Machine Learning and Pattern Recognition Education at a non-Ph.D. Granting Engineering Program – Opportunities and Challenges

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Abstract – It is not very often that an institution gets the opportunity to design an engineering curriculum from scratch; an opportunity that also comes with many challenges, as well as rewards. Apart from how to present which material in the most innovative, efficient and pedagogical way, there is also the ubiquitously delicate issue of how to balance teaching and research – a significant challenge considering that this new program is housed at a primarily undergraduate institution with no Ph.D. component. We have therefore formed a number of focus areas based on the faculty interest, one of which is machine learning and pattern recognition. We have developed a number of courses, all of which are offered to senior undergraduates as well as M.S. level graduate students. Lacking a Ph.D. program, we also had to find creative ways of integrating research activities into the undergraduate and M.S. level curricula, which we have done so through the "Engineering Clinic." The hallmark of Rowan's engineering program, the engineering clinic is an 8-semester sequence, where vertically and horizontally integrated students work on externally funded semester-long projects for credit. In this paper, we describe our unique approach to integrating teaching and research activities under the engineering clinic umbrella, and how this approach allows us to offer research experiences even to under classmen. We also describe the specific opportunities and difficulties this approach brings, and we describe recently awarded grants on incremental learning and data fusion as examples of how we maximize these opportunities and how we address the difficulties.

I. INTRODUCTION

A generous gift was announced in 1992 that radically transformed a small state college into a regional university with an ambitious plan to become a well-known and respected institution of higher education in education and research. Henry and Betty Rowan, citing the lack of an engineering program in Southern New Jersey endowed Glassboro State College with $100 million with a mandate to create a world-class engineering college. The challenge was to create quality programs to develop engineers who could compete in the new global economy. Four engineering disciplines (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical) were started in 1995. A dynamic group of faculty was recruited and promised the opportunity and challenge of a life time: create an engineering program from scratch. This was a rare opportunity indeed, as most educators spend their careers making the best of incremental curriculum innovation at established institutions.

With this mandate, the first class enrolled in 1996; the engineering building was completed in early 1998, and the first graduates left Rowan in 2000. The institution renamed itself as, first Rowan College of New Jersey, and then as Rowan University with the initiation of graduate programs. Accreditation under ABET (Accreditation Board for Engineering and Technology) Criteria 2000 was granted to all four engineering programs in 2001.

In Electrical and Computer Engineering (ECE), we have established the following as our departmental goals in structuring our program in response to this mandate [1]

- Develop agile technologists
- Cultivate capable communicators
- Instill entrepreneurial spirit
- Facilitate multidisciplinary discourse
- Sensitize to contemporary issues
- Impart essential ECE knowledge

Implicit in each of these goals is the need for a meaningful research experience. This is because, the scholarly work required to maintain such a program would not only enable the faculty to be engaged and up to date with state-of-the-technology, but also bring this technology driven content to the classroom to educate tomorrow's engineers. Furthermore, students who receive little or no research experience often lack skills for conducting independent research and consequently, skills for analytical thinking and problem solving. Such skills are vital for survival in today's rapidly changing and highly competitive marketplace.

A research program can only be meaningful, however, if it is active, self-sustaining, and fully supported by the institution. These requirements typically translate into a need for a strong graduate program, preferably at the Ph.D. level, so that properly trained graduate students can participate in cutting edge research. Rowan University, however, is currently a primarily undergraduate institution with strong commitment to teaching, and the graduate education in the College of Engineering consists of an M.S. level program.

The ECE department's desire to grow and sustain a strong research program along with a strong graduate program was initially received with some discouragement, criticism and a few raised eyebrows: on one camp, there were those who strongly argued that a graduate program, particularly at the Ph.D. level would take away resources from the undergraduate program and hence hinder our core mission. On the other camp, there were those who claimed that a meaningful research program was simply not conceivable without a Ph.D. program. Our challenge, as the ECE program at Rowan, has therefore been to prove both camps wrong. In particular, we strongly defend that a viable

research program as well as a strong graduate program are possible even without a Ph.D. program (though the Ph.D. program would certainly help), and that a strong graduate program, (and yes, including a Ph.D. program) can only enhance the undergraduate program, rather then weakening it.

