An Innovative Approach to the Introduction to Mechanical and Aerospace Engineering Course: Pressure

Catherine Mavriplis

Mechanical and Aerospace Engineering, George Washington University

Abstract

An innovative Introduction to Mechanical and Aerospace Engineering course is described. The course material focuses on the concept of pressure to relate concepts and subject matters in the intended field. Self- and group-guided inquiry is used in and out of class. Group activities are also prescribed. The course makes use of three non-fiction popular accounts of engineering feats, relating to 1) a high-pressure environment in the deep sea, 2) a low-pressure high altitude environment and 3) the pressure-less space environment. Traditional and reflective homework assignments are used to motivate the students to pursue their intended engineering education. Student outcomes included renewed enthusiasm for studying engineering, discovery of summer job opportunities related to field of study, development of student networks, and a deepening technical sophistication throughout the semester.

1. Introduction

Teaching freshmen an introductory course is always difficult. One has to bridge the large disparities in ability and interest of the students. Engineering freshmen, having typically been the brightest of their high school classes, are blasé about introductory or survey courses. Many of them think they already know what they want to do and others would rather play video games during the lecture. Having taught introduction to engineering classes of over 150 students, I knew it was difficult to get their attention, even with videos of exploding spaceships and catastrophic failures of buildings and bridges. So when I was asked to teach Introduction to Mechanical and Aerospace Engineering and come up with something innovative I decided to change the plan.

The purpose of the Introduction to Mechanical and Aerospace Engineering course in George Washington University's (GW) Engineering program is to introduce the students to the disciplines of mechanical and aerospace engineering, but also to keep their engineering interest from waning while they take freshmen year courses from instructors outside the engineering school (calculus, physics, English, etc). *In Talking About Leaving: Why Undergraduates Leave the Sciences*[1], Elaine Seymour and Nancy Hewitt found that "lack or loss of interest in science" (and engineering) and "poor teaching by

S.M.E. [Science, Mathematics and Engineering] faculty" were two of the four most cited concerns by both switchers and non-switchers. As one student put it:

> "'The first two years in physics are so dull. I mean, they have absolutely nothing to do with what you'll be doing later. I'm afraid that's why you might be losing good students from engineering that are really qualified and have the intelligence. There are ways to make the introductory material interesting so that it doesn't drive away good people through boredom.' (Male white engineering non-switcher)."

Furthermore, students in a focus group convened for a National Science Foundation report[2] identified introductory SME&T (Technology) courses as a major barrier. This same report recommended in 1996 that faculty members:

"A. Believe and affirm that every student can learn; recognize that different students may learn in different ways and with differing levels of ability; and create an environment in each class that both challenges and supports.

B. Be familiar with and use the results of professional scholarship on learning and teaching.

C. Build into every course inquiry, the processes of science (or mathematics or engineering), a knowledge of what SME&T practitioners do, and the excitement of cutting-edge research.

D. Devise and use pedagogy that develops skills for communication, teamwork, critical thinking, and lifelong learning in each student."

Reforms in undergraduate engineering pedagogy have been set in motion in the last few years by innovative faculty members and recommendations such as the one mentioned above. The reforms have been mandated by students in some cases: e.g. Ref. 3. Education and sociological research shows that they are necessary and effective: Astin[4] and Light[5] both showed that students who benefit the most from their undergraduate experience show evidence of successful interpersonal interactions with fellow students and faculty members in the context of "substantive academic work"[5]. However, faster progress in reform has been called for by the US Government as recently as 2002 (see Ref. 6).

"The greatest single challenge to SMET pedagogical reform remains the problem of whether and how large classes can be infused with more active and interactive learning methods." said Elaine Seymour in 2001[7]. Faculty members are often resistant to change, however the changing demographics of the student body require that we adapt our education delivery to include a broader range of personal learning styles and a broader ethnic and socioeconomic range of students.

