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Designing the Graduate Research Experience to Catalyze the Student-to-Researcher Transition*

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Over a twenty-five-year period, we have created, modified, and enlarged two first year graduate courses which introduce new PhD prospects to research via written construction and oral presentation of two research proposals. In addition to these writing and speaking tasks, we included professional development topics such as research ethics, advisor-advisee relations, the laboratory notebook, intellectual property and patents, and research group citizenship. The evolution of these formal elements I describe here as a series of curricular design challenges, each involving the classical design sequence of need identification, conceptualization, feasibility, production, and acceptance by our stakeholders: our graduate students, our faculty, and implicitly, employers of our graduated students.

Keywords: design; graduate curriculum; research; proposal

1. Introduction

Research is the defining difference between undergraduate and graduate education. To introduce this novel activity to entering PhD graduate students, we developed two first year graduate courses [1–3] which emphasize the nature of research, proposal writing and revision, and oral presentation, as well as appropriate professional development topics. In the second year, PhD candidates provide an oral progress report after three semesters, and at the end of year two, they stand for the traditional university preliminary exam including written and oral components. Thus, our curriculum for the first two years of graduate study includes creation of three written proposals and four oral presentations.

These academic requirements also address post-graduate needs of prospective employers. For example, a 1995 survey of chemical industry recruiters of MS and PhD graduates showed that communication skills are the most important characteristic sought in graduate degree engineers (Table 1) [4]. Our early development of research competence in a manner emphasizing written and oral communication opportunities clearly speaks to these stated needs.

As our focus here is engineering research, we begin by proposing a suitable definition We consider definitions for two component terms, ''engineering design'' and ''research''. According to Dym [5, 6], ''Engineering design is a systematic, intelligent process in which designers generate, evaluate and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints.'' The term ''research'' has been often defined; a useful version for our discussion follows: Research is ''Careful, patient, systematic, diligent inquiry or examination in some field of knowledge, undertaken to establish facts or principles'' [7].

Table 1. Most important MS/PhD candidate characteristics [4]

Item	Most	2nd Most	3rd Most
Communication skills	39	31	0
Academic institution	16	39	12
Thesis advisor	13	26	20
Grade point	13	31	18

We propose then a definition of ''engineering research'' by suitable combination and modification of the two preceding definitions to provide: ''Engineering research is a systematic, intelligent process in which (applied) researchers generate, refine and test hypotheses in some field of technical knowledge, undertaken to establish facts or principles.''

Graduate engineering research entails multiple dimensions not routinely encountered in an undergraduate engineering experience. These include persuasive argument in the form of written proposals and oral presentations. These activities require skills similar to those for engineering design, especially ''Identification of engineering design problems'' and ''Creativity and ideation in the design process.'' Further, they require many of the same attributes sought in the Engineer of 2020, including strong analytical skills, practical ingenuity, creativity, communication, high ethical standards, professionalism and lifelong learning. Associated professional development topics for our new graduate courses include research ethics, the laboratory notebook, intellectual property and patents, advisee-advisor relationships, and research group citizenship. These offerings serve two purposes simultaneously by

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providing (i) an extensive introduction to engineering research, and (ii) professional practice in written and oral communication, the most important MS and PhD characteristic sought by industry recruiters. [4] Our current first graduate year format has been followed over the last seven years by about 150 PhD candidates and has been well received by both students and faculty [2, 3].

2. Presentation

It is useful to cast the development and evolution of our PhD curriculum as a series of design challenges, even though recognition of this structure came after the fact of its establishment. We consider three aspects of the graduate curriculum design challenge: (i) establishment of need, (ii) design of initial "Introduction to Research" course, and (iii) subsequent changes which addressed evolving needs to yield our current two semester sequence: "Introduction to Research" and "The Research Proposition."

It is convenient to describe this evolution as a sequence of curriculum design challenges and responses. In particular, we describe the evolution of our teaching experience using the closed design sequence as described by Dieter [8] and Hills [9]:

> => => => State of the art(old) => Identification of need => Conceptualization => Feasibility analysis => Production => Acceptance => State of the art(new)

2.1 Establishment of need: round 1 (1992)

Most PhD programs, in STEM and often other fields, require passage of a university qualifier exam after a year or so of residence. Our experience in 1992 was that such qualifier exams were simply a repeat test of material from first year graduate courses, and such tests did nothing or little to reveal student aptitudes for research. Moreover, preparation for such tests was retrospective, while providing nothing prospective to prepare the new graduate student for research.

2.2 Conceptualization: round 1

A 1992 departmental faculty committee formed to produce recommendations for graduate training reported that "The mastery of first-year graduate coursework is but one positive indicator of a student's potential to perform well in the PhD program. Equally important is the ability to apply classroom knowledge to recognize, define, plan, and undertake a research program. The synthesis skills required to do so are typically not exercised in classwork but are indispensable tools for the conception of and execution of independent research." [10]

2.3 Feasibility and production: round 1

In consequence, we initiated in 1992 a one semester Research Proposition course[1] in which students constructed a formal, independent written technical proposal followed by oral presentation to a faculty committee. Over time, the course was repeatedly refined to include production of a draft, then final proposition to provide earlier feedback and allow time for revision before presentation to a faculty committee.