In order to meet this dual challenge, we first identified focus areas based on research interests of our faculty, one of which is machine learning & pattern recognition. Second, we identified clever strategies of engaging our undergraduate students, as well as our graduate students, in cutting edge research in these areas. In this paper, we describe the strategies that we have employed to build our machine learning and pattern recognition research laboratory. In particular, we describe the courses we have developed, but more importantly, the use of the 8-semester engineering clinic sequence, the hallmark of the Rowan engineering program, primarily designed to expose undergraduate students to research in real world problems.

II. COURSE DEVELOPMENT

Developing new elective courses in areas of relevant research interest is inevitably necessary to adequately prepare students to work on related research topics. Two courses, Artificial Neural Networks (ANN) and Theory and Applications of Pattern Recognition (PR) have recently been developed and offered, and additional courses are being planned. All electives are dual listed as both senior undergraduate and graduate courses. Students taking these courses for graduate credit are presented with additional content and are expected to produce additional work commensurate with the requirements of graduate credit.

These courses are currently offered every other year as a sequence of consecutive courses, with PR offered in Fall and ANN offered in the following Spring. The undergraduate PR course content includes Bayesian theory, discriminant analysis, density estimation, gradient descent optimization and multilayer perceptron neural networks, cross-validation, decision trees, basic clustering algorithms such as K-means and Isodata, while the graduate course adds bias-variance dilemma, bootstrapping, boosting, multiple classifier (ensemble) systems and support vector machines. The undergraduate ANN course content includes perceptron model, detailed coverage of multilayer perceptron, Hebbian learning, radial basis function neural networks, Hopfield networks, unsupervised learning and self organized maps (Kohonen network), while the graduate section adds fuzzy inference systems, adaptive resonance theory, additional coverage of SVMs as well as other contemporary topics of interest. Both courses feature semester projects with the following options:

Undergraduate students

- Option A: Find a new application of pattern recognition or neural networks. Apply at least three techniques studied in class to this problem.
- Option B: Conduct literature review on a novel pattern recognition / neural network modality or technique.

Graduate students

- Option C: Develop a new technique, either from scratch, or by suitably modifying an existing technique for a specific problem; test it on at least four standard benchmark databases available at the UCI Machine Learning Repository (http://www.ics.uci.edu/~mlearn).
- Option D: Identify a new pattern recognition / neural network algorithm from a recent journal article. Implement the algorithm and evaluate it on at least 5 datasets from the UCI Repository and two real world datasets (may be provided by the instructor if requested).

Open to all students

- Option E: Suggest your own project topic. Must be preapproved by the instructor.

Students are also presented with potential project topics from faculty's existing research projects, which are typically received with great interest. Many students are usually already familiar with these projects due to their involvement in these projects through the engineering clinic, as described below. As a result, students are provided with a wide range of project opportunities. It is not unusual for student projects resulting in conference publications [2].

We are also planning on developing and offering additional courses, possibly jointly with the Computer Science (CS) department, on machine learning, computational models of learning and artificial intelligence. In fact, the CS department already has these courses in their books, however have been unable to offer them due to prior lack of interest. We are considering revamping the content of these courses with the CS department to add such topics as PAC learning, evaluating hypotheses, ensemble of classifiers and mixture of experts, expectation maximization, instance based online learning, reinforcement learning, and genetic and evolutionary algorithms. This would create additional demand from engineering students to provide the necessary justification for offering these courses.

