A Graduate Course in
RESEARCH METHODS

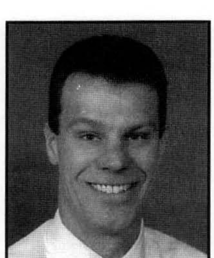
Veronica A. Burrows and Stephen P. Beaudoin
Arizona State Universtiy • Tempe, AZ 85287-6006

The traditional model of graduate education in engineering incorporates aspects of both the "academy" (individual study of oral and written exposition by experts) and the "crafts" model (apprenticeship with a "master" from whom the skills, art, and applied knowledge are learned in a hands-on approach). These aspects are usually implemented through traditional academic courses and through mentored research, respectively.

In recent years, faculty in the ChE program at Arizona State University became concerned that entering graduate students, although quite academically competent, were deficient in the background knowledge and skills necessary for the successful research proposition—hence some portions of our course are modeled on the "research proposition course" described by Ollis.[1] Although these skills have been traditionally gained through the "research apprenticeship" portion of graduate study, we believe that explicit instruction in these areas can be of great value to both the students and to the research programs of the faculty.

***Veronica Burrows** is Associate Professor of Engineering in Chemical and Materials Engineering at ASU. She received her BS in chemical engineering from Drexel University and her PhD from Princeton. Her research interests include the applied surface chemistry of semiconductors and thin film sensors. Her educational activities and interests include "girl-friendly" science and technology experiences for K-12 students, criterion-based assessment techniques, and technology-enhanced learning for visually impaired students.*

***Steve Beaudoin** is Associate Professor in Chemical and Materials Engineering at ASU. He received his BS in chemical engineering from MIT, his MS from UT-Austin, and his PhD from North Carolina State University. He is a recipient of an NSG CAREER award and has been named Outstanding Undergraduate Educator in ChE at ASU. His research interests are microelectronics manufacturing, including chemical-mechanical polishing, polymer dielectric processing, and particle and thin film adhesion.*



After considerable informal surveying and faculty discussion, we embarked on the design of a course to be required of all ChE graduate students in their first year. The course would be designed to address these deficiencies in a structured way and to provide students with a strong training in the basic skills required for the conception, design, organization, execution, and communication of technical research, or indeed, of any technical project. One of the unexpected positive outcomes of this discussion was the recognition by the faculty that it *is,* in fact, possible to define an approach to research that is commonly accepted by all of us.

COURSE CONTENT

We began the development of this course with a statement of course philosophy. The following statement was constructed early in the development process by participating faculty:

> *Master's and PhD engineering degrees in this program are primarily research degrees. While your course work is an invaluable part of your graduate experience, it is not considered to be more important than your research experience. The research experience allows you to establish yourself as an expert in a new technical discipline, and to make a new contribution to the state-of-the-art in your technology. Excellent researchers take a common approach to research, and it is our goal to teach you this approach.*

Faculty then identified the desired skills of students about to undertake their research and grouped them into the categories "project management skills" and "communication skills." Although most entering graduate students have had formal training or course work in technical communication, few have had explicit training in project management.

The organization of the course content is loosely structured on the problem-solving heuristic of the McMaster Five-

Point Strategy for problem solving:[2]

- *Define—Define a research problem, research objectives, and constraints*
- *Explore—Research the literature, identify meaningful decision criteria, generate hypotheses, choose reference conditions*
- *Plan—Generate multiple paths to achieving the research objectives, map out the approach, identify and assemble resources*
- *Act—Conduct research, analyze results*
- *Reflect—Check for errors, check for reasonability, integrate with current state of knowledge, reflect on new opportunities created by results, communicate results*

Table 1 gives a topic list for this course. Each topic is identified with its associated step in the McMaster strategy. Topic readings are assigned from a variety of sources. We strive to include up-to-the-minute materials from technical literature, presentations, and conferences. Students are expected to discover some of their own sources on many of the topics and to report on these sources to the class via the course web site/discussion board.

TABLE 1
Research Methods Course Topics

Week	Topic	McMaster Heading
1	Overview, McMaster Strategy (and other heuristics) for Problem Solving	Define
2	Types of Research: Fundamental vs. Applied vs. Phenomenological vs. Problem Solving	Define
3	Tools, Techniques and Heuristics for Problem Definition	Define
4	Critical Review of Technical Literature and the Context of Research	Explore
5	Hypotheses and Falsifiability	Explore/Plan
6	1) Idea Generation and Creativity Techniques	Explore/Plan
	2) Kepner Tregoe Tools	Explore/Plan/Act
7	Defining Short-, Medium-, and Long-Term Objectives	Plan
8-9	Research Plans: Hypotheses, Experimental Design, and Statistical Design of Experiments	Plan
10	1) Documenting Research 2) Intellectual Property	Act Act
11	Research Ethics, Safety, and Professionalism	Act
12-13	Communicating Research: Publications, Presentations, Proposals	Reflect
14	Faculty Presentations on Research	Reflect

The course [is] designed to . . . provide students with a strong training in the basic skills required for the conception, design, organization, execution, and communication of technical research, or indeed, of any technical project.

Templates and checklists for most of the project management tools (*e.g.*, the Kepner Tregoe tools, brainstorming checklists, impact/changeability analysis, prioritization matrix, Gantt charts) are also provided electronically. Faculty presentations, the final topic item listed in Table 1, provide an opportunity both for faculty to formally present their research topics and recruit students onto their projects, and for students to observe and critique experienced researchers' organization and presentation styles.

