GLOBAL ENGINEERING EXCELLENCE: THE ROLE OF EDUCATIONAL RESEARCH AND DEVELOPMENT[1]

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ABSTRACT

As the world rapidly transitions to one that is globally and culturally integrated and driven by accelerating technological advancements, there is a growing international concern about the worldwide capacity of engineering programs to produce a well-prepared engineering workforce. Many in the global engineering community are again calling for major reform of engineering education. This time, however, a more transformational and sustainable approach is appearing in the form of engineering educational research and development. Because the vitality of any field depends on the vigor of its community of scholars and practitioners and their dedication to the advancement of knowledge through research and development, assuring sustained global engineering excellence depends critically on building the global capacity for scholarly research and development in engineering education.

Key words: Engineering educational research and development. Engineering education innovation. Global capacity.

INTRODUCTION

Not too long ago, industries could create new products and services and continually improve them over a couple of decades or more. It took nearly a quarter of a century for the radio to reach 25 percent of the U.S. population, over a third of a century for the telephone, and over one-half a century for the automobile (VEST, 2008b). People could develop special expertise early on and apply it successfully for much of their careers. Educational institutions could teach a fairly stable set of skills and subjects and know that most of it would be useful throughout a graduate's lifetime. Today the innovation cycles are much shorter. It took 16 years for the personal computer to reach 25 percent of U.S. households, 12 years for the cellular phone, and just six years for the World Wide Web. There are many products and services today where the development time is longer than the resulting life cycles. In light of these rapid technological advancements and a growing global economy, many in the engineering community argue that we need to significantly transform how we go about educating engineers. (AMERICAN SOCIETY FOR ENGINEERING EDUCATION, 2007; DUDERSTADT, 2008; NATIONAL ACADEMY OF ENGINEERING, 2004).

The dominant model today for engineering education innovation involves periodic curriculum reform based largely on experience and reflective teaching practices, and historically has resulted in calls for teaching more topics. It is a model which historically is inefficient in its exploration and transferability of engineering education innovations and, therefore, it may not be as effective in keeping pace with the rapid advancements in engineering practice driven by today's highly-competitive, complex, and interdependent global economy. There is concern that it may lead to a capability gap between the skills of current engineering graduates and future engineering needs.

Another model has recently begun to emerge that seeks to advance engineering education innovation by encouraging educational developments based on educational research, which

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calls for shifting our focus from teaching topics to student learning. However, it is a model whose impact is still being proven, and one in which many engineering faculty may not yet be well prepared to pursue with rigor. Consequently, there is a growing tension within the global engineering education community between the relative merits of a reform-based versus research-based paradigm for engineering education innovation. (BORREGO et al., 2008; DE GRAAFF and LOHMANN, 2008).

In this paper, we suggest an alternative, one that reflects the merits of both paradigms, which we will call the *educational research and development (R&D) model*, and that simultaneously sharpens the focus of the intended outcome of engineering education innovation: helping students *learn to become engineers*, i.e., moving past teaching topics and even beyond student learning to focusing on the professional formation of engineers and their preparation for the practice of engineering in a broad societal and global context.

The remainder of this paper is divided into three parts. We first describe the need for a new model for engineering education innovation, and then describe the model itself: engineering education innovation based on the mutually reinforcing and synergistic activities of educational research and development. We will make the point that global engineering educational development is a much more mature field than engineering educational research, and therefore the current focus on engineering educational research should be to bring about a better balance between the two. A more balanced portfolio between engineering educational research and development will result in higher levels of engineering education innovation. We conclude by identifying some critical needs today which must be addressed to advance the global capacity for engineering educational research (to bring about this better balance). We will discuss these issues largely through an American lens; however, linkages to equivalent international perspectives will also be made.

THE NEED FOR A NEW MODEL FOR ENGINEERING EDUCATION INNOVATION

Wanted – the global engineer. An accelerating number of articles, chapters, and books speak to the implications of globalization and the urgency of a new kind of engineer. (CONTINENTAL, 2006; NATIONAL ACADEMY OF ENGINEERING, 2005). Among the implications is the rapidly expanding domain of engineering driven by an insatiable societal appetite for new technologies. (VEST, 2008b). In one dimension engineering is venturing into micro-worlds, such as bio-, nano-, info-technology where things become smaller, faster, and more complex, and the boundaries between science and engineering blur. In another dimension engineering is being called upon to wrestle with macro-challenges of great societal importance, e.g., energy, sustainability, and health care, where solutions require engineers to reach across the disciplinary boundaries into social science, business, public policy, etc. The body of knowledge, skills, abilities, and attitudes demanded of engineers are expanding significantly. Engineers today are expected to understand complex systems, new materials, information systems, multi-disciplinary design, global markets, business practices, social norms, political contexts, safety, sustainability, manufacturability, reliability, maintainability, etc., and they also need to be culturally sensitive, socially aware, politically astute, broadly knowledgeable, lifelong learner, team player, effective communicator, multi-lingual, ethical, innovative, entrepreneurial, flexible, mobile, etc. Can our engineering programs really instill all this?

