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Report on the Learning Experiences of Undergraduate Students in a Novel Aerospace Engineering Course Integrating Teaching and Research

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Dr. McLaughlin has been a professor of Aerospace Engineering at the Pennsylvania State University since 1986. From 1986 to 2004 he served as head of the department. He received his graduate degrees including the Ph.D. in Aeronautics and Astronautics, from the Massachusetts Institute of Technology and the B.S. degree from the University of Manitoba in Canada. Following his studies at MIT, he was a professor at Oklahoma State University for eleven years and he spent five years as Group Manager at Dynamics Technology Inc., in Torrance, Calif. He teaches and conducts research in the general areas of experimental aerodynamics and aeroacoustics focusing on measurements that connect flow instabilities and turbulence to the radiated noise. High-speed jet noise experiments in the high subsonic and supersonic flow regimes have provided major databases for the validation of developing jet noise simulation codes. With student advisees he has pioneered the use of unheated helium-air gas mixtures to simulate hot supersonic jets for aeroacoustic experiments. The experiments have helped develop scaling methodologies for prediction of the aeroacoustic properties measured in larger government and industry facilities. More recent contributions have been pursuing a noise reduction method for which a patent application has been filed as a co-inventor. He has widely published the results of his research and continuously presented findings at national meetings and invited lectures. Dr. McLaughlin is a fellow of the AIAA and the 2010 winner of the AIAA Aeroacoustics Award. He has served on several advisory panels including the FAA REDAC Committee. He is a past chair of the Aerospace Department Chairs Association, the AIAA Aeroacoustics Technical Committee, and the AIAA Academic Affairs Committee.

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Abstract

This study concerns the learning experiences of undergraduate students in a pair of loosely connected undergraduate Aerospace Engineering courses that integrate teaching and research. The first one-third of each course is devoted to conventional lectures and/or laboratory exercises with computer interfaced data acquisition systems. The latter two-thirds focus on design and research projects in Aerospace Engineering with a few lectures interspersed. The teaching method has some unique characteristics: i) Undergraduates gain a research experience by working in small groups of two or three students supervised by a volunteer graduate student research mentor, ii) The particular research project is developed by the course instructors and the volunteer graduate student research mentor in advance of the course as one related to the graduate student's thesis research, and iii) The research projects integrate departmental facilities and capabilities for continued research in design, fabrication, experimentation, and computation for future teaching or research activities. The present study analyzes the experiences of the undergraduate students by exploring the following research questions: 1) In what ways do undergraduate students benefit from these courses' teaching methods? 2) How did this experience affect undergraduate students' interest or motivation for continued research in a particular area? and 3) What are the particularly important aspects of the instructors' responsibilities that require attention in this teaching arrangement? Pre- and post-course surveys along with interviews in focus groups were used for data collection. The benefits for the undergraduate students related to their future careers are addressed in the paper along with the difficulties encountered in the group dynamics, communication skills, and uneven time commitments.

Introduction

Integrating teaching and research in senior-level coursework in Aerospace Engineering has evolved over the past several years. Research has shown that, regardless of the particular type of research, undergraduate students benefit from these experiences in different ways. Not only are research projects proven to increase undergraduate students' skills in collecting and analyzing data[1], but they have also been found to enhance students' awareness of what it is like to be a graduate student, thus opening further options for their career paths.[2] To some extent such integration of teaching and research is reasonably common in senior level capstone design projects. A common aspect of such design projects is the establishment of student teams who work together with little day to day supervision to meet a project goal, normally set by the overall course instructor. At Penn State University, Departments of Mechanical and Electrical Engineering have conducted such a project activity course in which students form teams to work on design projects under comparatively modest levels of faculty and teaching assistant supervision.[3] In these courses the project goals are provided by industry, and the level of expertise of the faculty and teaching assistants on the specific design projects is often quite modest. The University of Colorado, Boulder has a similar capstone design course in their Aerospace Sciences Engineering Department that enjoys considerable industry sponsorship that accompany their generated project ideas and goals.[4] Such support has been cultivated over many years of similar projects that have produced accomplishments that have sustained the financial support of the industrial participants. Such sponsorship has been of sufficient level to support assistantships for graduate students working in similar technical areas as the projects. These students provide the day to day supervision required to produce the quality of the work required to develop a self-sustaining program. The National Science Foundation funds programs that provide support for faculty and graduate students called "Research Experiences for Undergraduates" that provide some excellent activity for undergraduate students.[5] Securing such support for an extended period of time should not be a realistic expectation.

