A GRADUATE COURSE IN THEORY AND METHODS OF RESEARCH

JOSEPH H. HOLLES
Michigan Technological University • Houghton, MI 49931

In today's university "typical graduate students" are becoming less common. Students continue to enter graduate school directly from undergraduate programs in the traditional manner, but many do not. Alternatives include returning to graduate school after working for a few years, mid- or late-career professionals seeking advanced degrees, and students with bachelor's degrees in different disciplines. Although many positives can result from this situation it is also not without its disadvantages. For example, a wide range of students can also result in a wide range of student concepts of and expectations for graduate school.

Over several years, those in the Department of Chemical Engineering at Michigan Tech observed that graduate students often did not posses the necessary skills to deliver proper professional presentations. Clearly, this ability is a necessity for graduate school (*e.g.*, research group presentations, thesis proposals, regional and national meetings, final thesis defense). Additionally, as future workforce members with advanced degrees, these students will be expected to give professional presentations in their jobs. The initial approach to address this problem was to require all incoming graduate students to give a formal department-wide presentation during their first year. Perhaps not unexpectedly, this approach failed since no one was responsible for ensuring that all students were indeed meeting this requirement. As such, another method was developed to ensure that students were not only gaining experience in delivering professional presentations, but were also being educated on how to prepare and deliver presentations. From this original focus on professional presentations, the course has evolved to include other topics of interest to graduate students.

METHODS

The Department of Chemical Engineering at Michigan Technological University developed a graduate course entitled "Theory and Methods of Research." This course is required for all chemical engineering graduate students. The class is offered during the fall semester of the student's first year in

Joseph H. Holles *is an assistant professor of chemical engineering at Michigan Technological University. He received his B.S. in chemical engineering in 1990 from Iowa State University and his M.E. and Ph.D. from the University of Virginia in 1998 and 2000, respectively. His research area is nanoscale materials design and synthesis for catalytic applications with an emphasis on structure/property relationships and in-situ characterization.*

graduate school, meets three days each week for one hour, and is three credits. Required graduate courses account for 15 credits in our program and no course was deleted when this course was started. Typically, seven to 13 students take this class.

Currently, the major goals of this course are: 1) Equip the students with the skills and experience to prepare and present professional presentations, and 2) Educate the students about many of the common experiences that make up graduate school. Thus, the original concept has grown to include equipping the students with a greater variety of oral and written communication skills that they will require as a graduate student.

Other institutions have taken a variety of approaches to educating their students about the graduate experience. A course that has many similarities with ours is Arizona State University's "Research Methods" for first-year graduate students.[1] Other courses that contain a smaller subset of comparable topics include: "Introduction to Literature Review and Proposal Writing" at the University of Iowa, with a similar goal of improving oral and written communication skills[2]; and a thermodynamics course at Mississippi State that includes the investigation of the role of journal articles in research.[3] More narrowly focused courses have also been developed with an emphasis on educating engineering students about learning processes and resources to help them in a teaching career.[4, 5] Additionally, a workshop was developed to focus on major communications required to obtain an advanced degree in engineering[6]; techniques for helping faculty teach the research process were presented[7]; and common difficulties facing graduate students were discussed along with possible actions to deal with them.[8]

RESULTS AND DISCUSSION

Reference information for the Theory and Methods class comes from a wide variety of sources. Two required books have been selected: *A Ph.D. Is Not Enough* by Peter J. Feibelman[9] and *Graduate Research* by Robert V. Smith.[10] These books cover many of the topics discussed in class and can continue to serve as handbooks for the students throughout their graduate and professional careers. In addition, all students are provided with a copy of *On Being a Scientist: Responsible Conduct in Research* by the Committee on Science, Engineering, and Public Policy of the National Research Council.[11]

The course is started with a lecture on "Why Graduate School?" Since the students are already attending graduate school, this discussion may appear to be too late, but in fact many still have doubts. The lecture revisits several typical reasons for attending graduate school and allows students to voice their own reasons, reinforcing students' motivation for taking on this challenge. Some of the benefits of graduate school are discussed, including what graduate school can do for the student and also what graduate school will not do. The different components of graduate school such as class work, seminars, teaching assistantships, and research are introduced. This lecture also provides an opportunity to outline a few of the career options available to students once they have completed a graduate degree.