With these mandates and suggestions in mind, the present course was designed to be innovative, engaging for a breadth of students (and the professor), to involve group and active learning in the classroom and outside of class, to include a sense of personal engagement in the subject matter and the intended academic paths of the students. The innovative approach taken here was to 1) center the course on one concept and show how it relates to many, if not all, aspects of mechanical and aerospace engineering and 2) use instruction methods that are non-traditional for SMET courses but more engaging and perhaps closer to liberal arts instruction methods while remaining technically challenging.

Pressure was chosen as the physical concept. Pressure is a fundamental quantity used to describe and quantify fluid mechanics, solid mechanics, thermodynamics and hence many other topics in both mechanical and aerospace engineering. It is a simple enough concept to reach freshmen: the units are simple and some simple calculations and explanations of concepts can be handled with relatively little prior knowledge. Furthermore, it relates to and uses tools of the first year curriculum: chemistry, calculus and physics. Other concepts could also be used, however this paper describes a course centered on pressure.

The method of delivery of the course was designed to be innovative as well (at least for our engineering school). The principle of self-guided and group-guided inquiry was used. Many educational theories and data show that "... involving students in discussion fosters retention of information, application of knowledge to new situations, and development of higher-order thinking skills -- and discussions do this much better than lectures do."[8] Freshmen experience the transitional education stage, changing from dependent learners (children) to adult learners who need to be independent and exercise control, according to Knowles' theory[9]. Using the self-guided inquiry method as a way to engage students in discovery of the breadth and depth of the mechanical and aerospace engineering disciplines seemed necessary to this instructor, when the traditional method of presenting a large array of topics to freshmen seemed to have failed in previous introductory courses.

In this paper, the course objectives are described, the construction of the course and the method of delivery are detailed, and student requirements are stated. Student outcomes and those affecting the faculty are also described.

2. Course Objectives

The goals of the course are several:

- to introduce the students to the disciplines of mechanical and aerospace engineering,
- to keep their engineering interest from waning while they take freshmen year courses from instructors outside the engineering school (calculus, physics, English, etc),
- to convert as many undecided students to mechanical and/or aerospace engineering,
- to improve retention,
- to introduce the students to the faculty of the department and give them a feeling of belonging to the department,
- to help students with their other courses, namely math and physics,
- to show the students how these disciplines relate to what they want to study: engineering,
- to fulfill requirements of ABET EC2000 accreditation and
- to start the students thinking in an engineering frame of mind.

No small task!

3. Course Construction – Strategies

In order to not lose the interest of those students who may have very different interests from their classmates, several strategies were used. Most lectures were left to open-ended self-guided inquiry on topics relating to pressure. In fact, the instructor guided the students to explore the relationships between their topic of interest and the chosen concept, in this case pressure. Another strategy used was to cover several areas of mechanical and aerospace engineering and yet give the students freedom within those topics to explore their own interests.

Additionally, the work involved in this one credit course needed to be light or at least appear so. For this reason, reading a non-fiction book relating to pressure was required. This requirement was made to make the course more enjoyable for students. Reading a non-technical account of an adventure would hopefully resound with many students as a pleasurable experience. Furthermore, this requirement was assumed to be more typical of a humanities course rather than an engineering one. The students were therefore given the choice of three books or one of their own choosing with the approval of the instructor. The three books chosen were non-fiction accounts, often breathtaking, of some adventure that required a significant technological feat dealing with pressure. The three books selected were:

- *Ship of Gold in the Deep Blue Sea* by Gary Kinder[10]
- *Around the World in 20 Days - the Story of Our History-Making Balloon Flight* by Bertrand Piccard and Brian Jones[11]
- *A Man on the Moon: The Voyages of the Apollo Astronauts* by Andrew Chaikin[12].

