2006-1990: ENGAGING UNDERGRADUATE STUDENTS IN MACHINE LEARNING RESEARCH: PROGRESS, EXPERIENCES AND ACHIEVEMENTS OF PROJECT EMD-MLR

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Engaging Undergraduate Students in Machine Learning Research: Progress, Experiences and Achievements of Project EMD-MLR

Abstract

Project EMD-MLR is a National Science Foundation funded, on-going effort that aims at engaging undergraduate engineering and computer science students into research on Machine Learning. In our present paper we will provide a brief overview of the project's characteristics and share our experience about engaging undergraduate students in research in year 1 of the project. More specifically, we will report the overall achievements accomplished so far in terms of research products such as student-developed software, publications and other dissemination efforts. Additionally, we report on student assessment results regarding the quality of their experience through their participation in aspects such as the student-teacher interaction, the knowledge and experience that students acquired, while performing research and the type of impact their involvement had on their future academic and/or career aspirations.

1. Introduction

Machine Learning (ML) is a discipline that started evolving as early as the 60's in the form of Artificial Intelligence and that nowadays has permeated several aspects of high-tech applications as well as everyday life. Its charter is to study, develop and build models able to perform "intelligent" tasks that may be second nature for humans, but are well beyond the capabilities of traditional computing paradigms. ML applications such as vending machines that recognize valid paper bills, document processing software that corrects our grammar and syntax in real time, voice-driven over-the-phone account management of credit, smart photographic cameras that automatically adjust their exposure and speed settings depending on the scene environment, as well as challenging strategy computer games, have become a big part of our everyday routine. Other, less obvious, applications, such as automatic target recognition, earthquake prediction, gene expression discovery, intelligent credit fraud protection and affectionate computing, to mention just a few, are examples of cutting-edge applications of ML in various technological, scientific and financial domains.

This paper describes the outcomes of a prototype project titled "*PROJECT EMD-MLR: Educational Materials Development through the Integration of Machine Learning Research into Senior Design Projects*", whose intellectual focus is ML. The project is an on-going, multi-institute effort that started in May 2004. The project partners are two major universities in Central Florida, namely Florida Institute of Technology (FIT) in Melbourne and the University of Central Florida (UCF) in Orlando. In addition to the two host universities, there are two 2-year Central Florida colleges, Seminole Community College (SCC) in Oviedo and Brevard Community College (BCC) in Melbourne. Project EMD-MLR is a National Science Foundation funded project under NSF grant CCLI-0341601 for the period of May 2003 to Arpil 2006 and under the auspices of the Educational Materials Development track of the Course, Curriculum and Laboratories Improvement (CCLI-EMD) program.

A key goal of Project EMD-MLR is to engage undergraduate students into research in ML. It must be mentioned, however, that the concept of integrating ML into the undergraduate curriculum is not novel. Similar efforts of such engagements have been successfully implemented in the past. For example, within the framework of the project titled "*Machine Learning Advances for Engineering Education*" at UCF[1,2,3,4], which is funded by NSF under the Combined Research and Curriculum Development (CRCD) program, ML teaching modules were developed and subsequently integrated into introductory engineering courses. Furthermore, the project developed two new senior level courses, Current Topics in Machine Learning I and II. Additionally, another project[5,6,7,8] held at University of Hartford titled " *Machine learning Laboratory Experiences for Introducing Undergraduates to Artificial Intelligence*", also funded by NSF under the Course, Curriculum, and Laboratory Improvement (CCLI) program has development a framework for teaching core AI topics using a unified theme of ML. Moreover, a suite of adaptable, hands-on laboratory projects have been developed that can be closely integrated into a one-semester AI course.

However, Project EMD-MLR has certain characteristics that make it distinct in comparison to the aforementioned efforts. First, the project is a multi-institute partnership. Furthermore, the project's focus enhances partnerships amongst 4 neighboring institutions, and many more affiliate Universities dispersed within the US and abroad. The University partnerships constitute the anchor of an elaborate dissemination plan that is multi-faceted and self-sustained. Moreover, it plans to impact 80 students in a span of 2 years, some of which are members of underrepresented groups (in particular UCF and SCC students). Additional, distinct characteristics are reflected in the immediate objectives of Project EMD-MLR, which are listed below

1. Introduce research into the undergraduate curriculum of many engineering and science disciplines. The number of undergraduate students that will be affected by the project will be 40 per year, 80 in total.