We have also designed, developed and offered a number of other relevant courses that complement the PR and ANN courses, such as Digital Communications, Digital Image Processing, Theory and Engineering Applications of Wavelets, and Principles of Biomedical Systems and Devices. We are also planning on additional courses, such as Advanced Signal Processing and Statistical Pattern Recognition.

III. THE ENGINEERING CLINIC SEQUENCE

A. The Clinic Experience

Rowan's 8-semester, engineering clinic sequence provides a unique mechanism for involving undergraduate students in research. The philosophy of the clinic is similar to one 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, including hands-on/minds-on instruction, treatment of integrated topics, teamwork, effective communication, multidisciplinary experience and entrepreneurship.

In its current college wide implementation, the freshman and sophomore clinics are independently structured courses (3 credits/semester) emphasizing engineering measurement, competitive assessment (reverse engineering), multidisciplinary design and structured design, respectively, during the first four semesters. [3,4]. Upper-division (junior and senior) clinics, two credit each semester, are particularly project driven: for each semester of clinic work, juniors and seniors sign up for semester or yearlong projects that are constructed by dividing externally funded large-scale projects into smaller tasks [5]. All clinics include module-based instruction to cover additional discipline-specific or project-related content. While freshman and sophomore clinics are independently structured with their individual course content, interested and capable students at these levels are also allowed to sign up for junior / senior clinic projects. This flexibility then allows the faculty to recruit and train exceptionally bright and capable students interested in research, early on for their respective projects. Furthermore, any engineering student can participate in any engineering clinic project, regardless of the department sponsoring the project. In fact, ECE students are required to participate in at least one out-of-discipline project during four semesters of junior-senior clinic, to enhance their multidisciplinary exposure.

B. Integrated Research and Learning Communities

In order to combine educational and research aspects of our goals and mission, we form integrated research and learning communities (IRLCs), working within the scope of the engineering clinic projects. IRLCs that are formed for machine learning and pattern recognition projects include students of all levels, freshman through graduate (vertical integration), collaborating on various research activities. An attempt is also made to balance the communities with respect to gender, racial, ethnic and technical backgrounds (horizontal integration). Students are given responsibilities commensurate with their intellectual and academic skills. For example, freshmen are involved in literature search, procurement of products, and data collection, whereas sophomores are responsible for basic data analysis, preparation of reports, and conducting experiments under the guidance of juniors and seniors. Juniors and seniors are involved in design and development of the project, including software development and basic theoretical analysis. Finally, graduate students under faculty guidance, are responsible for supervising the group activities, detailed theoretical analysis, algorithm development and optimization. Each graduate student typically supervises one or two clinic projects, which eventually constitute their thesis work. The community is collectively responsible for technology transfer and dissemination efforts, through conference and journal publications.

This paradigm exposes students to interdisciplinary research, promote intellectual growth and responsibility, and improve their communication and team working skills. Graduate students further benefit by developing skills for supervising externally funded projects. We note that this student centered, collaborative learning paradigm inherently addresses all our ECE program goals mentioned above. Earlier studies with research communities of primarily graduate students have been very promising in providing above-mentioned benefits [6]. We believe that involving undergraduates in such communities will have even further reaching benefits for both undergraduate and graduate students.

C. Clinic Consultant

An additional unique aspect of the ECE program is the one credit per semester Clinic Consultant course for juniors and seniors. Students who take this course basically sign up for an additional clinic project (other then the main project they signed up for junior / senior clinic) to offer consulting services. For example, students who have worked on a particular project the previous semester may sign up for consulting that project during the next semester to help train the new students in the project. Students can also sign up to offer their services in an area of individual expertise. For example, a student who is particularly interested in and capable of programming can offer his/her services for coding / debugging algorithms developed by the other clinic team. The clinic consultant course provides an efficient mechanism for technology transfer between students working on similar projects while ensuring continuity in the projects.