The first deals with finding and retrieving a sunken treasure, requiring the consideration of the high pressures of deep-sea operations. The second deals with low pressure, as the balloon flight is at high altitudes. The last deals with the lack of pressure in space. Furthermore, the topics involved in these three accounts were chosen to cover a range of mechanical and aerospace disciplines, to try to catch as many students' interests as possible. Some students chose their own books, in particular one on ascending Mt. Everest[13], addressing the low-pressure environment of high altitude.

4. Course Delivery – More Strategies

Self- and group-guided inquiry was used as the operating principle of each classroom session. There were two sessions per week: one 75 minute session in a computer laboratory where students each had access to a web-browser and one one-hour session in which no computers but only a chalkboard was available.

In the computer room session, the first one of the week, the topic for the day was briefly introduced by the instructor and then the class was instructed to brainstorm to form (as a group) the "organizing questions" for our inquiry of the day. This exercise took roughly thirty minutes. The students were then expected to search online using a web browser for references to our topic of the day in an effort to start to formulate answers to our "organizing questions". The group then reconvened to report their findings and discuss avenues of investigation. Students were expected to continue this self-guided inquiry outside of the classroom.

As an example, one day early in the semester the topic of the day was to discuss the basic engineering challenge of the "Ship of Gold in the Deep Blue Sea" adventure. The professor asked: "How does one find and retrieve a sunken treasure?" The students brainstormed ideas and formulated the following "organizing questions" with which they could frame their investigations:

- How much pressure can a person withstand? And how long?
- What type of vessel would you need to go that deep?
- How much gold would you be able to bring back up? Is the cost worth it?
- How are you going to pick up the gold?
- Decision: manned or unmanned? See what's been done before.
- How do you find the gold?
- How are you going to do it with no light?
- How deep? What is the pressure there?
- How do you counter pressure? How long does it / or can one take?

In their online investigations, the students found many websites covering a wide breadth of topics related to deep sea operations: e.g. biology of the human body and its physiological reaction to high pressures at large depths, accounts of other unmanned underwater research vessels, etc. Often the findings of these investigations prompted further questions thereby opening up an even wider array of technological challenges to the achievement. For example, materials to be used was one such issue that was not identified by the students in the first brainstorming session. In these instances, either the discovery is self-guided or it can be "helped along" by the professor who can ask some prompting questions to guide the discovery process.

In the second session of the week, the one with only a chalkboard, students were invited to discuss their findings from the previous session and out-of-the-classroom investigations and to ask open questions lingering in their minds. This is a chance for the professor to have small off-the-cuff "lectures" about pertinent topics, e.g. how is pressure measured? What kind of units are used? Or why is pressure so high deep in the sea? These discussions were linked to current courses the students were enrolled in (usually physics and calculus) and future courses in the curriculum. After a number of these sessions, students begin to form a better concept of the curriculum and how their first year studies relate to and are necessary for the more advanced engineering specific courses ahead.

In this type of session, students were also grouped by twos or threes by their common interests in a topic related to the investigation e.g. biomedical aspects, materials aspects, robotics, etc., and were asked to further investigate a specific question. For example, students in the robotics/mechanisms group were asked to come up with a preliminary design for a robotic arm that would be able to pick up a gold coin from the ocean floor. Student groups were then asked to report to the larger group of the whole class. This type of activity and the brainstorming one provides opportunities for serious student-student interactions in their discipline of mutual interest. This type of small group collaborative work is one of the intended ABET EC2000 program outcomes criteria (Criterion 3(d)).[14]

5. Student Requirements

Students were expected to:

- read one of the three non-fiction books listed in Section 3 (or to choose a suitable alternate) and report periodically throughout the semester on their impressions of the accounts,
- participate in classroom brainstorming and online research exercises and class discussion,
- participate in small group brainstorming, discussion and problem solving,
- complete four homework assignments,
- complete two hands-on activities: build and fly a rocket from Ref. 15 and participate in the annual departmental Egg-Drop competition e.g. see Ref. 16,
- write a final term paper,
- and several times a semester fill out a one minute anonymous index card where they are asked to complete the following sentence: "I've been sitting here for an hour and I'm still wondering about …"