2. Develop educational materials focused on Machine Learning, that will be of value to many academicians, students and professionals with interest in this field, or applications that this field addresses.

   (a) To develop a software collection of machine learning related algorithms based on MATLAB with accompanying documentation and usage examples based on real-world problems.

   (b) To develop educational material regarding selected, current topics in machine learning that will be used as chapters of an introductory textbook in Machine Learning for undergraduate students.

3. Involve students from 2-year community colleges (BCC and SCC) in this educational development process. The plan is to involve 10 community college students per year.

4. Disseminate nation-wise and world-wide the developed material. The project's ultimate intention is to create a Machine Learning repository at FIT that would be useful as an on-line resource dissemination tool to all machine learning researchers and students around the nation and all over the world.

It should be noticed, that a central product of the project is the planned, on-line ML Repository consisting of software implementations of state-of-the-art ML algorithms and techniques. It is anticipated that this repository will be primarily useful to students specifically interested in ML, as well as to ML researchers in the academia and industry. Furthermore, it is expected that the repository will also act as the means to popularize ML and encourage the utilization of its techniques to real-world problems in Engineering and Computer Science. Even further, undergraduate and graduate students, academicians and practitioners of broader disciplines could also benefit from its availability in varying degrees. This is because ML-oriented approaches can be effectively applied and adapted in/to many other real-world problems encountered. In general, the project staff foresees the repository playing the additional role of becoming a recruiting tool to attract more undergraduate students into STEM disciplines. All the aforementioned objectives are being achieved by a team of 10 faculties with strong teaching and research experience in ML, as well as extensive experience on supervising undergraduates participating in research experiences.

Project EMD-MLR's main teaching practice is to involve undergraduate students into Student Design Project (SDP) teams with each team working on an individual machine learning project with a definite research orientation. The term "SDP" refers to senior design projects in engineering disciplines or capstone course in computer science disciplines. Each team consists of 4 undergraduate students (3 from a group of seniors at FIT or UCF and one sophomore student from BCC and SSC, respectively). Each SDP team is advised weekly by at least one EMD-MLR faculty and, if needed, will is more frequently by a Ph.D. student mentor. Each SDP consists of an (i) educational materials development component and a (ii) supervised research conduct component.

The former component entails the implementation and documentation of an assigned, Machine Learning algorithm and/or approach. Code is developed in the C/C++ programming languages and executables are delivered as MATLAB MEX files. The design and implementation of the code follows well described, pre-specified guidelines, which are collectively referred to as development standards. These standards include software design, coding, and testing methodologies as well as applications of well established software engineering principles, which will guarantee the deployment of functionally robust, computationally and memory usage efficient code. Moreover, the development standards achieve a uniform "feel-and-look" across all team projects' products, whether it is code or documentation, to facilitate easier understanding of the algorithms and a straightforward code reuse capability for other interested parties. The standards enforcement itself is accomplished by appropriate team coordination and supervised by the EMD-MLR faculty. The latter of the SDP's component is the conduct of research by the teams utilizing their own software implementations and, potentially, third-party implementations of ML algorithms and/or approaches.

2. Project Outcomes

In total for Year 1, the project involved 11 faculties across the 4 institutions, 4 graduate students at UCF, 12 senior students from FIT, 11 senior students from UCF, 5 sophomore students from BCC and 3 sophomore students from SCC. A total of 31 undergraduate students were impacted originating from the 4 participating institutions during the period of May 2004 to April 2005. These students were embedded in 4 student project teams at FIT and UCF (total of 8 teams). The project was also supported by strong Industry and Academic Advisory Boards consisting of 8 and 9 affiliates respectively. A polling of the project participants showed encouraging results with respect to the project's impact. Due to their involvement in EMD-MLR, about three quarters of undergraduate participants are considering attending graduate school in the near future, while about half of the participating community college students are making plans to continue their education by pursuing a bachelor's degree in STEM disciplines.

