1, Winter 1998, pp. 6-7.
[29] A.J. Marchese, *et al*, “Design in the Rowan University Freshman Engineering Clinic,” *Proc. 1997 ASEE An. Conf.*, Session #3225, Milwaukee, WI, June 15-18.
[30] R.P. Hesketh, *et al*, “Multidisciplinary experimental experiences in the Freshman Engineering Clinic at Rowan University,” *Proc. 1997 ASEE An. Conf.*, Session #2326, Milwaukee, WI, June 15-18.
[31] J.L. Schmalzel, K. Jahan, Z. Keil, J. Mariappan, A. Marchese, and S. Mandayam, “An interdisciplinary design sequence for sophomore engineering,” *Proc. 1998 ASEE Nat. Conf.*, June 28–Aug 01, Seattle, WA.

[32] A.J. Marchese, J. A. Newell, R. P. Ramachandran, B. Sukumaran, J. L. Schmalzel and J. Marriappan, "The Sophomore Engineering Clinic: An Introduction to the Design Process Through a Series of Open Ended Projects," *ASEE Annual Conference and Exhibition,* Charlotte, North Carolina, Session 2225, June 20-23, 1999.

[33] R. P. Ramachandran, J. L. Schmalzel and S.A. Mandayam, "Engineering Principles of an Electric Toothbrush," *ASEE Annual conference and Exhibition*, Charlotte, North Carolina, Session 2253, June 20-23, 1999.

[34] J. A. Newell, A. J. Marchese, R. P. Ramachandran, B. Sukumaran and R. Harvey, "Multidisciplinary Design and Communication: A Pedagogical Vision," *Int. J. of Engr. Ed.*, Vol. 15, No. 5, pp. 376-382, 1999.

[35] R. P. Ramachandran, A. J. Marchese, R. Ordóñez, C. Sun, E. Constans, J. L. Schmalzel, H. L. Newell, H. Benavidez and J. Haynes, "Integration of Multidisciplinary Design and Technical Communication: An Inexorable Link," *Int. J. of Engr. Education*, vol. 18, pp.32—38, 2002.

[36] A. J. Marchese, R. P. Ramachandran, R. P. Hesketh, J. L. Schmalzel and H. L. Newell, ``The Competitive Assessment Laboratory: Introducing Engineering Design Via Consumer Product Benchmarking," *IEEE Trans. on Education,* vol. 46, pp. 197—205, February 2003.

[37] L. M. Head, G. Canough and R. P. Ramachandran, "Real World Design as a One Semester Undergraduate Project: Example of a Robust and Low Cost Solar Lantern," *IEEE Trans. on Education,* vol. 45, pp. 357—363, November 2002.

[38] H. C. Gabler, R. Krchnavek and J. L. Schmalzel, "Development of an Automated Crash Notification System: An Undergraduate Research Experience," *IEEE Frontiers in Ed. Conf.,* 1998.

[39] R. P. Ramachandran, J. C. Chen, L. M. Head, J. L. Schmalzel and H. C. Gabler, "Automatic Compact Disc Transfer for Quality Assurance Testing," *IEEE Frontiers in Ed. Conf.*, Session F3B, Reno, Nevada, October 10-13, 2001.

[40] Marchese, J. Chen, and J. Schmalzel, "The NCIIA Venture Capital Fund at Rowan University," *Proc. NCIIA Conf.,* Washington, D.C. 6-9 March 2001, pp. 64-82.

[41] A. J. Marchese, J. L. Schmalzel, S. A. Mandayam and J. C. Chen, "A Venture Capital Fund for Undergraduate Engineering Students at Rowan University," *J. of Engr. Ed.*, Vol. 90, No. 4, pp. 589-596, October 2001.

[42] J.L. Schmalzel, A.J. Marchese, R.R. Krchnavek, L.B. Weiss, V. Shah, "Developing a micro-business: Engineering intrapreneurship," *Proc. National Collegiate Inventors and Innovators Alliance Conf.*, Washington, D.C. 6-9 March, 2001, pp. 393-8.

[43] J.L. Schmalzel and J.J. Gommel, "Multidisciplinary design in a capstone course," *Proc. 1995 ASEE Nat. Conf.*, June 25-28, Anaheim, CA, pp. 2615-9

[44] S. A. Mandayam, J. L. Schmalzel, R. P. Ramachandran, R. Krchnavek, L. M. Head, R. Ordóñez, P. Jansson and R. Polikar "Assessment strategies: Feedback is too late," *IEEE Frontiers in Ed. Conf.,* 2001.