Alternative models of assessment for 21st century engineering doctoral students

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Abstract: *Many have approached doctoral education as a "sink or swim" exercise. This random approach of pursing a Ph.D. is no longer sufficient. The strongest, most determined doctoral students survive, but at what cost? Doctoral training should not be left to chance. Given the purpose of a Ph.D. and the leadership opportunities given to Ph.D.s in academia, industry, government, and non-profit sectors, one would expect training of doctoral students to be more consistent across disciplines, departments and institutions within the United States. Although programs such as "Preparing Future Faculty" and "Re-envisioning the Ph.D." provide resources for students considering or pursuing Ph.D.s., students who actively seek such resources are the most likely to benefit from the guidance offered. Anecdotal and empirical findings confirm that the experiences of doctoral students differ greatly. Upon graduation, there is variability in the skills demonstrated by new Ph.D.s. Students who report having positive experiences typically have received either formal or informal training during their Ph.D. experiences. Several questions remain, however. Whose responsibility is it to train Ph.D. recipients in areas in which they are weak? Does this responsibility rest on the major professor, the dissertation committee, the department, or the institution? This paper presents an overview of the global preparation of engineers and implications for doctoral engineering education; a summary of the measures that might be used by departments and institutions to level the playing field for all those pursuing doctoral degrees; and a model of assessment to measure students' engagement with teaching, industry, and professional skills.*

Introduction

The Carnegie Foundation for the Advancement of Teaching has launched an effort for preparing the next generation of Ph.D.s. One of the reports by Golde and Walker (2006) discussed the development of disciplinary "stewardship," which summarized the important roles of Ph.D.s to: (1) *generate* new knowledge within a field via rigorous research; (2) *conserve* the useful ideas of past work and current work within a discipline; and (3) *transform* disciplinary knowledge into pedagogies of engagement, comprehension, and application. A break-down of these roles would lead to a list of competencies that are required of future Ph.D.s. For example, the creation of new knowledge requires a Ph.D. to be creative and innovative, and the communication of disciplinary knowledge requires a Ph.D. to be able to explain technological terms to laypeople or to people in other fields. These attributes add depth and breadth of knowledge for future engineers.

Some initiatives have aligned educational goals and practices at university or program levels (Wulff and Nerad, 2006; Huba, *et al.*, 2006; Golde and Walker, 2006). There have been efforts in Australia focusing on differentiating the levels of knowledge and skills and the applications of these knowledge and skills across the education continuum. Particular attention has been made to the educational purpose and requirements of doctoral students across all disciplines (Australian Qualification Framework, 2011). Related to assessment of educational practices, Wulff and Nerad (2006) proposed an assessment framework comprised of five basic components: program activities, students, faculty and staff, desired outcomes, and the context. By focusing on formative assessment and internal decision making by the primary decision makers, they strive to bring out alignment across these components. Another example is Huba *et al.*'s (2006) outcome-based framework that transformed the doctoral program at the Department of Educational Leadership and Policy Studies at Iowa State University via a redesign of rubrics and mapping of curriculum to learning outcomes along with a redesign of the portfolio and preliminary examination process to reflect learning outcomes. Similar to Wulff and Nerad (2006), they collected formative feedback from students and faculty members to inform the decision making-process.

Although programs and initiatives such as "Preparing Future Faculty" (Austin, 2002) and "Re-envisioning the Ph.D." (Nyquist and Woodford, 2000) provide resources for students, anecdotal and empirical findings confirm that the experiences of doctoral students differ greatly due to multiple complex factors, such as educational background, disciplinary and departmental context (Austin, 2002; Golde and Dore, 2001). Given the purpose of a Ph.D. and the leadership opportunities given to Ph.D.s in academia, industry, government, and non-profit sectors, one would expect training of doctoral students to be more consistent across disciplines, departments, and institutions within the United States. In an effort to explore these inconsistencies, this paper presents an overview of the global preparation of engineers; a summary of the measures that might be used by departments and institutions to level the playing field for all those pursuing doctoral degrees; and a model of assessment to measure students' engagement with teaching, industry, and professional skills.

Overview of the Global Preparation of Engineers

Across the globe, accreditation agencies and engineering societies have explored competencies and outcomes for practicing engineers. Focused primarily on undergraduate education, these competencies do not vary significantly across departments and programs. However, there are not universally agreed upon criteria to ensure consistent training of engineering Ph.D. students.