In Year 1 four student project teams were formed at each university (FIT & UCF), a total of eight. Implementation and research topics were either assigned both on a team and individual basis, meaning that a team might have been working on single topic or each team member might have his or her own topic. The decision was made taking into account the individual strengths and interests among the team members of each team. The objectives, scopes, demands and results of each project topic were very diverse and numerous. In more detail, the topics pursued and completed in Year 1 by the teams were the following:

- Fisher's Exact Test for comparison of classification performances
- An Experimental Comparison of Semi-Supervised ARTMAP Architectures GCS and GNG Classifiers
- Design of an Ellipsoid ARTMAP classifier within the Fuzzy Adaptive System
- ART Framework
- Development of an analysis tool for Speech Signal Processing and Recognition
- Efficient implementation and experimentation with the Discriminant Adaptive Nearest Neighbor Classifier
- Development of a Hilbert Space Filling Curve Nearest Neighbor Classifier
- Implementation of the Probabilistic Neural Network on a Beowulf Cluster
- Assesing the utility of discretization of numerical attributes in Decision Tree Classifiers
- Implementation of Distributed-Learning Gaussian ARTMAP on a Beowulf Cluster
- Development of a LERAD algorithm for real-valued attributes

Here it is worth noting that implementation and research outcomes of the above projects directly benefited (and vice versa) other, additional research activities that were mainly pursued by graduate students on independent, but related topics, such as the following:

- On-line Gauss-Newton based learning for fully recurrent neural networks
- Correctness and Performance Properties of Pipelined Parallel Competitive Neural Network Algorithms on Clusters of Workstations
- Experiments with Micro-ARTMAP: Effect of the Network Parameters on the Network Performance

- Parallelization of Fuzzy ARTMAP to improve its convergence speed: The network partitioning approach and the data partitioning approach
- Pipelining of Fuzzy ARTMAP without Match-Tracking: Correctness, Performance Bound, and Beowulf Evaluation
- Pipelining of Fuzzy ARTMAP (FAM) without match-tracking

Additionally, in the course of the project the student developed 11 software implementations of well-known, as well as novel Machine Learning algorithms and techniques that are accompanied with related documentation. The implementations are suitable to be used as educational material for both introductory/undergraduate and advanced graduate curricula, as well as for research purposes in Machine Learning. Almost all implementations are provided as source code and MATLAB MEX files. Furthermore, each implementation is supported by documentation describing the essence of each algorithm or technique. Finally, the implementations are listed below:

- Fuzzy Adaptive System ART
- Fuzzy Adaptive System Ellipsoid ARTMAP
- Fuzzy C-Means
- Discriminant Adaptive Nearest Neighbor
- Probabilistic Neural Network
- Distributed Learning Gaussian ARTMAP
- microARTMAP Classifier
- Growing Cell Structures
- Growing Neural Gas
- Fisher's Exact Test for comparison of classification performances
- Analysis Tool for Speech Signal Processing and Recognition

Research findings and gained experiences accrued during Year 1 were disseminated to an international journal (Neural Networks) and 4 international/regional conferences (IJCNN'05, ICPP'05, ASEE'05 & NISOD'95). In total, Project EMD-MLR has supported the presentations and publications of 2 journal papers, 5 conference papers and 1 invited talk. The interested reader is referred to the corresponding references[10-23] for more information on these products. Finally, we offer access to the produced material via our project's new web portal[9].

3. Student Assessment Results

In this section we present student assessment results that were obtained during the first year of the project. Tables 1 through 3 on the next pages depict the student responses to 3 selected sections of the questionnaire. Note that the students were given the questionnaire to complete at the end of their participation in the project. The particular sections were soliciting for student feedback on the quality of interaction they had with their advising faculty, the way the project was conducted and finally the project's outcomes. It needs to be emphasized here that the tabulated results provided should be primarily interpreted as qualitative measures of the project's impact, since the number of students participating in the exit survey was a quantitatively small sample. Out of a total of 31 student participants unfortunately only 18 responded to the voluntary survey.