In the Aerospace Engineering Department at Penn State University, a course delivery method has been developed to meet the needs of students interested in research (or project engineering) with manageable levels of institutional support. The goal of the activity is to provide "hands-on" components that are relatively similar to activities experienced by professional engineers in industry or research laboratories. This experience for undergraduates has been met with an opportunity for graduate students (and sometimes faculty) to make faster progress on a nascent research project for which little infrastructure in terms of experimental facilities, or analysis computer codes, exist. In such a situation, it is not uncommon for undergraduate students to have skills in CAD, hands-on machining and fabrication, or computer programming at a level to allow them to make serious contributions to a university research project.

Involving a significant number of undergraduate students in research projects led by faculty members typically requires an extra amount of supervision. If separate funds for the extra supervision are not provided, such arrangements are difficult to sustain. Inadequately supervised undergraduates can cause set-backs in the research and barriers to future opportunities. Because of this, it is not surprising that serious involvement of undergraduate students in university research programs remains limited.

It is not typical for engineering graduate students to derive much experience in project management (or leadership) during their conventional graduate studies. Therefore, establishing an arrangement where graduate students can serve as mentors to groups of undergraduate students provides an opportunity for some supervision/management experience. Ideally, the chosen ***graduate student mentors*** have had a few semesters of graduate work to "get a start" on their research so at least the technical advice they provide meets a reasonable standard.

The new concept of our approach is that undergraduate students will obtain a significant research experience working under direct **mentorship of experienced graduate students,** and the whole course is structured on this basis. A schematic diagram of such an organization (and mentorship) is shown in Figure 1 below. In practice, a hierarchy of graduate students work with a senior PhD student and the course instructors to provide a meaningful learning experience for all involved, particularly the undergraduate students. Another aspect of our teaching approach that we feel is quite unique is that a large number of the undergraduate research projects continue over multiple semesters, though with different team members.

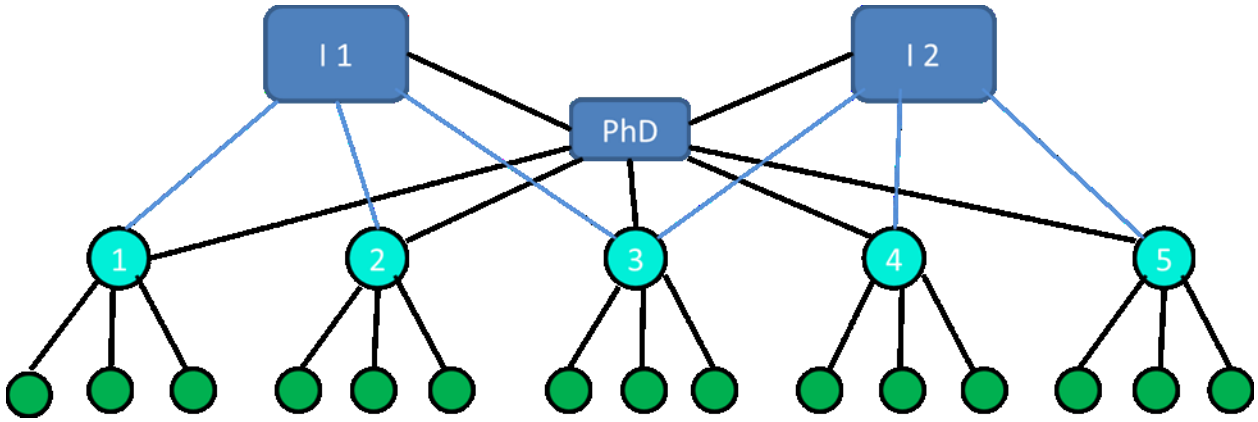

Figure 1. Initial Organization of Instructors and Students in Course.