Indeed, even if they could, engineering enrollments in some developed countries are declining as students see other fields as more attractive, and in many developing countries enrollments are rising rapidly and outstripping their institutional capacities to deliver a quality educational experience. (DUDERSTADT, 2008; GEREFFI et al., 2008). Further, while it is easy to speak of “engineering programs” and “universities” as if they are all alike, the tapestry of engineering programs worldwide is as different as the systems of higher education in which they are embedded. (CONTINENTAL, 2006; LUCENA et al., 2008). Developing global engineering competence takes on different meanings when viewed and understood in national contexts.

How should engineering education respond to assure an adequate supply of well-prepared engineers for the future? The dominant model today for engineering education innovation (renewal), at least in the U.S., is largely based on periodic calls for major curriculum reform. One-half century ago U.S. engineering education reformed from one based on practical arts to one based on science, and then late in the twentieth century it reformed again emphasizing more design, and then again to foster more curricula integration, and at the beginning of this century, the call is for global mobility. Curriculum innovations have been based largely on reflective teaching practices and experience. (HAGHIGHI, 2005). While that model has certainly produced capable engineers as evidenced by the remarkably advanced society in which we live, the scale, complexity, and sustainability of the challenges ahead should give pause for thought as to whether such a model has the requisite efficiency and rigor to keep pace with today's rapidly rising demands for technological solutions in an increasingly global society.

Preparing engineers to meet the challenges of today and tomorrow will likely require another kind of response. (HAGHIGHI et al., 2008; NATIONAL ACADEMY OF ENGINEERING, 2005). Seldom has engineering education advanced using well-established learning theories and proven pedagogical practices gained through scholarly educational research. (NATIONAL RESEARCH COUNCIL, 2000; SHAVELSON and TOWNE, 2002). We know *how* we teach is as important as *what* we teach. Clearly, content must come before pedagogy; pedagogy cannot make up for lack of content. However, good content can be seriously compromised by poor pedagogy. We need to more fully embrace what we already know: good content and informed pedagogy are critical for effective learning. We need to shift our focus from "teaching topics" to student learning. Dr. Charles Vest, president of the U.S. National Academy of Engineering (NAE), states well, "in the long run, making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details". (VEST, 2008a).

A NEW MODEL FOR ENGINEERING EDUCATION INNOVATION

Higher levels of practice in any field, whether engineering, science, architecture, business, education, etc., are driven by continual cycles of innovation, or what Ravesteijn, de Graaff, and Kroesen (2006) describe as "innovation as an evolutionary process. However, innovation depends on a vibrant community of researchers *and* practitioners *working in collaboration* to advance the frontiers of knowledge *and* practice through research *and* development. Unfortunately, this time-tested model for achieving higher levels of engineering performance remains largely untapped in engineering education. Our reform-based model has emphasized educational development and teaching topics and has seldom leveraged the power of educational research and its focus on student learning. Consequently, a research-based model has been emerging which emphasizes educational research as a driver to focus and accelerate educational development. (GABRIELE, 2005).

However, neither model alone will likely fully address the concerns about a potential capability gap between the skills of current engineering graduates and future engineering needs. While the reform-based model can be inefficient in its exploration and transferability of educational innovations, it is strongly rooted in educational practice and well connected to engineering practice. While the research-based model makes more apparent high-potential opportunities for educational innovation and their transferability, it also can become disconnected from both educational and engineering practice. However, when these two paradigms are combined into continual cycles of educational R&D, the result is much more likely to produce higher and higher levels of educational practice and engineering graduates capable of keeping pace with, if not otherwise advancing, engineering practice.

Transitioning to this new model requires mostly that we develop a better balanced educational R&D infrastructure. Engineering educational development is a much more mature field than engineering educational research. Thus, there is a critical need to advance the global capacity for engineering educational research to better leverage the existing infrastructure in engineering educational development and, thus, enhance global engineering education innovation.