Despite these inconsistencies, at the undergraduate level, multiple initiatives have been developed for outcome-based learning for engineers, especially during the past ten years. The United States' National Academy of Engineers produced a report envisioning and addressing the challenges facing future engineers (NAE, 2004). At the end of their report, they identified essential attributes that connected the past, present, and future of engineering. These enduring attributes or learning outcomes of engineers include nine aspects, namely, strong analytical skills, practical ingenuity, creativity, communication, business and management, leadership, high ethical standards and professionalism, dynamism, agility, resilience and flexibility, and lifelong learning (NAE, 2004, p 54-56). Although the focus of the report was to define the attributes of engineers of 2020 with an emphasis on undergraduate engineers, this list might be used to provide a basis for exploring and understanding learning outcomes for engineering Ph.D.s.

Other research studies or accreditation practices for engineers at the undergraduate level also provide a solid foundation for engineering students who pursue graduate studies (Lattuca, 2006, ABET 2010). The Accreditation Board for Engineering and Technology (ABET), founded originally by several engineering societies in the United States, has contributed to the outcome-based quality assurance of engineering education for mostly undergraduate programs and several Master's programs in the U.S. Organizations such as the European Network for Accreditation of Engineering Education (ENAEE website) and Engineers Australia Accreditation Board (EA, 2005) have made similar efforts in drafting the desired outcomes or attributes of future engineering graduates similar to ABET criteria. These accreditation organizations have influence upon national, regional, and even international engineering education. For example, ENAEE has accredited around 700 first-cycle programs (equivalent to four-year engineering undergraduate programs in the U.S.) and second-cycle programs (equivalent to Master's programs in the U.S.) in Germany, Ireland, Turkey and Russia using an accreditation framework which composes six categories, namely, knowledge and understanding, engineering analysis, engineering design, investigations, engineering practice, and transferable skills (EUR-ACE, 2008).

Beyond undergraduate education, global engineering societies also support the consistency in training practicing engineers. For example, the International Engineering Alliance (IEA) and the European Federation of National Engineering Associations (FEANI) are the two main international organizations for professional engineers' registration (Allan, 2009). Respectively, they created two comparable competencies' lists for engineering professionals. Thirty-one European countries are members of FEANI, which compiled the above-mentioned EUR-ACE standards. IEA has established an international standard of competence for professional engineers via the Engineers Mobility Forum (EMF) agreement (EMF-Washington Accord website, 2009), an agreement among accreditation bodies to acknowledge "the substantial equivalency of programs accredited by those bodies." The member organizations of the EMF agreement include North America (U.S. and Canada), Australasia (Australia and New Zealand), Asia (Chinese Taipei, Hong Kong China, India, Japan, Korea, Malaysia, Singapore, and Sri Lanka), Europe (Ireland and United Kingdom) and South Africa. EMF also established three accords to define different levels of these attributes (2009). As ratified at IEA Biennial meetings Kyoto in 2009, the Washington Accord is used to define the attributes of graduates from 4+ year Professional Engineer programs. This is the most advanced degree level within the EMF agreement. In addition, EMF agreement defined another comprehensive list of attributes for professional engineers, engineering technologists, and engineering technicians. The differentiating characteristics cover the breadth and depth of knowledge, the complexity of analysis, and a number of other aspects.

Doctoral Education Trends and Suggestions for Improvement

A comparison of the above-mentioned statements or standards issued by accreditation bodies and professional societies suggests several general trends related to doctoral engineering education. Measures that might be pursued by department and institutions are listed below each trend or challenge.

1. There is an overall lack of differentiation of expectations for engineers graduated with B.S., M.S., and Ph.D. degree levels. Although accreditation bodies like ENAEE did break the grouping of engineers into the first and second cycles, which are equivalent to undergraduate and Master's programs respectively, and although organizations such as the Australian Qualification Framework Council specified the educational purpose and requirements for doctoral students, missing from literature is information about the specific roles, competencies, and expectations of *engineering Ph.D.s* globally. For this reason, the goals and purposes of engineering doctoral education are not standard.
    a. Engineering departments need to state clearly the depth and breadth of competencies expected of students at the bachelors, masters, and doctoral levels. In this way, a continuum of educational competency within engineering may be created, and students might obtain a global view of the educational goals expectations within their engineering disciplines.
    b. Once students know the sector in which they would like to work, Ph.D. competencies that are most important for success in that sector need to be developed by students within their engineering doctoral programs. A case in point is the development of "Engineering Doctorate Programmes" supported by Engineering and Physical Sciences Research

Council (EPSRC, 2007) in the United Kingdom. These programs featured a strong industrial involvement in the education process of an engineering doctorate (different from traditional Ph.D. degree holders in engineering) from these programs. By so doing, they tried to facilitate early career advancement of engineering doctorate degree holders in industrial sectors after graduation.