Figure 1 depicts the organization we are currently trying to follow. Fifteen students (green circles) and 5 graduate student mentors (turquoise circles) are shown for demonstration. Each project has a ***graduate student mentor*** with only the most experienced students supervising more than one project. The graduate students meet with their undergraduate team(s) a couple of times a week (ideally) and are available for consultation at other times. These graduate students are volunteers who are involved in some aspect of project engineering in their own research. They are chosen largely on their understanding that, to receive the benefit of undergraduates working on their project, they will be required to invest much more time at the beginning than simply undertaking the specific tasks themselves. Such mentoring abilities require considerable coaching by the instructors and the senior PhD student.

During the first couple of offerings of the developing courses there were not enough interested and experienced graduate students to produce the mix of mentors required to provide one for each 3 undergraduate students. As with anything done for the first time, it is common for new graduate students to perform below expectations in their first mentoring experience. Initially, the instructors and the experienced PhD student needed to spend more time providing project supervision than will be required in the equilibrium state of the courses, one that can be self-sustaining. During the courses' start-up, some graduate students have been chosen for the mentor positions without adequate and proven experience. Some of the newcomers do well, but some falter, for any number of reasons. Recognizing this to be the case, careful monitoring of all projects is conducted by the instructors and the PhD student assistant. A "mid-course correction" is often taken in the organizational structure; noted by the red lines for increased supervision and dotted lined for decreased involvement. Figure 2 shows how the instructors shift supervision to get more directly involved with the undergraduate students and put more emphasis on coaching the "younger" graduate student mentors. It is also recognized that a certain number of these adjustments will be appropriate even after the courses are well established.

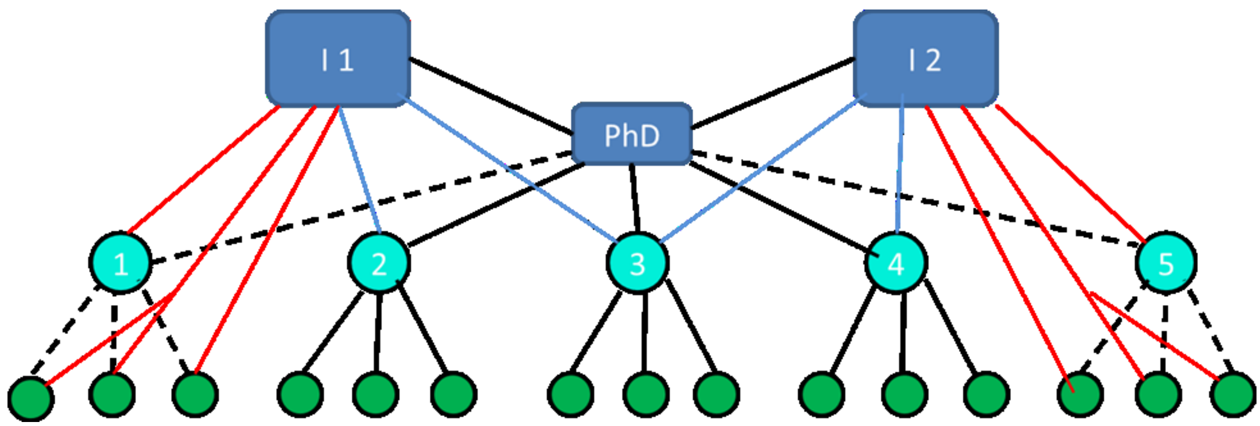

Figure 2. Supervisory Structure Following Mid-Course Correction

Pilot Courses

This work is the beginning of a longer-term study focusing on the learning experiences of undergraduate students conducting research projects in small teams under the direct supervision of a graduate student mentor. The two undergraduate courses that used the graduate student mentoring technique were:

1) AERSP 405 "Experimental Methods and Projects" and
2) AERSP 497C "Wind Energy Engineering and Projects".