The second class session focuses on library usage. For this session, the reference librarian serves as a guest lecturer. This session acquaints students with the library and the specific search engines and databases available to them. The librarians also make the lecture discipline-specific by focusing on topics relevant to chemical engineers (*e.g., SciFinder Scholar*). In addition, this class serves to guide the students away from URLs as references and towards scholarly books and journals. A typical schedule for the entire semester is shown in Table 1.

TABLE 1
Typical Class Schedule

Week	Session	Topic	Week	Session	Topic
1	1	Welcome/Introduction	8	1	Paper Writing
	2	Library		2	Paper Writing
	3	Why Grad School?		3	Paper Writing
2	1	Holiday	9	1	Ethics
	2	Communications Basics		2	Ethics
	3	No Class		3	Ethics
3	1	Presentations	10	1	Student Led Ethics Discussions
	2	Presentations		2	Student Led Ethics Discussions
	3	Writing Abstracts		3	Student Led Ethics Discussions
4	1	Copyright	11	1	AICHE Conference
	2	Scientific Method		2	AICHE Conference
	3	Scientific Method		3	AICHE Conference
5	1	1st Student Presentation	12	1	Patents
	2	1st Student Presentation		2	Research Notebooks
	3	1st Student Presentation		3	2nd Student Presentation
6	1	1st Student Presentation	13	1	2nd Student Presentation
	2	1st Student Presentation		2	2nd Student Presentation
	3	1st Student Presentation		3	2nd Student Presentation
7	1	1st Student Presentation	14	1	2nd Student Presentation
	2	Proposal Writing		2	2nd Student Presentation
	3	Proposal Writing		3	2nd Student Presentation

First Presentation

The work required to complete the first presentation is broken down into four separate assignments. To initiate this preparation, the next course topic is communication basics. Since this topic applies to all types of communication subsequently discussed in the course (outline, presentation, and proposal), it is necessarily broad. The first communication focus of the course is on memo writing. Students that have had previous industrial experience can provide valuable input at this point. They usually have examples of both good and bad memos, and other students are very receptive to real-life experiences of their classmates. The basics of memo writing lead into Assignment 1 (all assignments and the skills or concepts they reinforce are summarized in Table 2), which is to prepare a memo discussing five research methods, instruments, or techniques that will be useful to the student's graduate research. This is the first example of using the class to encourage the students to think about their own research and to talk to their advisors. If student-advisor pairings have not been made, the class instructor or a common first-year graduate student advisor may fill this role.

The list of five research methods, instruments, or techniques serves as the basis for next three assignments. A master list of all the topics mentioned in the memos is compiled and the most frequently listed and widely applicable topics are noted. Each student then selects one of these topics for their first presentation. At this point the students prepare an outline of the topic they have selected for their upcoming presentation (Assignment 2). In this manner the students are required to both learn about their topic and break down what they wish to talk about. In addition, library skills are reinforced since the students must use the library to obtain information for their presentation.

Once the outline is complete, the students begin preparation of their presentation. In parallel, the students also prepare an abstract of their talk (Assignment 3). Preceding this assignment, one class period is devoted to a discussion on writing abstracts. The focus is on abstracts most relevant to graduate school: journal article, presentation, and proposal to present. In this situation, the students prepare an abstract for their presentation. Since the research method, instrument, or technique may be of interest to others outside of class, the abstract is e-mailed to all the faculty and graduate students in the department with an invitation for them to attend the subsequent presentation.