2. The overall goals for engineers are similar across nations evidenced by a comparison of the standard documents from engineering professional organizations and accreditation organizations, although competencies are not presented in great detail and are stated in different ways. Competencies are composed of several common themes: technical knowledge, engineering ability, and professional skills and attributes. There are differences in the way each criterion depicts aspects of learning outcomes and specific requirements.
    a. Competencies should reflect disciplinary differences and the expectations of professional societies within that discipline.
    b. Engineering societies might champion efforts to promote consistent training and continuing professional development of engineering Ph.D.s within their disciplines.
3. Professional attributes are emphasized as much as technical or engineering abilities. This trend is similar across different organizations. For example, Newport and Elms (1997) pointed out that engineering competencies alone are not sufficient for success as an engineer.
    a. Institutions must give doctoral students opportunities to acquire specific professional attributes required of engineering Ph.D.s that are aligned with their post-graduation careers plans (e.g., obtaining a job in academia or industry).
    b. Institutions should create opportunities for students to enrol in professional development programs that offer them experience in learning new skills or competencies (e.g., providing connections to industrial representations or travelling to international conferences).

In sum, the consistency to train engineers has been ensured mostly on the undergraduate and Master's degree levels (UNESCO, 2004). Less effort has been devoted to the assessment of doctoral engineering compared to the available criteria for undergraduate engineering assessment (e.g. Engineer 2020 (NAE, 2004), EC2000 (Lattuca, *et al.*, 2006)). There is an overall lack of agreement about the training of engineering Ph.D.s. Despite the perceived need to measure the outcomes of doctoral programs in U.S., "there are no agreed-upon standards or programmes relating to such measures" (UNESCO, 2004, p265). The need to ensure the standards and training outcomes for engineering education has attracted considerable interest in the field of engineering education.

Integrative Assessment Model

In response to the trends and challenges listed above and to prepare engineering doctoral students for broader career options, the authors propose the development of an integrative assessment model of doctoral education that incorporates the need for engineering Ph.D.s to demonstrate technical and professional competency in different sectors (i.e., industry and academia).

Table 1 displays sample skills that may be assessed from industry and academic perspectives. Although not an exhaustive list of competencies, the competencies in the table come from our own studies and from the studies of other empirical studies that have looked at the knowledge and skills that are essential for careers in academia and industry (Cox *et al.*, 2011; Watson and Lyons, 2011; Preparing Future Faculty website, 2011). Although the doctoral dissertation explores the extent to which students demonstrate technical depth, skills such as those listed in Table 1 might be combined in a portfolio or another alternative method of evaluation to determine the extent to which engineering Ph.D.s are demonstrating technical and professional breadth.

In the U.S., such a model is needed, since the majority of engineering Ph.D.s obtain jobs in non-academic environments (Akay, 2008); since more jobs are available for engineering Ph.D.s in industry than in academia; since many engineering faculty have not worked in industry (Pawley, 2008); and since many engineering doctoral students may not know which sector they want to enter after obtaining their Ph.D.s.

Table 1 Integrative Assessment Model for Engineering Ph.D.s

	Industry	**Academia**
Technical Skills	Strong analytical skills*	Strong analytical skills*
	Multidisciplinarity*	Multidisciplinarity*
	Interdisciplinarity*	Interdisciplinarity*
	Commercializing products*	Conducting state-of-the art research*
Professional Skills	Leadership*	Obtaining funding*
	Teamwork*	Teaching*
	Communication skills*	Publishing*
	Project management skills*	Administrative skills*
	Independent learning**	Mentoring***
	Problem solving skills**	Directing Research***
	Working independently**	

Notes: * Cited from Cox, *et al.* 2011; ** Cited from Watson, *et al.*, 2011; *** Cited from Preparing Future Faculty website, 2011.

Conclusions

Although global organizations have defined competencies and learning outcomes for undergraduate engineers, standard learning outcomes at the doctoral engineering level have not been defined as clearly beyond the development of a dissertation. Authors encourage faculty, administrators, accreditation bodies, and engineering societies to begin a global conversation that aligns workforce trends with assessments for doctoral engineering students. In this way, doctoral students may be exposed early in their graduate careers to technical and professional experiences that will allow them to become leaders in their workplaces and in a global society.

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