These courses were taught in: i) AERSP 405, Fall 2011 and Fall 2012, and ii) AERSP 497C, Spring 2012 and the current Spring 2013. So far, both courses have featured a significant amount of project work while the AERSP 497C course focused only on projects related to Wind Energy. The AERSP 405 course included a wide variety of projects related to Aerospace Engineering, including a few wind energy projects. Both courses devote about 3 weeks to conventional classroom instruction that covers the basics of data acquisition systems and data management.

For the AERSP 497C course, an emphasis is given to the wind turbine system as a whole including teaching the fundamental aerodynamic principles that define blade loads and power production of modern wind turbine systems.

Assessment

Several assessment strategies were used in the fall 2011 and spring 2012 semesters to learn about the undergraduate students' experiences of the courses' teaching methods. Pre and post surveys were administered to the undergraduate students at the beginning and end of each semester. These surveys consisted of 11 items that had the goal of learning how the course teaching methods, mentors, and research/project work were helpful to students' learning. In addition, at the end of each semester, undergraduate students participated in focus groups and graduate students and faculty participated in individual 20-30 minute interviews. Finally, several class and lab sessions, as well as some individual group meetings, were observed by an engineering education researcher. The main research questions that were of interest to the instructors and education researcher are:

1) In what ways do undergraduate students benefit from these courses' teaching methods?

2) How did this experience affect undergraduate students' interest or motivation for continued research in a particular area?

The data collected during the surveys and interviews are presented below. It has to be kept in mind that, so far, a limited amount of data were collected. Therefore, this works can be seen as a preliminary study.

1. Surveys

The pre survey administered in the fall 2011 semester was completed by 20 students (of the 24 undergraduate students enrolled), and the post survey was completed by 22 students. Of the 8 items, 5 had an increase in means from pre to post, as seen in the table below:

Table 1: Fall 2011 pre and post means

	Mean (Pre)	Mean (Post)	Delta
1. The way this course is taught helps me learn.	3.95	4.42*	**0.47**
2. I enjoy doing undergraduate research.	4.53	4.47	-0.06
3. My team works well together.	4.32	4.37*	0.05
4. My choice of research topic is interesting.	4.58	4.47	-0.11
5. Having a graduate mentor is helpful to my learning.	4.11	4.61*	**0.50**
6. Working with my team is helpful to my learning.	4.16	4.11	-0.05
7. I would like to attend graduate school after I graduate.	3.21	3.58*	0.37
8. I would like to take another course that uses similar teaching methods.	3.89	4.21*	**0.32**

* Increase in means from pre to post.

\+ In Fall 2011 there were a small number of students working Wind Energy projects.

The data were analyzed using a chi-square goodness of fit test. Statistically significant differences approximately at the 0.5 level from pre to post were observed for the following items:

- The way this course is taught helps/helped me learn.
- Having a graduate mentor is helpful to my learning.
- I would like to take another course that uses similar teaching methods.

The fall 2011 surveys indicate that the course had a positive effect on students' learning and appreciation of teaching with graduate student mentors.

The pre and post surveys administered in the spring 2012 semester were completed by 12 students (of 15 students enrolled). Of the 11 items, 6 had an increase in means from pre to post (see Table 2).