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Prior to the presentation, two class periods are devoted to covering the mechanics of successful presentations. One example that is extremely practical is by Prof. Niemantsverdriet,[13] while a more thorough treatise on preparing scientific presentations is found in "The Craft of Scientific Presentations" by Alley.[14]

Assignment 4 is to prepare and deliver the presentation on their chosen topic. In this way the students learn about the research method, instrument, or technique and also educate other students in the class about the topic. A major benefit of this approach is that the students can be exposed to a number of topics in a time-efficient manner. For this assignment, the talks are 20 to 25 minutes long. One of the requirements for this assignment is to include a detailed example of how the research method, instrument, or technique is used to solve a current research problem. Again, this requirement allows the students to integrate their research into the coursework.

When the students deliver their presentation, their fellow students help with the evaluation. I use an advance copy of the presentation to prepare a short true/false and multiple-choice quiz. This quiz is an attempt to gauge the ability of the presenter to convey knowledge about his or her topic. The class is free to fill in the answers to the quiz at any time during the presentation. In addition, each student in the class completes a peer evaluation of the presentation. Since

TABLE 2
Assignments

Number	Topic	Skills/Concepts Reinforced
1	Research Methods, Instruments, and Techniques Memo	Library, Written Communication, Advisor Discussion, Research Integration
2	Topic Selection and Outline Preparation	Library
3	Abstract of Presentation	Written Communication
4	Research Methods, Instruments, and Techniques Presentation	Oral Presentation, Research Methods, Research Integration
5	Written Grant Proposal	Written Communication, Advisor Discussion, Research Integration
6	Classroom Ethics Discussion	Library, Scientific Method, Oral Communication
7	Critical Review of Journal Article	Oral Presentation, Library, Scientific Method, Writing Journal Articles, Ethics, Advisor Discussion, Research Integration

different people focus on different things, many comments develop. An instructor evaluation is also completed. All evaluations are anonymous and are shown to the presenter as a feedback mechanism. Peer evaluations are extremely effective as students tend to take criticism from their peers more constructively than from the instructor. Also, by performing a peer evaluation, class members are forced to consider what the speaker is doing and if they could somehow do it better in their own presentation.

Proposal Writing

The class focus then shifts from oral to written communication. For Assignment 5, the students select a source and apply for funding to support their graduate studies. First, the students must identify a potential funding source in discussion with their advisors. Once that's done, the assignment is to complete all necessary applications and forms—not only for the funding agency, but also any forms required by the research and sponsored programs office of the university. This form of written communication was not part of the original course, but was added as a result of student and advisor evaluations and feedback. This topic provides an opportunity to have a guest lecturer from outside the department. On several occasions, a grant-writing expert from the research office has presented this lecture. *Getting Science Grants* by Blackburn[15] serves as a reference for this topic. Once the students have completed the assignment, little additional work is required to actually submit the proposal. Student effort for the last step does not go unrewarded since the graduate school will give students $100 for each proposal they submit. To date, three proposals have been submitted as a result of this assignment; none have yet been funded, however.

Paper Writing

This topic can be covered while the students are completing their proposals and starting work on their final presentation. This set of lectures is broken into two main topics: the mechanical and descriptive process of preparing a paper for publication and of the sections of a paper, and a personal approach to writing papers.

The discussion is initiated by examining why papers are written: to share research findings, to allow others to build upon results, to gain tenure, and as evidence to funding agencies of progress. This is followed by discussing the mechanics of manuscript submission, from selecting a journal to ordering reprints. The different types of journal articles such as communication, regular article, note, review, or letter are also discussed. Discussions on journal hierarchy and the journal's impact factor are also included. This section is concluded