IV. CURRENT PROJECTS

We have been supervising clinics for our joint and individual projects for the past several years. So far, we have been pleasantly surprised by the maturity, experience, team working and communication skills students gain throughout the course of the projects, as well as the quality of the work performed as a result of the synergistic efforts of under class, upper class, and graduate students with the faculty. Some of our recently funded projects include the following, all of which support concurrently run clinic projects.

Data Fusion for Nondestructive Evaluation of Gas Pipelines: Funded by the U.S Department of Energy, this project explores two independent approaches to data fusion: invariance transformations and multiple classifier systems, with particular application of detecting and identifying various defects in the gas transmission pipelines. Two graduate (M.S.) students and four undergraduate students are working on this project.

Breast Density Estimation from Digital Mammograms: Funded by the American Cancer Society, this project seeks to develop image processing and pattern recognition techniques for estimating the breast tissue density from the digitized mammograms. One graduate and four undergraduate students are currently working on this project. The work conducted in clinics for this project resulted in [7].

Ensemble of Classifiers for Incremental Learning: This project has been funded by the CAREER program of National Science Foundation (NSF), in part because of its educational component of exposing cutting edge machine learning issues to an integrated community of undergraduate and graduate students through the engineering clinics. The project seeks to develop novel incremental learning and data fusion algorithms using the ensemble of classifiers approach. Three undergraduate and two graduate students are currently working on this project. Students involved in this project as part of their clinic work have generated multiple conference papers for IJCNN and ICANN [8-10], one of which has won IEEE regional undergraduate student paper competition and will compete at the national competition [9].

Early Diagnosis of Alzheimer's Disease: Just recently funded by the National Institute on Aging (NIA) of National Institutes of Health (NIH), this project seeks to develop new diagnostic biomarkers using multiresolution analysis of event related potentials (ERPs) of electroencephalogram (EEG) for early, accurate and non-invasive diagnosis of the Alzheimer's disease. The classification of processed signals will be achieved through the ensemble based neural network classifiers, in conjunction with the algorithms developed in the above mentioned projects. This project is a joint effort between University of Pennsylvania (UPENN) and Rowan University, where UPENN will recruit the patients, acquire EEGs and obtain ERPs, whereas Rowan will conduct the data analysis, processing and pattern recognition. There will be two graduate students and 4~8 undergraduate students working on this project.

V. CONCLUSIONS: OPPORTUNITIES & CHALLENGES

We acknowledge the challenges of sustaining an active and successful research program without the support of a Ph.D. program, particularly in machine learning and pattern recognition areas, as these areas are often associated with upper level graduate education. We do not have access to Ph.D. students who bring years of education, experience and background with them, nor can we take advantage of the long term stability of these students who typically spend 3~5 years in the Ph.D. program. While a strong Ph.D. program is most certainly a great asset for successful research efforts, and that we are currently considering it in our long term goals, we cannot wait for such a program to start. We therefore take advantage of the opportunities of our innovative curriculum and show that a viable and meaningful research program is possible even without having a Ph.D. program.

We extensively use the engineering clinic sequence, particularly at the junior and senior level along with M.S. students supervising the clinic teams to carry out a wide spectrum of research activities. The integrated research and learning communities created within the scope of these clinics not only benefit the project, but more importantly the students in their educational endeavors, which is our core mission. We offer newly developed courses, and plan on developing new ones, in areas closely related to the research areas and deliver additional content within junior / senior clinic. We utilize the clinic consultant course to ensure continuity among clinic teams to quickly train those joining the project for the first time, as well as to take advantage of those students with special expertise. Finally, when our resources or expertise are simply not adequate to be involved in a particular area of research (such as medical diagnosis), we do not hesitate to collaborate with those institutions (such as UPENN) having such expertise and resources.

Overall, the clinic experience along with the clinic consultant and the newly created courses have proven to be invaluable for us in pursuing our research efforts. We believe that this setting can serve as a national model not only for peer institutions with limited graduate program resources, but also for those with strong graduate programs as well.

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