AC 2008-1677: TRAINING UNDERGRADUATES IN THE BROADER CONTEXT OF THE RESEARCH ENTERPRISE

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Training Undergraduates in the Broader Context of the Research Enterprise

Abstract

Undergraduate students participate in research through a variety of mechanisms, including on-campus research assistant positions, summer research experience programs, independent study research credits, and even research-oriented degree requirements. Educators from several units on our campus have collaborated to develop undergraduate-level training materials associated with the context of research. Topics covered include the scientific method, ethics in research, documentation and treatment of research data, publication practices, presentation of results, the structure of the broader research community, the graduate school application process, effective presentations, and abstract writing. The "learning objects" (videos, readings, case studies, and discussion activities) we created have been used to introduce undergraduates to the conduct of science and engineering research. These resources have been tested in formal classroom and seminar venues, through an "Introduction to Engineering Research" course in our Engineering Physics bachelor's degree program and a seminar series offered to undergraduate students engaged in research with the Materials Research Science and Engineering Center (MRSEC) at the University of Wisconsin - Madison.

Introduction

In response to initiatives by the National Science Foundation, including the Recognition Awards for the Integration of Research and Education (RAIRE), as well as a growing realization that undergraduate researchers benefit from training in ancillary research skills such as searching the scientific literature or presenting research findings,[1] many institutions have developed undergraduate research programs that incorporate additional training on research skills as part of their mission. In addition to providing undergraduate students with opportunities to pursue research projects with faculty members, these programs also offer workshops,[2,3,4] courses,[5,6] and even "boot-camp"-style summer research experiences[7] that focus on topics such as performing scientific literature searches, the role of the engineer in society, research and engineering ethics, communicating research findings, careers in research and even applying to graduate school.

The topics covered by these programs and the ones we describe below are among the issues that the Council on Undergraduate Research points to as critical for a successful undergraduate research experience associated with "socializ[ing] students in the research laboratory culture."[8] This ranges from topics as diverse as the values and ethics of research, safety, group dynamics, intellectual property, and graduate school applications. Lessons on many of these topics have been presented for young scientists in the National Academies' "On Being a Scientist."[9] In particular, this resource highlights case studies and advocates the active learning technique of "collective deliberation" on the topics in a group discussion format. In addition to the National Academies' booklet, there are a number of resources available that provide cases on the responsible conduct of research and guidance for instructors (or discussion facilitators) and on how to guide this process of learning and discovery.[10,11,12]

In our experience, the open ended aspect of case studies may be less comfortable for students (and faculty) trained in science and engineering because there is no single right answer and conclusions are arrived at through deliberation, but there are numerous benefits to be gained from this type of active learning approach. Active learning approaches such as peer instruction,[13] group discussion,[14] and cooperative learning[15,16] in college-level science courses have been demonstrated to increase both conceptual understanding of science topics and quantitative problem-solving skills compared to traditional lecture approaches.[17,18] The use of active learning methods has also been shown to increase student attendance and to decrease attrition rates.[19] Although it is often challenging for instructors to adapt their courses to incorporate more active learning, we have found it to be easier to incorporate active learning tools and techniques when these concepts are designed into the course from the beginning.

Background

In fall 2004 the Department of Engineering Physics at the University of Wisconsin – Madison introduced a third bachelors degree program with the name "Engineering Physics" (EP); this was in addition to graduate and undergraduate degrees already established in Nuclear Engineering and Engineering Mechanics (with an Astronautics Option). The EP majors spend two years on common math, science, engineering and liberal electives courses and then specialize in a research-active emerging technology focus area in their last two years. Based upon emerging technological opportunities and EP faculty research expertise, three focus areas were chosen: (1) nanoengineering, (2) plasma science, and (3) scientific computing. The EP majors work closely with a faculty research mentor and receive eight research credits over their last four semesters and complete an honors thesis.

The key outcomes anticipated in establishing is new BS in Engineering Physics curriculum were: (1) a research-oriented undergraduate experience that prepares students to succeed in highly competitive graduate research programs or high-tech industry positions; (2) a new engineering degree whose structure and approach will serve as a model for other engineering departments across the country pursuing innovative reforms; and (3) a reformed curriculum and teaching model that will not only benefit students in EP but will also benefit students in other engineering and science degree programs at UW.[20]

