
AC 2012-3350: IMPLEMENTATION OF AN UNDERGRADUATE RESEARCH COURSE

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A capstone course comes as the peak experience for students in higher education programs. The challenge may sometime extend to their advisors as well. We report our experience with teaching a senior research project course to Physics students at a teaching university using a recently set up Applied Electrostatics Laboratory. The design of the course allowed for great flexibility in choosing independent research topics and performing the actual research. Students were introduced to the laboratory facilities, and to different topics related to electrosprays and nanotechnology. Each student was given time to choose an independent topic in accordance with his/her interests. Although working in relatively different directions, joint sessions greatly enhanced their perspective on the research and topics approached. Various challenges and solutions are discussed. Modest funds were available for independent projects and helped in shaping the research. Students designed experiments, collaborated, collected and analyzed data, participated in local and international conferences. Details of their unique experience, impressions, and enthusiasm are presented. The course was refreshing in terms of research performed at undergraduate level. We hope that our experience can be useful to others teaching similar courses.

Introduction

Hands-on learning stimulates curiosity, renders relevant the theory used in the classroom, and provides practical foundation for senior capstone projects [1]. It is known that there are significant difficulties in transferring learning from one field to another, such as mathematics to physics. Laboratory work helps such transfer of skills and is an important component for student success and preparation for real-life [2, 3]. Physics faculty could also help by focusing on how to interpret real-world information and to set up the solution. [4]. However, capstone experience is an outstanding opportunity in integrating knowledge and skills from different fields and can be used as an opportunity for a genuine undergraduate research experience [5]. Moreover, such experience is a major block in proving student performance for program accreditation purposes [6]. A large national survey of engineering programs (444 programs) showed that most programs offer a one-semester long capstone course followed by two-semester capstone [7]. A similar remark is valid particularly for accredited engineering physics programs as well, while in more than two thirds of non-accredited programs no capstone course is required [8]. The general objectives of the capstone experience usually aim at creating a stimulating scientific and professional environment, enhancing professional creativity by providing the opportunity for open-ended interdisciplinary questions, developing skills for working in multidisciplinary teams, and improving oral and communication skills [9]. Our Physics program offers a one-semester capstone experience and we aim at presenting our course implementation and student

performance in a recently developed research lab [10]. We are hopeful that our work can be helpful to other small Physics programs.

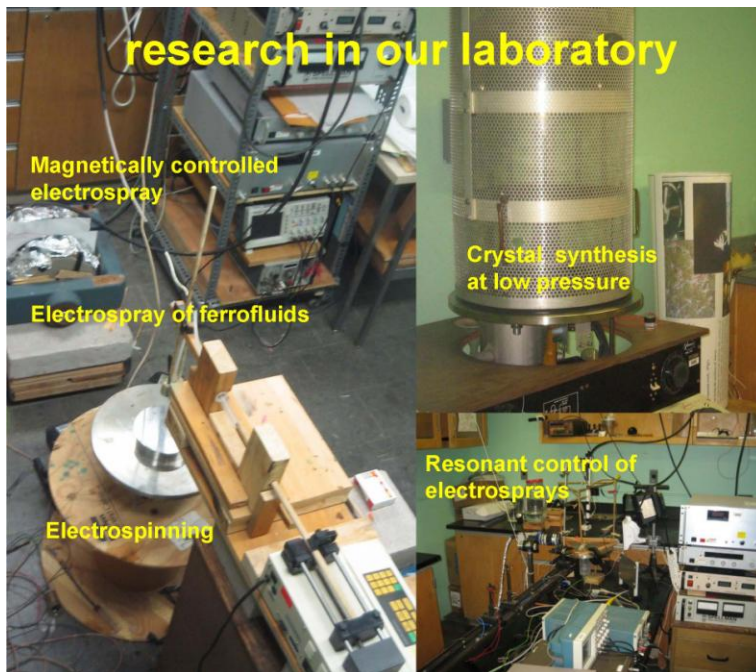


Fig. 1 Projects and capabilities of the Applied Electrostatics lab.

Laboratory description

The Applied Electrostatics Laboratory (Fig. 1) is equipped with a few high voltage power supplies (also one high voltage amplifier), single syringe and double syringe pumps, Keithley picoammeter, a modified Veeco system for studying electro spray at reduced atmospheric pressure, a high speed camera system, and a 3-D printer. The research capabilities include electro spray and electro spinning, high speed imaging of droplets, micro and nanoparticle generation, thin films deposition, ferro-fluids, and gas discharge studies. We also had access to the Biology Department's microscope. In order to generate an electro spray, one essentially needs high voltage and contained liquids with small openings. The key to many applications is controlling the electro spray.

Course design

Our Physics program has agreed that each faculty should have the opportunity to teach the capstone course periodically. Students enrolled in the course can choose from the projects that would be conducted with the faculty in charge of the course that particular semester, or if they

worked previously or have preference in working with another faculty member in a different field they can do so. The assessment of student work is then done by the chosen faculty and grades are submitted by the faculty member running the course at that time. In this way each faculty has the chance to work with students in the projects of his/her interest while students have the freedom to choose among different project areas offered by all faculty. The course implementation presented here refers to Spring 2011. There were five students enrolled in the course; four of them opted to work with the instructor in charge of the research course and one worked with a different faculty member in the field of astronomy.