The index cards are similar to the "one-minute papers" suggested by Richard Light in Ref. 5. They provide an opportunity for students to ask any question in a "safe" (non-public) environment. They allow a time for reflection on the part of the student. They also provide a direct communication line to the professor without having to self-identify. The professor reviews the responses and chooses some to read to the class at the beginning of the next session. This allows the professor to identify any problems in the class (typically complaints), any misunderstood concepts (such as students misidentifying the Greek symbol ρ (density) as p (pressure)), and to track progress in the students' deepening in understanding among other things. By reading the responses to the whole class, the professor makes public the thoughts of the individual students in a non-threatening way. This can help to reassure some students (often females) that their standing or understanding in the course is not way off-base.

The homework assignments contained some formal and usual engineering exercises, such as calculating the pressure at a specific sea depth, but also some personal writing. The writing was of their personal reactions to the books and an account of interviews they were required to initiate and sustain throughout the semester with students of mechanical and aerospace engineering in the three years ahead of them as well as with faculty members in the department. These interviews were designed to help the students get to know the people in the department, perhaps to find mentors, and to familiarize themselves with the curriculum that lies ahead for them. The interviews help to dispel fears by breaking down barriers of the unknown.

The final paper the students were assigned to write was a technical report of the book they read. The students were asked to pick one specific technological development in the engineering project described in the book and present it in a technical manner, i.e. with figures and/or technical drawings, and providing a technical description and analysis if possible, stating the problem and the eventual method of solution. A section on their personal reactions to the book was also required.

The substantial writing and speaking requirements for this course are also useful to fulfill ABET EC 2000 communication requirements (ABET Engineering Criterion 3(g)).[14]

By varying the types of assigned requirements for students, one allows for a wider range of learning styles and provides a variety of opportunities for students to perform and demonstrate their capabilities. It also allows students to browse and discover their own areas of interest and excellence.

Together, the semester-long reading and analysis of the book, the periodical index card surveys and the periodical interviews with other level students and professors provide an opportunity for deepening technical understanding and increased technical and personal sophistication for the students. The assignments related to these three activities provide the instructor with an opportunity for longitudinal study of the student's progress within one semester.

6. Student and Other Outcomes

As mentioned above students were asked to periodically fill in anonymous index cards at the end of a lecture, stating one question that remained unanswered for them. Furthermore, the homework assignments included reflective writing of their experiences and thoughts on the subject matter. Lastly, a final paper was required, in which students wrote about the book they read, including technical analysis and personal reactions. The outcomes mentioned here were deduced from these two sources.

There were many positive outcomes of this experience: for example, some students reported getting excited about topics they never thought they had an interest in, while others started to explore summer job opportunities related to engineering topics discussed in class. Some even stayed up all night to finish reading their book!

In terms of motivating students to study mechanical and aerospace engineering, as a part of the first year experience, the reading assignments were successful. Most students reported that they enjoyed reading the books and participated well in the classroom discussions and exercises. Here is a typical quote from a student at the end of the semester:

> "I'm really glad I read *A Man on the Moon* because it helped me rekindle my interest in space and space travel. After attending the Advanced Space Academy in Hunstville, Alabama three years ago I developed a desire to work for NASA and to become part of our nation's space program. However, over the last year I have become less enthusiastic about it and I'm not sure why. But reading this book reminded me of why I wanted to work for NASA in the first place. I loved the teamwork, the problem solving, and the exploration and adventure; that is what Apollo is all about."

Few students (< 7%) said that they did not enjoy the readings.

The richness of the three engineering projects described in the books provided endless sources of development of interests. Furthermore through the commonalities of the described projects, students learned on their own some of the intended lessons of an introductory engineering course: e.g. that teamwork is key to engineering development. As one student wrote about the Apollo missions:

> "Over and over again in the book, the astronauts that Chaikin interviewed reiterated the amount of team work and the number of people that contributed to this victory."