PEDAGOGY AND COURSE DELIVERY

The course is in a team-based active/cooperative learning environment. Class presentations are technology-enhanced, using presentation software and using web resources via computer projection. All course materials (except for course texts) are available electronically on a course web site. Although students are not required to purchase a text for this course, we require reading in—and strongly recommend that students purchase—*Strategies for Creative Problem Solving* by Fogler and LeBlanc,[3] and *Writing the Laboratory Notebook* by Kanare.[4]

A typical class begins with an agenda, a statement of the learning objectives to be achieved, and an opportunity for questions on assigned pre-class readings or previous work. The class then proceeds with the topic of interest in an active learning format that normally includes comprehension-level exercises (levels of learning as defined by Bloom[5]). These exercises are accomplished in assigned semester teams and always include reporting of results and discussion. In-class assignments are assessed and critiqued during class time.

ASSIGNMENTS AND ASSESSMENTS OF STUDENT WORK

Out-of-class assignments at higher levels of learning are assigned to support the main topics (see Table 2, next page). Although grading approaches vary with instructors, an innovative criterion-based assessment method[6] has been successfully applied in this course. Specific expectations, de-

Continued on page 279.

Graduate Research Methods

Continued from page 237.

rived from the assignment's learning objectives, are provided for each assignment in the form of a checklist. Checklist items include both present/not present elements, and elements assessed on a scale of quality (for example, "excellent," "okay," and "weak"). A submitted assignment is assessed as having exceeded expectations, met expectations, or as needing improvement.

Work that needs improvement must be reworked until it meets expectations. Requiring rework of an originally weak product is a realistic model of most work environments, and assures minimum competence for all course learning objectives. Another important aspect of this assessment approach is that students are required to exceed expectations in order to achieve higher grades. This approach encourages student innovation, creativity, and attention to work quality. In addition, it again models a more realistic work environment where successful professionals will strive to go beyond the mere meeting of minimum requirements.

TABLE 2
Research Methods Out-of-Class Assignments

Assignment	Topic	Level of Learning Expected
Technology Gap Analysis	Problem Definition	Analysis
Literature Summary	Critical Review of Technical Literature	Analysis
Critical Proposal Review	Types of Research, Hypotheses, Critical Review	Analysis
Generation of Proposal Topics List (Part I of Proposal)	Idea Generation and Creativity Techniques	Application
Selection of Proposal Topic (Part II of Proposal)	Kepner Tregoe Tools: Problem Analysis and Decision Analysis	Application
Preliminary Research Plan (Part III of Proposal)	Defining Objectives, Research Plans	Application
Patent Search and Review	Intellectual Property	Comprehension
Research Ethics Case Study	Ethics, Safety, and Professionalism	Application
Completed Research Proposal (Part IV of Proposal)	Communication of Research	Application
Oral Presentation of Proposal (Part V of Proposal)	Communication of Research	Application
Peer Assessment of Research Proposal	Communication of Research	Analysis

COURSE EFFECTIVENESS

One of our original goals for this course was to improve student preparation for the conduct of independent research, as we believe that this is the major element that distinguishes graduate from undergraduate work. The number of students who have completed this course (more than thirty) is too small for any statistically significant study of outcomes. We have, however, the following anecdotal evidence that this course has met most of our original goals:

- *Student performance on both the dissertation prospectus and the Qualifier have improved dramatically, with fewer students being required to make major revisions or complete rewrites of these and more students passing without any required revisions.*
- *Faculty report greater satisfaction with student ability to generate falsifiable hypotheses and to use these hypotheses to consistently guide the design and interpretation of the research.*
- *Faculty external to the ChE program (at least one non-ChE faculty member is required on each Dissertation Committee) have expressed interest in importing the class into their own programs, based on their observations of ChE student performance on dissertation prospectuses and dissertations.*
- *Students report high satisfaction with the course and its content. Students who have taken this course after an earlier research experience (e.g., undergraduate research, or after having completed an MS at another institution) are especially positive about the course, most expressing the wish that they had taken a course of this nature before their earlier research experience.*

We are currently exploring the possibility of making the course available to graduate students in other engineering and science disciplines at Arizona State University.

REFERENCES

1. Ollis, D.F., "The Research Proposition," *Chem. Eng. Ed.*, **29**(4) 222 (1995)
2. Woods, D.R., *A Strategy for Problem Solving*, 3rd ed., Department of Chemical Engineering, MacMaster University, Hamilton, ON, CANADA (1985); also *Chem. Eng. Ed.*, **13**(3), 132 (1979)
3. Fogler, H.S., and S.E. LeBlanc, *Strategies for Creative Problem Solving*, Prentice-Hall PTR, Upper Saddle River, NJ (1995)
4. Kanare, H.M., *Writing the Laboratory Notebook*, American Chemical Society, Washington, DC (1985)
5. Bloom, B.S. ed., *Taxonomy of Educational Objectives, Book 1: Cognitive Domain*, Longman, NY (1984) (1956 original)
6. McNeill, B.W., L. Bellamy, and V.A. Burrows, "A Quality-Based Assessment Process for Student Work Products," *J. Eng. Ed.*, **88**(4), 485 (1999) ❒