The course provides an opportunity to better understand the role of theoretical and experimental research in physics by carrying out independent research under the close supervision of a faculty member; it involves reviewing the physics literature, conferencing with the faculty supervisor, and independent research and laboratory work. The experimental work is conducted in the Applied Electrostatics Lab [10], particularly geared towards applied electrostatics (in a more general sense). The research capabilities of the recently developed lab include electrospray and electrospinning, high speed imaging of droplets, micro and nanoparticle generation, thin films deposition, ferro-fluids, and gas discharge studies (see Fig 1). Students were explained that much of the research will revolve around electrosprays and micro and nanoparticle synthesis by this method, although their research experience could cover other topics as well.

At the end of the course, students were expected to become proficient in topics related to electrostatics, electrosprays and their applications in nanotechnology; also, it was expected that they conducted systematic work in the lab, collected and analyzed experimental data, and reached pertinent conclusions.

The main idea of the course was to involve students in real research in a direction they like within the capabilities of the available lab and using additional research facilities and equipment at our university. A few introductory lectures initially offered on applied electrostatics and electrosprays complemented the details on the available lab choices. In addition, safety instruction was delivered with specific care on the high voltage guidelines that must be followed in the lab. Students were informed in the syllabus that as part of their evaluation in the course they have to give a presentation during the term, present their work at the local student conference, and give a final talk in front of Physics faculty and open audience.

Another key idea of the course was to dispel the usual student impression that can easily develop during undergraduate studies that almost everything is already known. If traditional courses emphasize the learning of known concepts, this research course, on the contrary, focused on unveiling the unknown. Students were thrilled to work on something not yet discovered, but they also might have had doubts that they could do such a thing and they needed help, as undergraduates have significantly less time for research than graduate students do.



Fig. 2 Setup using an electromagnet for controlling the electrospay.

Upon two weeks of general research and familiarization with the lab equipment and capabilities, students were interviewed in an informal manner and specific projects were assigned to each student; also, a plan of investigation was spelled out in consultation with the instructor. No specific textbook was used, but many research articles were customized to the area of research preference specified by each student. The course was assigned a specific time for students and instructor to usually meet in the lab, work on specific tasks, and exchange ideas. Each student had a lab key and could access the lab independently. Individual projects were approved:

- Electrospays of Water-Based Ferrofluids
- Magnetically Controlled Electrospays
- Amorphous NaCl particulates synthesized by means of electrospay
- Synthesis of microfibers with magnetic properties

Two of the students had exceptional ideas about directions of research they wanted to pursue, but all the projects were original research. Ferrofluids are normally used for lubrication, sealing, cooling, or as educational or artistic material. However, little is known about electrohydrodynamic atomization of these fluids and according to our research no specific study was actually reported on their electrohydrodynamic atomization. One of the main issues in electrospay research is their control. As fluids carrying electrospayed superparamagnetic nanoparticles can be influenced by the magnetic field, a new way of controlling the spray can be developed. Synthesis of microfibers with magnetic properties that can be assembled as magnetically controlled filters can be another interesting idea. Finally, engineering crystal synthesis by means of electrospay (Fig. 3) is largely an open field in which we have already had some interesting results.



Fig. 3 a) Student working in the lab on crystal synthesis by means of electro spray; b) the high voltage module.

Moreover, with the recent purchase of a research-grade SEM (not available at the time of the project) the opportunities in this direction are countless. Each project, given enough time, could potentially be developed into a master's or doctoral research.

As research progressed, the group (Fig. 4) also met for informal discussions of individual projects and other topics at a campus café in a relaxed atmosphere. Although individual projects were assigned, students also worked as a group, shared their results with their peers, and actually helped each other. During the fourth week of the semester an evaluation of research progress was conducted. About 30 minute individual conferences in the instructor's office were used to assess the progress, plans and needs of each student enrolled.

Challenges were encountered all the time and the team learned how to overcome or bypass problems. For instance, there was need for an electromagnet with intense magnetic field to be applied on the electro sprays. A spare one was identified and borrowed for the duration of the course. The entire system with its control units had to be transported and modified for the purpose.



Fig 4. Students and instructor outside the laboratory building

Attempting to measure the corona and electro spray currents in magnetic field turned out to be ineffective due to the small nature of the currents (in the range of nano to micro amperes) and the large electromagnetic noise in the room. After making the necessary arrangements, the system was moved in an anechoic chamber available in the department where experiments and measurements could be performed.

A 3-D printer was projected to be modified to work in conjunction with an electrospaying system. The order was placed for the device but it was not received in time to effectively use it in the project. The project had to be modified to what was already available in the lab. We certainly see here the limitations of the one-semester capstone as opposed to longer ones.

There were certain difficulties we had to deal with due to limited lab space and the necessity to move or dismantle some setups in order to run the desired experiments.