The process of self-discovery is usually better than having a professor tell you it is so in a lecture, as shown in educational research[9].

Self-described reactions show a growing technical sophistication throughout the semester. One student, who was behind most of the semester and almost did not write the final paper, finally wrote in his end-of-term paper:

> "I remember watching the news about this flight [the 1999 around the world balloon flight of Piccard and Jones] when I was in high school. Although I must admit I did not watch it closely, I remember thinking about how hard it must be to do something crazy and yet amazing like a balloon flight around the world. […] But in reading this book I was inspired by the actual flight. […] I was also completely amazed by the technical challenges of the balloon flight as described in the book. I was amazed at how such a massive piece of fabric could be constructed and how they decided on which were the right materials to use. […] I was a little bit reluctant to read this book in the beginning, however after I got into it, I was amazed at what I learned technically and personally."

Many students thanked the instructor for choosing several books, informing her that they enjoyed discussing the different books with each other. The choice of several rather than one book therefore aided to cover a larger spectrum of mechanical and aerospace engineering topics. It also helped to reach more students and to keep them interested.

The course had outcomes on people outside the classroom as well. Through the interviews, upper level students had interesting comments and realizations. One junior said in her interview:

> "I never realized how much of this major is about pressure until you started asking questions about it."

The interviews with professors and students revealed the differences in communication styles and sharing. When the students told them about the book they were reading, many of the professors said they didn't know much about it and turned the conversation subject to something they were experts in; whereas the upper level students tried to relate the subject to courses they had taken and asked questions about the book and expressed interested in the subject. These findings reinforce the idea that near-peer interactions are not only safer for students but often more fruitful.

The index card exercise allows the instructor to take a "pulse" of what's going on in the students' heads. For example early in the semester responses to the "I've been sitting here for an hour and I am still wondering about…" question covered a wide range: for example,

- "the relationships between pressure and temperature. Is it possible to boil water before the temperature reaches 100C?"
- "how calculus is applied in the real world. I specifically want to know how I'll know when to use spherical and conical integrations because they still confuse me."
- "how vacuum tubes amplify electric signals."
- "how a CD plays music."
- "about galaxies."
- "if I made the right choice switching from computer science to mechanical engineering in the view of graduating on time and being behind. Although I like this a lot better than computer science."

Midway through the semester a similar exercise where students were asked to complete the sentence "I've been sitting here for half a semester and I am still wondering about…" elicited the following responses:

- "I would like to learn more about pressure and movement in space."
- "at what point there is no more pressure in the atmosphere."
- "chemical reactions and pressure. Most specifically combustion and power as in a car engine."
- "if we could discuss how pressure is used in different fields like music."
- "jet propulsion."
- "control systems for pressure."
- "the manometers. I know you've explained it multiple times – I think I just need to sit down and work through it."

Absent from all the responses were any worries about performance in this or other courses, graduation, etc. (which had made up 40% of the early semester responses). The students became more interested in pursuing engineering interests.

Unfortunately, conclusions on retention cannot be made at this time since the course was only offered once. Enrollment figures only show that there were no dropouts but a gain of one student in the semester following the delivery of this course. Similarly, conclusions on the improvement in quality and diversity of the students cannot be drawn from one instance of the course. The intent was that this alternative format would be effective for a larger percentage of learners but this has not been measured other than from the qualitative reactions of the students mentioned above. Further implementation of the course over a number of years and tracking of student performance over that time would help to clarify the conclusions.

7. Conclusion

By restructuring the introductory mechanical and aerospace engineering course to be centered on the fundamental concept of pressure and by using innovative and self- and group-guided inquiry teaching techniques, the author has developed a course that engages a wider range of students and deepens student learning and sophistication. The introduction of reading assignments of non-fiction accounts of extraordinary engineering feats helped to keep the interest of a large percentage of the students and provided a structure from which students could explore their own interests in their chosen field of study. These reading assignments and other reflective teaching techniques, non-traditional to engineering, helped to students to develop self-confidence and take a more active part in their career plan.