Proposal creation is analogous to an undergraduate design project, inasmuch it involved ideation to create a hypothesis (concept), a literature review to establish novelty and plausibility (need) , an outline, then draft, and final, written proposal (production) followed by an oral presentation to a faculty panel(client). Students received critical feedback at several points in their proposal "design": (i) oral conversation with instructor to clarify hypothesis and prior work, (ii) written feedback on draft written proposal, and (iii) oral conversations concerning draft outline and draft presentation slides.

2.4 Acceptance 1

A survey of 1992–1995 graduate students showed their evaluation of original course components:

> "Extremely valuable: Writing the rough draft; comments received on the rough draft and giving a practice talk."
>
> "Generally helpful: Doing a literature review; writing the proposal outline (with references); preparing the technical presentation and receiving class questions after the practice talk." [1]

A gender specific response was also revealed:

> "Women were more positive than men about all activities involving communication, including writing and receiving comments on the rough draft, giving the practice talk, and responding to class questions. Eleven of thirteen women liked the course (regardless of benefit), but eight of twenty-eight men hated it !" [1]

2.5 Establishment of need: round 2 (1999)

The formal proposition course focused exclusively on document construction and oral defense. It did not include professional development topics.

2.6 Feasibility and production: round 2

In consequence, a one unit first semester seminar was developed to address such topics including research ethics, advisor expectations and advisor-advisee relationships, intellectual property and patents, the laboratory notebook, and laboratory/group citizenship.[11]

2.7 Acceptance: round 2

The resulting two semester sequence of fall seminar then spring proposition course provided a balanced

Table 2. Graduate Curriculum (current)

Graduate Semester:	**Fall 1**	**Spring 1 Fall 2**		**Spring 2**
Courses:	Intro to Research	Research Proposal	Research	Research
	X	Research	Research	Research
	X	X	Research	Research
	X	TA	TA	Research
% Research	18%	45%	75%	100%
Written proposal	Y	Y	N	Y*
Oral presentation	Y	Y	Y	Y*

* University preliminary exam.

introduction to research for our first year PhD students, and was welcomed by both faculty and students [2, 5].

2.8 Establishment of need: round 3 (2008)

As faculty are inventive, and endlessly restive concerning the training of their graduate students, additional suggestions arose: "While our original, independent research proposition course [1] engaged the student in technical writing and presenting, it did not connect directly with either the PhD advisor or the eventual thesis area. Both faculty and new graduate students sought an earlier engagement with research planning. The students also requested earlier engagement with their PhD research committees. Thus, motivation for our newer, second course was born" [2].

Additionally, the spring independent proposition did not aid new student integration in the research groups. Instead, some faculty felt that as a required, second semester graduate course involving writing an independent, non-thesis topic, it detracted from spending first year time in the laboratory communities.

2.9 Conceptualization: round 3

To provide earlier research engagement yet maintain and deepen the proposal preparation and defense experience, it was suggested that we move the initial proposition into the fall semester, to be followed by a second, spring proposition which would be a nascent PhD plan.

2.10 Feasibility and Production: round 3

Up to 2007, all new graduate students participated as teaching assistants for both semesters of their first year, with a consequent fall semester of three core courses (transport phenomena, thermodynamics, and applied mathematics) plus seminar for a total of 10 units plus TA duty. To make room for moving the first proposition course to the first semester, the TA duties were shifted into the second and third semesters. The second semester thus allowed space for a new, second proposition course focused on development of a nascent PhD plan, with the fourth core class (kinetics and reactor design), a TA assignment, and three units of lab research completing the semester workload.

To intensify the early student contact with her PhD committee, an oral progress report (one hour presentation with slides, no written report) was added, to be presented in January of the second year in residence (Table 2).

2.11 Acceptance: round 3

A faculty survey regarding the impact of this two course proposal sequence showed that the new format resulted in faster engagement with a PhD research topic, earlier conversations with research advisor and PhD committee, and smoother integration into the lab group [3].

Graduate students have consistently rated these research communication and professional development courses as strongly as our conventional graduate first year courses in applied mathematics, transport phenomena, thermodynamics, and reaction engineering [3].

3. Curriculum structure

The resultant, current sequence of courses appears in Table 2. It shows a continually stronger participation in formal and informal research. The strength of research writing and presentation is evident: By the end of year two, a PhD candidate has written three research proposals and given four formal presentations of these documents. This early, substantial emphasis on formal written and oral communication, combined with successively deeper involvement in the informal research group/lab, provides a strong and early professional development of new research students, and results in catalyzing the student-to-researcher transition. It also provides repeated practice in oral and written research communication, thereby addressing the prime characteristic sought by industrial recruiters of graduate engineers [4].