Nevertheless, most of the problems were resolved or avoided successfully. Students were challenged but also rewarded by the solutions found and the continuation of their research. They learned to be tolerant and accept constraints related to sharing the lab, equipment, and limited funds for acquiring needed supplies and materials for research.

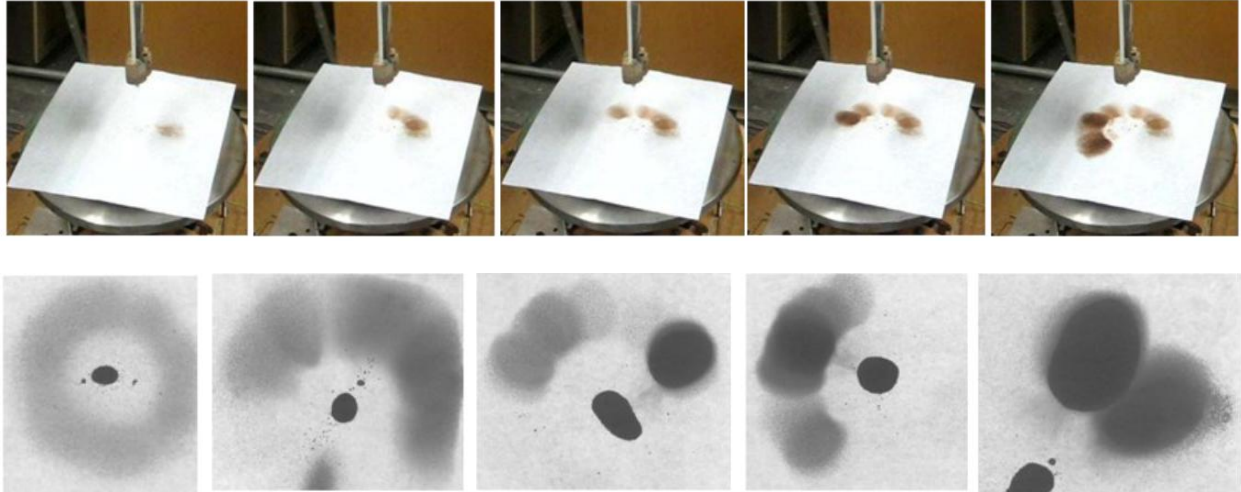


Fig. 5 Patterns of ferrofluid electrospray in a transitory regime [12].

Students were encouraged to analyze the collected data on time in order to present at a local student conference. The fundamentals for poster design were also explained. Students came up with the poster title and content according to the guidelines. A group talk at the conference was also organized where all the group members presented. The audience really liked the presentation. During the final stages of the research course an abstract and later a paper based on student research was sent for consideration in an international conference [12].

As announced in the syllabus, a final presentation of the projects was organized during the last day of the final exams week. The talks were announced in advance and Physics faculty were invited to attend. Students prepared for the talks and did a very good job, except for one student who could not be present.

Assessment

The assessment of student achievement in this course was performed

1. directly, by monitoring student progress and required student presentations and
2. indirectly, by collecting faculty feedback on presentations, presentations in local, regional, and international conferences.

The analysis and results of the laboratory work were presented at local and international conferences [11-16]. Many of the presentations were very good and excellent. One of the students presenting in a conference [12] was awarded second place for the best student presentation (in a student pool otherwise consisting of graduate students only).

It is noticeable that although we were based in a Physics rather than a Physics and Engineering department, many ABET program outcomes were satisfied in the course: program outcomes (a), (b), (c), (e), (f), (g), (j), and (k) [17] are easily satisfied. Students developed skills and ability to apply knowledge from mathematics, physics, and engineering. They developed their ability to design and conduct experiments, as well as to analyze and interpret data. They designed new setups and systems within constraints such as economic, health and safety, and ethical. They gained an ability to identify, formulate, and solve scientific and engineering problems. Students were helped in their projects to better understand professional and ethical responsibilities. They had different chances to present their work and hone their ability to communicate effectively. Moreover, their work on new topics helped them develop the ability to use techniques, skills, and modern engineering tools.

Student feedback was collected on many occasions through informal discussions with students. Here are some student comments from the evaluation sheets:

- *The professor is very open to student ideas and invests a lot of time in helping us pursue them. It's been educational and a lot of fun in the lab.*
- *This is a great class. We get the opportunity to perform hands on research, which I feel is a definite benefit.*
- *Excellent course. The instructor is one of the most helpful Professors here. He is a pleasure to work with in and out of the classroom.*
- *Thank you for all that you have done for me.*

Student evaluations have also averaged 4/4 for the course, showing an obviously pleasant student experience.

Conclusions

We report a successful implementation of a capstone course in a Physics program making use of a recently setup lab. The course design was such as to allow students great freedom in terms of project topics and directions of research. All project topics were significant real research topics to which students were exposed. Various challenges were used as opportunities for solving additional engineering problems, for developing a scientific and engineering-oriented mind, for extrapolation and integration of knowledge from different fields. Students were enthusiastic and enjoyed the course, which was different from any standard courses they had had in school. They successfully presented their work in local, regional, and international conferences. The course appears to have performed well with respect to many of the ABET outcomes.

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