Table 1: Student Questionnaire Results: Advising Project Faculty Evaluation Section

Your advising faculty was able to inspire enthusiasm and excitement about your research topic. Regarding this statement:				
I strongly agree 66.67%	I agree 27.78%	I disagree 5.56%	I strongly disagree 0.00%	Unanswered 0.00%
How would you rate the availability to contact and/or to interact with your advising, project faculty?				
Beyond expectations 44.45%	Met expectations 55.55%	Marg. satisfactory 0.00%	Unsatisfactory 0.00%	Unanswered 0.00%
Overall, you received ample, personal attention by your project advisor (faculty and/or graduate student) during the entire course of your involvement in the project. Regarding this statement				
I strongly agree 72.22%	I agree 27.78%	I disagree 0.00%	I strongly disagree 0.00%	Unanswered 0.00%
How helpful was your advising faculty and/or graduate student in overcoming some of the difficulties you faced during the implementation and research phases of the project?				
Very helpful 61.11%	Helpful 33.33%	More or less helpful 5.56%	Indifferent 0.00%	Unanswered 0.00%
How effective was your advising faculty and/or graduate student in communicating background knowledge and ideas during your interaction with him?				
Very effective 61.11%	Effective 27.78%	Sometimes effective 11.11%	Ineffective 0.00%	Unanswered 0.00%
Your advising faculty strongly encouraged you to further pursuit your research interests and potential, academic aspirations. Regarding this statement:				
I strongly agree 55.56%	I agree 22.22%	I disagree 22.22%	I strongly disagree 0.00%	Unanswered 0.00%
Your advising faculty was reasonably demanding in terms of what he expected from you, when it came to deliverables and other obligations. Regarding this statement:				
I strongly agree 33.33%	I agree 66.67%	I disagree 0.00%	I strongly disagree 0.00%	Unanswered 0.00%
In summary, your overall experience interacting with your advising, project faculty and/or graduate student was:				
Very good 66.67%	Good 27.78%	Fair 5.56%	Poor 0.00%	Unanswered 0.00%

A closer look of Table 1 reflects several facts. First, the faculties advising the teams were deemed motivating, strongly engaged with the teams and their projects and effective in mentoring and guiding the teams. Secondly, the student participants felt that the project staff was available to aid in the various challenges the teams faced, while setting reasonable, attainable development and research goals. The vast majority of the participants found that their overall experience working in a team setting and being advised by a faculty was, overall, positive.

In Table 2 one can see that the students regarded the demands of their participation as reasonable and that they had sufficient access to various resources that were necessary for the accomplishment of their tasks. Here we need to mention that an important activity of the project is the monthly All-Hands Meeting (AHM), which is held in an alternating fashion at FIT or UCF. All participants from all 4 institutions converge to a 3-4 hour meeting at one of the host universities. During these AHMs the various teams give presentations regarding their research topics and the level of progress they have attained. Moreover they share challenges that they may have faced during their research and report how they were able to overcome them. Furthermore, these meetings also provide the opportunity to exchange ideas and opinions, whether these are on research topics or general issues related to the project. Finally, during the AHMs students are frequently asked for feedback and assess the quality of work being done by each team. Table 2 shows that the majority of the polled students felt that the participation in the AHMs had a positive effect on improving their skills of communicating ideas, that these meetings created the opportunity to get exposed to wider aspects of ML, and that, in general, the good progress of other teams were a motivating factor and a source of encouragement in their own endeavors.

Table 2: Student Questionnaire Results: Project Conduct Evaluation Section

The amount of time you had to invest per week, in order to successfully complete the implementation and research phases, was:				
Less than expected 5.56%	Reasonable 77.78%	Above expectations 16.67%	Unreasonable 0.00%	Unanswered 0.00%
You found the background material provided by your advising faculty and/or graduate student very helpful in completing your work. Regarding this statement:				
I strongly agree 27.78%	I agree 50.00%	I disagree 16.67%	I strongly disagree 5.56%	Unanswered 0.00%
You had sufficient access to necessary resources (e.g. computers, software, reading material, etc.) to help you in completing your tasks. Regarding this statement:				
I strongly agree 55.56%	I agree 33.33%	I disagree 11.11%	I strongly disagree 0.00%	Unanswered 0.00%
The presentations you had to give during the AHMs helped you communicate to others the ideas of your work more effectively. Regarding this statement:				
I strongly agree 33.33%	I agree 38.89%	I disagree 16.67%	I strongly disagree 5.56%	Unanswered 5.56%
The AHMs were worth attending, because they were an opportunity to learn more about other Machine Learning topics. Regarding this statement:				
I strongly agree 22.22%	I agree 44.44%	I disagree 22.22%	I strongly disagree 5.56%	Unanswered 5.56%
The AHMs were worth attending, because, by seeing other participants' progress and results, you would get motivated and encouraged regarding your work on your own topic. Regarding this statement:				
I strongly agree 22.22%	I agree 38.89%	I disagree 27.78%	I strongly disagree 5.56%	Unanswered 5.56%