Acknowledgements

Many of the ideas for this course, particularly in the self-guided inquiry method were developed by the author and her colleague Rachelle Heller, a professor of Computer Science at the George Washington University, when they designed and co-taught an Interdisciplinary Science and Engineering Science Seminar reported in Ref. 17. That seminar development was funded by the National Science Foundation under Award #9714729. Dr. Heller provided helpful suggestions in the design of the present course. Many of the techniques were learnt by the author and her co-authors of Ref. 17 at the University of Wisconsin Oshkosh's Curriculum Reform Institute when they attended in 1998. The author would also like to thank her departmental chairman, Michael K. Myers, for helpful discussions and faith in her abilities to reform this course.

Bibliography

1. Seymour, E. and Hewitt, N., *Talking About Leaving: Why Undergraduates Leave the Sciences*, Boulder: Westview Press, 1997.
2. NSF Division of Undergraduate Education, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology, A Report on the Review of Undergraduate Education from the Committee for the Review to the National Science Foundation Directorate for Education and Human Resources*, 1996, also available at http://www.ehr.nsf.gov/ehr/due/documents/review/96139/start.htm
3. Moser, SCEP Ask MacVicar to Ensure Student Voice in Reform, *The Tech*, **105** (40), 1985, Oct. 8th.
4. Astin, A., *What Matters in College: Four Critical Years Revisited*, San Francisco: Jossey-Bass, 1993.
5. Light, R. J., *Making the Most of College: Students Speak Their Minds*, Cambridge: Harvard University Press, 2001.
6. US Congress, House Rpt.107-505 - Part 1 – Undergraduate Science, Mathematics, Engineering, and Technology Education Improvement Act, 2002, available at http://thomas.loc.gov/cgi-bin/cpquery/0?&&dbname=cp107&&&r_n=hr505p1.107&&sel=DOC&
7. Seymour, E., Tracking the Processes of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology, *Science Education*, **86**, 79-105, 2001.
8. Gardiner, L. F., Why We Must Change: The Research Evidence, *Thought & Action,* Spring, 1998.
9. Knowles, *Studying the Adult Learner from Patient Teaching*, Loose Leaf Library Springhouse Corporation, 1990.
10. Kinder, G., *Ship of Gold in the Deep Blue Sea*, New York: Vintage Books, 1998.
11. Piccard, B. and Jones, B., *Around the World in 20 Days - the Story of Our History-Making Balloon Flight*, New York: John Wiley & Sons, 1999.
12. Chaikin, A., *A Man on the Moon: The Voyages of the Apollo Astronauts*, New York: Penguin, 1994.

13. Krakauer, J., Into Thin Air: A Personal Account of the Mt. Everest Disaster, New York: Villard Books, 1997.
14. ABET, *Engineering Criteria*, Baltimore: ABET, http://www.abet.org/criteria.html
15. NASA Quest Space Team Online, Rockets: A Teacher's Guide with Activities In Science, Mathematics, and Technology, http://quest.arc.nasa.gov/space/teachers/rockets/
16. ASME Egg Drop Competition, ASME, 2004, http://www.asme.org/eggdrop/
17. C. Mavriplis, R. Heller, C. Sorensen, H. D. Snyder, A Walk on the Moon: An Interdisciplinary Inquiry-Based Course, Proceedings of the WEPAN 2000 National Conference, June 2000.

Biographical Information

CATHERINE MAVRIPLIS holds a Ph.D. in Aeronautics from the Massachusetts Institute of Technology. She is currently an Associate Professor of Mechanical and Aerospace Engineering at the George Washington where she teaches fluid/thermal sciences, applied mathematics and introductory courses. Dr Mavriplis' research is in the area of computational fluid mechanics.