The cornerstone to a successful launch of a student into a research project is a new course designed for the EP degree program, EP 468 *Introduction to Engineering Research* (the first in a series of four courses in the research sequence). In this one-credit course students are introduced to issues in the context of research. An outline of the syllabus from a recent offering of the course is given in Table 1. The main objectives of EP 468 are to provide: (1) content knowledge relevant to the conduct of research, apart from specific technical skills, (2) a supportive framework for engagement in research, (3) connections to other EP majors, and (3) opportunities to find a research project topic and a research mentor. In subsequent courses in the research sequence, students work with their faculty mentors to formulate a research proposal, conduct the research to solve or otherwise address the problem, and present their research in a written thesis and oral defense of the results. Throughout this process, the advanced students meet weekly to develop and hone their skills. Frequently the advanced students meet in conjunction with the EP 468 students to provide guidance and promote community amongst the majors.[18]

Table 1. Syllabus topics form the Fall 2007 semester of EP 468 *Introduction to Engineering Research*

Week 1:	Introductions - Expectations – Strategies for Identifying a Research Project
Week 2:	Scientific Method – Developing a Research Proposal
Week 3:	Library Skills - Literature Searches
Week 4:	Reading a Journal Article - Reviewing – Intro to “Journal Club”
Week 5:	Communicating about Research - Writing a Scientific Paper/Proposal
Week 6:	Publication, Authorship - Intellectual Property - Patents, Copyrights, Trademarks
Week 7	Treatment of Data - Documentation of Research
Week 8:	Engineering Ethics – Error, Negligence, Misconduct
Week 9:	The US Model of Research Universities - The Physical and Social Environment of Research – Safety
Week 10:	The Role of the Engineer in Society - Engineering Research Careers
Week 11:	How to Work in a Diverse Research Team
Week 12:	Funding of Research
Week 13:	(class cancelled)
Week 14:	REUs – Graduate School - Scholarships and Fellowships
Week 15:	Wrap Up Discussion

Early on in the process of developing this major and particularly in the creation of EP 468, it was realized that there were numerous faculty and staff at the university with similar goals for undergraduate students in other research-oriented programs. The course materials being developed were seen as a mechanism for benefiting students in other engineering and science research programs and building connections between faculty and staff across science and engineering disciplines. A working group comprised of seven faculty and staff from engineering, chemistry and biology was convened and a list of core concepts and topics in common to the learning objectives of these various programs was developed.

One of the outcomes was the development of a list of learning objects that could be used by multiple programs. The learning objects themselves would take the form of short videos by experts, readings, and discussion activities. The topics encompassed a number of skills and issues relevant to undergraduates pursuing research. Table 2 provides a catalog of the topics identified by the working group. One of the key objectives was to provide opportunities for active learning with the use of the learning objects to enhance student engagement in a classroom or seminar environment. By active learning we mean activities that engage students in doing something besides listening to a lecture and taking notes. There is ample evidence to show that these instructional practices yield superior results to “conventional” classroom lecturing.[21,22]

Ultimately, the creation of learning objects was prioritized by the needs of EP 468 and a new seminar for undergraduates engaged in research with the Materials Research Science and Engineering Center (MRSEC) at the University of Wisconsin – Madison. The MRSEC Undergraduate Seminar Series was initiated in the Fall 2007 semester and involved undergraduates working with MRSEC faculty in a research capacity. To maximize participation in this optional seminar, students were encouraged by their research advisors and provided the incentive of a free dinner. In the Fall 2007 semester, seminars on the topics of "The Scientific Method", "How to Document your Research", and "Research Ethics" were conducted.

Table 2. Topics in the Context of Engineering Research

- Scientific Method
- The Role of the Engineer/Scientist in Society
- Working in a Diversity in Research Team
- Ethics in Engineering/Scientific Research
- Error, Negligence, Misconduct, Human Subjects in Research
- The Basics of Laboratory Safety
- Literature Search Skills
- Strategies for Reading Journal Article
- Peer Review of Scientific Papers
- Plagiarism
- How to Document Your Research
- Treatment of Research Data
- How Research Is Funded
- Student Research and Intellectual Property
- Publication, Authorship, Patenting, Copyright and Trademark
- Writing an Abstract
- Presentation of Research
- REU and Fellowship Opportunities for Graduate Study
- Research Career Paths

We plan to make the short videos and discussion activities, as well as an annotated compilation of readings and other resources, publicly available in the summer of 2008 via the website of the Interdisciplinary Education Group of the MRSEC at the University of Wisconsin – Madison.[23] Although the initial creation and compilation of videos, activities and readings for both the EP 468 course and the MRSEC Undergraduate seminar series was quite time-consuming, we plan to utilize these resources repeatedly in the future. It is also our intention that by publishing these resources on the internet, others who may wish to implement similar courses, seminars or individual modules within a course will be able to do so with a lower time investment.