Finally, Table 3 contains results regarding the students' own perception of how successful the outcomes of the project were. According to these data, the majority of the students felt satisfied

with their own performance. Also, they felt that they gained a deeper understanding of what research is about and what it entails. Furthermore, the vast majority of the participants found their experience to influence them positively in terms of making plans for continuing their education into graduate studies. Overall, the students seem to have found the experience provided by Project EMD-MLR as positive and useful.

Table 3: Student Questionnaire Results: Outcomes Section

How would you rate your overall performance during your participation in the project in terms of the quality of work you have performed and timeliness of meeting your deadlines?				
Very good 11.11%	Good 50.00%	Fair 22.22%	Poor 16.67%	Unanswered 0.00%
During your participation in the project you learned well what performing research is about. Regarding this statement:				
I strongly agree 33.33%	I agree 55.56%	I disagree 11.11%	I strongly disagree 0.00%	Unanswered 0.00%
The research I conducted during my participation in Project EMD-MLR lead or will lead to:				
One or more conference publications 38.89%	One or more journal publications 16.67%	None of the above 16.67%	I'm not sure or I don't know 22.22%	Not Applicable 5.56%
Before getting involved into the project, did you plan pursuing a graduate degree after completing your Bachelor's degree?				
Yes 55.56%	No 0.00%	I was unsure 33.33%		Unanswered 11.11%
My participation in the project has improved my perception of what graduate school and research is all about. Regarding this statement:				
I strongly agree 33.33%	I agree 50.00%	I disagree 5.56%	I strongly disagree 0.00%	Unanswered 11.11%
What was the effect of your participation in Project EMD-MLR in terms of making plans to pursuit a graduate degree in the near future?				
Positive effect 66.67%	No effect 16.67%	I disagree 5.56%	I strongly disagree 0.00%	Unanswered 11.11%
After finishing with your participation in the project what is the level of overall satisfaction you feel?				
High 22.22%	High-Medium 50.00%	Medium Low 22.22%	Low 0.00%	Unanswered 5.56%

Aside from these multiple-choice questions, the survey also included essay-type questions. While these results are not provided in this paper, an attempt is made to briefly summarize them. Among the compelling reasons, which convinced students to participate in the project, survey takers replied that their involvement would be counted as evidence of undergraduate research experience that will help them later for applying to graduate schools. However, the most dominant responses were about the strong recruitment by the project staff and the strong appeal of ML and its applications as a research area. When asked how many hours they had to spend per week while working on their research topics, answers ranged from 3 hours to 10 hours a week. Moreover, when asked about the best aspects of their participation, most students quoted the

hands-on experience they gained in software development, their interaction with the advising faculty and graduate students, and their involvement in exciting, cutting-edge research in ML. Finally, when asked what aspects of the project could be improved, the response was that (i) students should be exposed to the field of ML much earlier than the junior/senior year, (ii) while all research performed was focused on software, it should also give the opportunity for students to gain experience with hardware, (iii) advising faculty should state the research topic demands in a clearer format, (iv) communicating the AHM-related announcements and results should be done more effectively and efficiently in the future, and (v) provide financial incentive to future recruits for participating in the project.

4. Brief Summary

In this paper, we presented a brief overview of Project EMD-MLR, an NSF funded, proof-of-concept project that introduces undergraduate students to Machine Learning (ML) research through their involvement in supervised, student project teams. The main focus of the project is the development of educational material in the form of software implementations of state-of-the-art ML algorithms and accompanying documentation, as well as the dissemination of the teams' research findings. We briefly depicted the overall achievements accomplished so far in terms of research products such as student-developed software, publications and other dissemination efforts. Additionally, we reported on student assessment results regarding the quality of their experience through their participation in aspects such as the student-teacher interaction, the knowledge and experience that students acquired while performing research and the type of impact their involvement had on their future academic and/or career aspirations. Finally, more details regarding Project EMD-MLR can be found in the references[24].

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