Table 2: Spring 2012 pre and post means

	Mean (Pre)	Mean (Post)	Delta
1. The way this course is taught helps me learn.	4.08	4.50*	**0.42**
2. I enjoy doing undergraduate research.	4.75	4.58	-0.17
3. My team works well together.	3.92	4.58*	**0.66**
4. My choice of research topic is interesting.	4.58	4.50	-0.08
5. Having a graduate mentor is helpful to my learning.	4.17	4.58*	**0.41**
6. Working with my team is helpful to my learning.	4.08	4.75*	**0.67**
7. I would like to attend graduate school after I graduate.	3.67	3.67	0.0
8. I would like to take another course that uses similar teaching methods.	4.33	4.50*	0.17
9. I am good at doing research in wind energy.	3.75	4.17*	**0.42**
10. I would like a career in wind energy.	3.83	3.75	-0.08
11. I would like to do some more research in wind energy.	4.33	4.17	-0.16

*Increase in means from pre to post.

The data were analyzed using a chi-square goodness of fit test. Statistically significant differences at the 0.5 level from pre to post were observed for only two items:

- My team works well together.
- Working with my team is helpful to my learning.

The spring 2012 surveys indicate that the course had a positive effect on students' perceptions of their teams and how working in teams can help their learning. Most students who completed the spring 2012 surveys had taken the fall 2011 version of the course. Prior experience with this course's teaching methods may be a reason why fewer items showed significant positive differences. We are planning on further investigating this in future course offerings and associated surveys.

2. *Interviews*

In the fall 2011 offering, six graduate students participated in individual interviews, and five undergraduate students participated in one focus group. In addition, three faculty members who advised groups participated in individual interviews. In the spring 2012 semester, four graduate mentors participated in individual interviews, and four undergraduate students participated in one focus group. Interviews lasted between 20 and 30 minutes, and were audio recorded and transcribed. The interview data analysis process began with a preliminary exploratory analysis, as described by Creswell[6], to get a general sense of the data. Next, codes, or "labels"[7] were assigned to the data. These codes were then used to determine themes that characterized each interview and themes that were common across interviews.

The interviews revealed information regarding positive experiences for graduate and undergraduate students, what they found helpful throughout the semester, and what challenges they faced as students and/or mentors for this course. These are summarized below. (Note: FG, and F indicate that the source of the information was the focus group with the undergraduate students, or the interviews with faculty, respectively). In this work, we focus on the experiences of the undergraduate students and faculty. An accompanying paper "An exploratory Study of the Research Mentor Experience in a Novel Undergraduate Aerospace Engineering Course"[8] discusses the findings for the graduate student mentors.

Positive experiences for undergraduate students

- Working in a group, on a project – it's what it will be like in the real world (FG, F)
- Having independence and freedom: "[you can] work on what you want during your own time," but the students still had the mentors and faculty to go to if there were any problems (FG)
- Working with the graduate students (FG): the graduate students "actually cared about the project that we worked on."

- It's good preparation for the real world (FG, F): The way the course was taught was "more akin to what we'd be getting in industry" (FG)
- This class looks good on a resume (FG): Having project experience is better when looking for a job, and it is something the students can actually talk about (FG)
- Students learned teamwork and other skills (FG):
    - Students learned things such as "managing a group and dealing with conflicts and stuff like that."
    - Students learned "group skills, time management, being able to communicate technically at a high level, both orally and…in our weekly progress report."

<u>What was helpful to undergraduate students</u>

- The graduate mentors and working in a team (FG)
- The organization of the course: having faculty be in charge, and graduate mentors as the direct contacts, and having group meetings with faculty to get feedback (FG)
- Having the first part of the course be in a traditional class format, learning about different lab techniques, and then going out and implementing what was learned (FG)
- Having regular group meetings with the faculty (FG): The faculty were experienced and "good at managing the projects" and providing feedback. They were helpful in "giving us the background, telling us how the programs run, telling us some of the issues we were going to run into…just that personal communication."
- Being able to do research and hands-on work (FG): it was a "nice change of pace from the classroom"; "it's hard to grasp a subject when you haven't actually seen it or done it…so this was nice"