TABLE 3
Ethical Issues

Cases	References
The Baltimore Case	Kevles, D.J., *The Baltimore Case*, W.W. Norton, New York Sarasohn, J., *Science on Trial*, St. Martin's Press, New York Stone, R., and E. Marshall, *Science*, **266** (1994) 1468 Gavaghan, H., *Nature*, **372** (1994) 391 Kaiser, J., and E. Marshall, *Science*, **272** (1996) 1864 Steele, F., *Nature*, **381** (1996) 719
Cold Fusion	Taubes, G., *Bad Science*, Random House, New York Close, F., *Too Hot to Handle*, Princeton University Press, Princeton Huizenga, J., *Cold Fusion: the Scientific Fiasco of the Century*, University of Rochester Press, Rochester
Cold Fusion Redux	Kennedy, D., *Science*, **295** (2002) 1793 Seife, C., *Science*, **295** (2002) 1808 Bechetti, F.D., *Science*, **295** (2002) 1850
The Undiscovered Elements	Weiss, P., *Science News*, **155** (1999) 372 Seife, C., *Science*, **297** (2002) 313 Dalton, R., *Nature*, **420** (2002) 728 Wilson, E., *Chemical & Engineering News*, **80**(29) (2002) 12
Schwarz/Mirken	Marshall, E., *Science*, **292** (2002) 2411 Adam, D., *Nature*, **412** (2001) 669 Ritter, S., *Chemical & Engineering News*, **79**(25) (2001) 40 Schwarz, P., C. Mirkin, and L. Villa-Komaroff, Letters to the Editor, *Chemical and Engineering News*, **79**(31) (2001) 8 Ritter, S., *Chemical and Engineering News*, **79**(46) (2001) 24
J. Schon at Bell Labs	Dalton, R., *Nature*, **420** (2002) 728 Jacoby, M., *Chemical & Engineering News*, **80**(44) (2002) 31 *Nature*, **429** (2004) 692 "Report on the Investigation Committee on the Possibility of Scientific Misconduct In the Work of Hendrik Schon and Coauthors" available at: <http://www.lucent.com/news_events/pdf/researchreview.pdf>

by examining the sections of the paper (title, abstract, introduction, etc.) individually and discussing the importance and reason for each section.

Authorship issues involved with journal articles are also discussed at this point. A little groundwork here will pay off later during the ethics discussion (viz. the J.H. Schon affair, see Table 3, previous page). Guidelines on the responsibilities of co-authors and collaborators by the American Chemical Society[16] and the American Physical Society[17] are examined and discussed. Finally, the students are encouraged to read and follow the instructions for authors prepared by journal editors.

In the second portion of this subject, a personal approach to paper writing is presented: start with the experimental section, then proceed through the results, discussion, introduction, conclusions, and end with the abstract. Although this approach is not original, it is a method the students can fall back on to avoid procrastination and writers block. The students are also warned that all advisors may not write papers in the same manner, and they are encouraged to learn how their advisors write papers by both reading previous work and talking to them.

Ethics

The initial classroom lecture focuses on some of the common ethical situations in science and engineering. These include plagiarism, data manipulation, authorship issues, and grant and manuscript review. Data manipulation is further elaborated by breaking it down into three categories: Trimming, Cooking, and Forging. The students then read *On Being a Scientist: Responsible Conduct in Research*[11] and discuss the nine hypothetical scenarios presented within. These scenarios are excellent since they focus on many big-picture issues such as data manipulation and conflict of interest specifically from the graduate student perspective. Each of the scenarios provides several questions to initiate the classroom discussion. The booklet also contains an appendix with a short discussion of how the situation presented in each scenario can be addressed or further explored. The appendix is withheld from the students until after the discussion in order to encourage them to come up with their own ideas. Many additional vignettes can found in *The Ethical Chemist* by Kovac.[18]

Each student then leads a short classroom discussion (15-20 minutes) of an important current ethics issue in science and engineering (Assignment 6). The short scenario and question style of the National Research Council booklet serves as a template for the students preparing the classroom discussions. Potential topics and references for the student-led discussions are listed in Table 3. This assignment also has the students doing more literature searches, thus reinforcing library skills. Finally, although less formal than the other two presentations, this is another opportunity to build upon their presentation skills.