Results

We will focus on the topics of *Writing a Scientific Paper* and *The Scientific Method* and the quantitative and qualitative data collected in Fall 2007 from students in both the EP 468 and MRSEC Undergraduate Seminar settings.

Topic: Writing a Scientific Paper

Because the EP 468 course only meets once a week and has a significant amount of material to cover, some topics are treated only by out of class work and other topics by in class work, or a combination of both. For the topic of *Writing a Scientific Paper* the pre-class assignments involved:

- Listening to a presentation by Prof. J. Blanchard on "How to Publish Your Research“
- Viewing a video by Prof. L. Grossenbacher on "Citing the Work of Others"
- Reading the following short pieces:
  - “Written Presentations” in *At the Bench* by K. Barker
  - “The Basics of Citation” from *Doing Honest Work in College* by C. Lipson
  - “Writing Papers and Abstracts” from *Building a Successful Career…* by P. Dee
- Preparing a *Reflective Writing Assignment* on the topic of:
  “Research the UW’s policy on plagiarism. In your own words, briefly summarize what is considered to be plagiarism.”

In class activities began with a brief discussion of the question "Citation-why do it?" (5-10 min), followed by an activity on the topic of plagiarism (20-30 min). This activity was based on an example on “Quoting Without Plagiarizing” in Charles Lipson’s *Doing Honest Work in College.*[24] Students were given small slips of paper with quotations and paraphrased sentences based on a sentence from a fictional reference *Joe Blow: His Life and Times*, by Jay Schrivener: "Joe Blow was a happy man, who often walked down the road whistling and singing." Students were asked to work with a partner and divide the slips of paper into two categories: wrong and right. This paired activity was followed by discussion about each example and whether or not it was plagiarism. Students were stricter than Lipson suggests in his example and the discussion of proper paraphrasing was quite detailed and involved.

The last part of class was an open ended discussion about the process of writing and submitting papers and proposals (15-20 min). This part of class got into a very interesting discussion about active and passive voice, which prompted a follow up conversation with Prof. L. Grossenbacher (the faculty member in the video they watched), who provided additional information to the class.

Five weeks later, students were given a writing assignment on “What was the most surprising thing you have learned so far this semester about how research is conducted? How did this new information conflict with your prior understanding/assumptions?” Three students commented on the topics that came up in the discussion associated with *Writing a Scientific Paper*.

> Student 1 Response:
> “The phrase ‘publish or perish’ always seems to come up whenever my parents tell their friends that I am interested in research. I did not, however, fully comprehend the intense process that one must undertake when writing a research paper….”
>
> Student 2 Response:
> “One of the most critical steps in conducting research is to publish the work after the research is done. After it is published one could then say that the research they have conducted is done.”
>
> Student 3 Response:
> “I think there is a misconception that the academic world is nobler than and not quite as cutthroat as, perhaps, the business world. … Realistically, I guess this conception is

naïve, and professors, researchers, and other students are not always above claiming credit for the work of others ….."

Although they address different aspects of the pre-class assignment and in class discussion associated with the topic of *Writing a Scientific Paper*, all three responses show an evolution of understanding from prior conceptions about practices associated with scientific research as a result of the class experience. It is especially encouraging to see that Students 1 and 2 are gaining a much greater appreciation for the importance of written communication in the conduct of research, even to the extent that the research itself is not complete until it is published. Student 3 is also developing less idealized view of the people engaged in the practice of scientific research.

Student comments indicated that they perceived the course workload, consisting of pre-class video viewings and readings, and periodic writing assignments (Eight half-page to two-page writing assignments over the course of a 15 week semester), to be high for the EP 468 course. However, students also commented that the workload was worthwhile towards their education as a researcher. The student's grade in the course were determined primarily by the written assignments (80%), with participation in discussions and activities comprising the remaining 20% of students final grade. Because the expectation of participation in the class discussions was made clear in the first week of class, all of the students regularly came fully prepared for the day's discussion and participated actively in class.