Our paper title claims that the curriculum of Table 2 "Catalyzed the transition of new graduate student to prepared researchers." The novel feature of the newer spring vs. older fall course is use of advisor conversations in proposal creation.

In 2011, we tested the title hypothesis by surveying the spring proposal class of 21 new PhD aspirants. Among the 21 participants:

95% agreed or agreed strongly that through CHE 702 (spring course) they increased competence in proposal writing and established a positive advisor-advisee relationship,

90% agreed or agreed strongly that they became comfortable giving oral presentations to both their research groups as well as to faculty, and competent creating visual presentations, and

85% agreed or agreed strongly that through CHE 702 they have "transitioned from new graduate student to prepared researchers."

Less successfully, but still a positive outcome, 65% agreed or agreed strongly that they had "become well integrated into their research group." I interpret this last result as meaning that interpersonal relationships take longer to develop deeply that do achievement of the first three objectives cited.

4. Discussions

We have shown how the design of a novel graduate curriculum has nearly the same elements as conventional approaches to design of objects, products and processes as described, for example, by Dym [5, 6] and Dieter [8].

4.1 Formal vs. informal introduction to research

The chief novelty of our approach has been introduction of formal first year graduate courses which introduce proposal construction and professional development. As these novel courses comprising 4 units (2 each) take some time away from the typical, informal first year immersion into laboratory and research culture, we might have expected some students and faculty to have objected to these new course additions. Over the seven years now of the two course offering, no such complaint has been received from either party.

4.2 Curriculum design in the service of research

Other sources of complaint might have occurred. For example, Magee et al. [12] described a new academy, the Singapore University of Technology and Design (SUTD) and raised the possibility that inclusion of "design-centric education and the goal of becoming a leading research-intensive university" might create a sense of "conflicting agendas." These authors then took the opposing, positive view that "design-centric education and research-intensity are synergistic for a 21st century university." Our NC State University curricular experiences provide an affirming example wherein considering the graduate research curriculum as an ongoing academic design challenge has led to the development, over more than two decades, of a curriculum that is a valuable education product and process which has widespread faculty and graduate student client satisfaction.

4.3 Methods for design of research classes

Agogino et al. [13] recently described creation of TheDesignExchange, which is "a site dedicated to the support and development of the design thinking community" whose "mission is to provide an open space for design thinking practitioners to show, discuss, and explore design thinking, allowing both novice and practitioners to expand and hone their expertise." The site has recently announced a "library of over 300 human-centered design methods," clearly an invaluable resource for its members.

In contrast, proposition and professional development courses, such as those described here, seem remarkably rare in graduate study, and the constructing of a corresponding "library" of such writing, speaking, and professional development courses seems infeasible at the moment. The likely reason is that most graduate courses are taught by faculty whose individual areas of research line up well with their particular graduate course topics. Thus, provision of "service" writing and speaking graduate courses is of little interest to engineering faculty, and despite writing frequently, most show disinterest in the teaching of "writing." Young faculty would lose research time needed for tenure, and senior faculty are sufficiently connected to their own research that teaching a proposition course for all has little allure. I suggest this result illustrates "The tragedy of the commons" in which the selfish interests of the faculty override the general welfare (needs) of their research communities.

4.4 Dissemination of course materials

This area is very undeveloped as a curricular topic. Our attempts to disseminate the proposition course formats through ASEE and Chemical Engineering Education [1-3] have not resulted in droves of new teaching recruits. The current most fruitful path may be making available the complete set of Power Point lecture materials, to be posted shortly on the NCSU Chemical and Biomolecular Engineering website. Former NCSU graduate students, and now faculty members, Kristen Comfort (U.

Dayton) and Karyn Heidt (Michigan Technological Institute) have developed courses derived from their graduate experiences in our proposition courses. Copies of slides are currently available from the author.

4.5 Reference materials

Many texts exist which describe the relevant activities of research writing, composition revision, and oral presentation. Our relevant lectures in these areas are derived from the following texts:

Proposal & thesis structure: R. K. van Wagenen, Writing a Thesis: Substance and Style, Prentice Hall,1991.

Revision: R. A. Lanham, Revising Prose (5th ed), Longman Publishing Group.

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5. Conclusions

Over the course of twenty five years, we have designed and re-designed two introduction-to-research first year graduate courses. Our PhD formal curriculum has been driven by changing academic needs, and our evolving responses to these variable needs are thus suitably described through the activities familiar in design:

> State of the art(old) => Identification of need => Conceptualization => Feasibility analysis => Production => Acceptance => State of the art(new).

Our curriculum design efforts over this time span have certainly shown that adding writing, speaking, and professional development components to our PhD program is feasible, productive, and accepted.

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