Second Presentation

The concluding topic for the course is a critical review of a journal article (Assignment 7) delivered as a class presentation (25-30 minutes). This serves as an ideal choice for a final assignment since it incorporates a number of the topics that have been previously covered in class. These topics include writing abstracts, writing journal articles, data presentation, scientific method, and even ethics. The students are free to select any article of their choosing for this review. It is strongly suggested that they select a manuscript relevant to their research. Again, discussion with an advisor can help them select an appropriate article. The students have now covered the scientific method and paper writing and thus have sufficient knowledge to allow a fairly in-depth critical exam of the journal article. The students are free to critique anything about the article, including the layout and the typesetting. While the authors of the article do not have much control over these issues, the students learn a little more about the process of publishing an article. Since the student has received feedback on their his or her presentation, the comments from that presentation are reviewed to see if the student has made changes and improvements.

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Other Topics

Several lectures are devoted to discussion of the scientific method. These lectures are developed from the corresponding material in Feibelman[9] and Smith[10] along with "The Craft of Research" by Booth, Colomb, and Williams.[12] The scientific method includes Observation, Hypothesis, Experimentation, and Interpretation. In practice, observation and hypothesis are usually done in advance by the advisor and the student performs the experimentation and interpretation steps. Thus, it is important to spend some time educating the students about the entire process. The discussion of experimentation is very open ended since it can include a wide variety of topics including statistical analysis and design of experiments. An outside lecture on either of these topics can be very beneficial.

Interspersed throughout the course are additional topics such as copyrights, patents, and research notebooks. These topics are all stand-alone and can be moved around as necessary to adjust the class schedule. *Patent Fundamentals for Scientists and Engineers* by Gordon and Cookfair serves as a resource for the patent discussion.[19] Before discussing research notebooks, determine if the university, college, or department has developed a set of guidelines for notebooks. If so, these guidelines can serve as the basis for this lecture. Finally, Kanare's book is a good reference on research notebooks.[20] In addition, the classes on copyrights and patents present additional opportunities to bring outside speakers into the classroom. A member of the department who had recently filed a patent application has presented this lecture. A patent lawyer or a representative from the intellectual property office is also a potential guest lecturer.

Throughout this class, two additional major concepts are continually reinforced. First, class members are reminded that as graduate students, it is necessary to talk to your advisor and discuss what you are doing and why you are doing it. Too many students of all backgrounds seem to maintain an undergraduate relationship with their professor and only talk to him or her when they have a problem. Many of the exercises in this class are specifically designed to avoid this problem by encouraging advisor/student interaction.

Second, the students need to understand what a graduate education entails. Many faculty members would agree with the statement that it is the student's degree and not theirs. If the students understand what they must do to attain their graduate degree and take ownership of that degree, it will be more valuable to them. To encourage this concept, this course attempts to cover many topics important to graduate school success that are not covered in other formal courses.

Results

Feedback has been obtained through end-of-course evaluations by the students and informally from the faculty. Feedback from both the faculty and students has been extremely positive. Faculty member have specifically noted that students have indeed improved their presentation skills across the board, thus meeting the original goal of this class. In addition, they have noted that students are better able to digest literature articles and extract critical information. Finally, the faculty state that students have shown an improved understanding of the research process, allowing them to get organized and more quickly proceed through the background research of their projects.

In line with the course goals, the students also state that the class has improved their presentation skills. The students also demonstrate enthusiasm for the lectures on copyrights, patents, and ethics. The students have indicated that the assignment they like the most and learn the most from is the critical journal article review (Assignment 7). Most students also cite this assignment as most useful when performing future research. The student-led ethics discussions are also very popular due to the sometimes soap opera nature of the events.

Student feedback was also the impetus for the addition of the Proposal Writing assignment in the class. The major comment from the first two student course evaluations

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was that a proposal writing section was needed. The faculty has also strongly supported this additional assignment as it allows the students to knowledgeably assist them as they write proposals.

CONCLUSION

The original concept of effective oral communication has served as the foundation for growth of a broad-based graduate course covering topics that are vital not only in graduate school but also in the professional world. In addition to communication skills, other topics vital to obtaining the full graduate school experience can be systematically discussed within the boundaries of this course.

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