<u>Challenges for undergraduate students</u>

- It was sometimes hard to work with the graduate student mentors because they often took the lead on a lot of things. Sometimes the graduate student was the one to mostly work with the faculty, with the undergraduates working under the graduate students: "there was like a hierarchy and it… kind of got in the way sometimes." But that's "real-world kind of stuff." (FG)
- "It can get time consuming." (FG)

Other comments about the course

- The variety in the class was good, there were many different options of projects to choose from (FG)
- "Definitely a worthwhile class" (FG)
- Students believe it is a great experience: "I've come out with a lot more than I started coming in" (FG)

The interviews showed that this class provided undergraduate students with experiences that help prepare them for their future careers. While graduate and undergraduate students enjoyed working with each other, they also occasionally experienced certain challenges: undergraduate students felt the graduate students sometimes did not let them participate that often, and graduate students felt it was frustrating to work with the undergraduates because they were not always responsible with their work[8]. Also, the graduate students recognized that the undergraduates would occasionally be much slower at getting things done than they would have been if they had undertaken the tasks themselves. This is a key aspect of this method of teaching. Faculty supervisors can take steps to reduce this problem mostly by coaching the students to include the probability this will occur in their project planning.

Overall, the authors feel that the teaching method has provided undergraduate students with beneficial experiences for their future careers. We are aware that limited data has been collected thus far, however future course offerings will substantiate the dataset and lead to further insight into the educational benefits.

3) What are the particularly important aspects of the instructors' responsibilities that require attention in this teaching arrangement?

The biggest challenge for the instructors is to build and continuously monitor the organizational structure illustrated in Figures 1 and 2. The instructors have to be able to recognize the group dynamics where certain group members grow naturally into a leadership position, while others remain in the background for convenience or due to lack of interest, motivation, or capability. It is here where the instructors have to work closely with the graduate student mentors on assessing these observations and applying appropriate ‘mid-course corrections’ that may involve shifting responsibilities of group members and redirecting a particular aspect of the group’s research project. As researchers, the instructors have learned the difficult, and oftentimes, frustrating process of conducting research. The present teaching method and organizational structure involving the volunteer graduate student research mentors and the ‘senior’ PhD student allows the instructors to better connect to the undergraduate students by means of the various levels of professional development of all participants. The truth is that this requires some additional commitment from the instructors compared to conventional classroom teaching. However, the instructors have recruited some undergraduate students into their research groups after the courses end, in which case the initial time commitment becomes rewarded through a new group member joining a faculty’s research group already partially trained. In order to sustain continuous course offerings with a sufficient number of graduate student research mentors, the instructors have to explain to their colleagues that allowing one of their graduate students to become a volunteer mentor can be beneficial for everybody involved.

Another challenging aspect is that of scheduling departmental facilities and resources. Undergraduate students are inexperienced in dealing with such setbacks and ways of resolving them. It is once more the instructors that work through the graduate student mentors to arouse initiative in the undergraduate students to organize group activities such that required facilities are available to them.

Conclusions

The objective of this work was to assess the learning experiences of senior-level undergraduate students in Aerospace Engineering courses that integrate teaching and research. The assessment was conducted using pre and post surveys and interviews. Though the instructors and educational researcher have a limited set of data available at this stage, we feel that our educational experiment showed promising results in the undergraduate students’ perceptions of their learning, experience, and interest gained in conducting research projects in teams supervised by a graduate student research mentor. The instructors’ challenges are ‘making it work’ as a positive learning experience for the undergraduate students and arousing their interest in academic research and giving a teaching and leadership experience to the graduate student mentors.

Collecting more data is definitely needed to gain quantitative support of the positive experiences of the undergraduate students. In addition, this work leaves us with some questions to think about: 1) Do the undergraduate students' positive learning experiences have any effect on the academic performance of the respective students after taking one of the courses?, 2) In the future, do these students feel that this learning experience was helpful to their careers in either industry or academia?

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