The only quantitative evaluation performed in EP 468 was conducted using the standard University of Wisconsin –Madison "Course and Instructor Evaluation" form. The survey was administered on the last day of class after the instructor had stepped out of the room and turned in for tabulation to the department student administrator by one of the students. With the exception of one question out of the 24 applicable questions posed, the mean value of student responses was higher than that of the mean of the department (sample size for the course was 10 respondents, 100% of the students registered; sample size for the department was 191). Particularly high ratings were given on the following questions:

"The presentation (volume, pace, enunciation, handwriting, etc.) was suitable." - score of 3.89/4
"It was obvious that the instructor was interested in the students." - score of 3.89/4
"I could clearly see the relation between the course material and course goals." - score of 3.80/4
"I felt free to ask question or express my opinions." - score of 3.78/4

Topic: The Scientific Method

As attendance at the MRSEC Undergraduate Seminar Series was extracurricular and purely voluntary, pre-seminar assignments were not feasible in this format. Therefore, the objects and activities used for these presentations needed to fit entirely within the course of an hour and ideally involve active participation on the part of the undergraduate student participants.

The seminar on the topic of *The Scientific Method* began with introductions as students helped themselves to dinner. While they ate, students watched a short video of Professor D. Siegel from the University of Wisconsin – Madison History of Science Department on the history of the scientific method. In the video, Professor Siegel expounded upon the historical development of three ideal scientific methods – empirical, rational, and hypothetical – and how these ideal methods relate to real, contemporary research methods. After the video, the seminar coordinator engaged the students in a discussion centered upon students comparing their own research methods and experiences with those presented in the video lecture.

The next half of the seminar was dedicated to an activity based upon that described by Overway[25] in which students explored their intuition versus empirical evidence. In this activity, the undergraduate students formed individual hypotheses about whether it is better to "stay" or "switch" in the Monty Hall "Let's Make a Deal" scenario. Then, as a group, the coordinator and students performed a set of experiments and analyzed the results to determine if they supported their hypotheses or if their hypotheses should be modified. The students participated actively in this game and afterwards, during discussion of the results of the experiments, several students gave unsolicited comments that they had enjoyed the activity. At the end of the seminar, undergraduates were asked to fill out a short evaluation survey. The survey questions shown in Table 3 were given at the end of each of the three seminars offered during the Fall 2007 semester. The overall response to the seminar topic of *Scientific Method* was positive, with students agreeing that the topics was interesting, they would consider taking another seminar, and that they found the active learning format to be engaging. Although slightly lower in mean response, it is encouraging to see general agreement with the statement "I feel that I learned about something important to my experience as a researcher."

In addition to ranking their responses to the questions in Table 3, students were prompted to make additional written comments about the seminar in which they had just participated. Included in these comments were opinions on the format of the seminars, such as "Game was fun but video a bit long", and suggestions for future seminars which included: plagiarism, research ethics, sources of experimental error, writing abstracts, and data and statistics.

Table 3: Student Feedback from MRSEC Undergraduate Research Seminar Series. Students were asked to rank their responses on a scale of 0 (disagree strongly) to 5 (agree strongly). Surveys were collected over the course of two seminars with 20 respondents.

Statement	Mean Response	Standard Deviation
I found the topic interesting.	4.1	0.9
I would consider attending another seminar.	4.5	0.8
I found the seminar format to be engaging.	4.3	0.6
I feel that I learned about something important to my experience as a researcher.	3.8	1.0

Conclusions

We have reported on the preliminary results obtained for a course and a seminar series associated with efforts to prepare and enable undergraduates to successfully participate in research. In addition to developing a course on the topic of "Introduction to Engineering Research" required for students in the Engineering Physics bachelor's degree program and a seminar series for undergraduate students engaged in research with the Materials Research Science and Engineering Center (MRSEC) at the University of Wisconsin – Madison, we have collaborated with educators from several science and engineering units on our campus to identify topics where undergraduates need more knowledge. This has lead to the development of a set of learning objects associated with the context of research. Two topics, *Writing a Scientific Paper* and *The Scientific Method*, were discussed in detailed. Details of both the approaches used and the outcomes obtained were reported. The preliminary results reported are overwhelmingly positive for these topics as well as the others presented in both the course and seminar formats. Further work on developing learning objects for additional topics and evaluating their effectiveness is underway.

Acknowledgements

Support for this project was provided by National Science Foundation grants at the University of Wisconsin – Madison: Materials Research Science and Engineering Center (MRSEC) on Nanostructured Interfaces (#DMR-0079983 and #DMR-0520527) and Internships in Public Science Education (IPSE): Making the Nanoworld Comprehensible (#DMR-0424350). Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the Foundation.

The authors are grateful for the assistance received from numerous Department of Engineering Physics colleagues and others throughout University of Wisconsin - Madison and the surrounding business community in creating videos and other learning objects in their areas of expertise. We also gratefully acknowledge the training provided by IPSE interns Kelly Luster in video production and Heidi Williamson in webpage design.

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