Fortunately, we have a head start to bring about a better balance. In the United States, the importance of engineering educational research began to surface in the mid-1980s when the National Science Board (NSB) issued its landmark report, *Undergraduate Science, Mathematics, and Engineering Education* (1986), in which it stated:

The recommendations of this report make renewed demands on the academic community – especially that its best *scholarship* [emphasis added] be applied to the manifold activities needed to strengthen undergraduate science, engineering, and mathematics education in the United States. (p. 1).

Although the report focused on undergraduate education, it was instrumental in reviving the U.S. National Science Foundation's (NSF) role to "initiate and support science and engineering education programs at all levels and in all the various fields of science and engineering". (NSF, 2003). The report was also among those that sparked a vigorous national dialogue on the role of scholarship in improving the quality of U.S. higher education. For example, the highly influential report, *Scholarship Reconsidered: Priorities of the Professoriate*, by Ernest Boyer of the Carnegie Foundation for the Advancement of Teaching, offered a new taxonomy and terminology to describe academia's multifaceted forms of scholarship. (BOYER, 1990). In engineering, the subsequent introduction of EC 2000 by ABET[3] in the 1990s was a major driver to improve the quality of U.S. engineering education. (ABET, 1995). Its outcomes-focused, evidenced-based cycle of observation, evaluation, and improvement characterizes many aspects of a scholarly approach to educational innovation. The dialogue and decisions made in the 1990s paved the way for engineering education to become a more scholarly field of research, development, and professional achievement by the beginning of the twenty-first century. For example, the criteria for election to the NAE now more fully reflect the value of educational contributions as an important consideration, and the recent creation of degree-granting departments of engineering education at Clemson University, Purdue University, Utah State University, and Virginia Tech are groundbreaking events in the landscape of engineering programs. (CLEMSON, 2008; NAE, 2008a; PURDUE, 2008; UTAH STATE, 2008; VIRGINIA TECH, 2008).

Collectively, these efforts made it possible for the American Society for Engineering Education (ASEE) to recently launch a major initiative in which educational scholarship is the driver to transform U.S. engineering education and to better prepare its graduates for the global economy. The initiative began in June, 2006 as a society-wide effort, entitled "Advancing the Scholarship of Engineering Education: Launching a Year of Dialogue". (ASEE, 2006). During the following months, conversations were held with the constituent sections and groups to discuss and record the critical issues. (MOHSEN et al., 2008). However, it quickly became evident that a major nationwide effort was needed to better position U.S. engineering education for the global economy. Thus, with the support of the NSF, ASEE launched a major project in the fall of 2007 entitled, "Engineering Education for the Global Economy: Research, Innovation, and Practice". (ASEE, 2007). The goal of the project is twofold: "to prepare a report by June 2009 that provides a blueprint for the transformation of engineering education through educational scholarship to better prepare graduates for the twenty-first century, and to initiate and report on substantive actions to advance the recommendations of the report by June 2010. Thus, the goal of the project is both a blueprint for and initiation of actions to rapidly transform engineering education."

These efforts, and similar efforts internationally (DE GRAAFF and LOHMANN, 2008), have created an emerging community of *engineering* faculty engaged in educational research. However, there is also a growing community of faculty aspiring to join their ranks, and, of course, a much larger community of engineering faculty engaged in educational practice who could benefit from the results and insights gained from engineering educational research. The question now is: how can we build vibrant and mutually reinforcing communities of educational researchers and practitioners dedicated to advancing engineering education innovation through educational research and development?

BUILDING AND SUSTAINING COMMUNITIES OF EDUCATIONAL RESEARCHERS AND PRACTITIONERS

Three near-term challenges must be addressed if we are to build and sustain global communities of educational researchers and practitioners. We need to: 1) define educational scholarship and the role of research and development within it; 2) focus engineering education innovation on the professional formation of engineers in the broader societal context; and 3) build an infrastructure that sustains engineering educational R&D.

A. Defining Educational Scholarship

A common phrase used today to describe the emerging area of educational scholarship is the "scholarship of teaching and learning". (HUTCHINGS and SHULMAN, 1999). The roots of the scholarship of teaching and learning may be found in the historic debate of "teaching versus research." While it has been reasonably understood that to be a "scholar" in teaching required one to demonstrate contributions similar to scholarly technical research, it has also been common to be considered an educational scholar if one was an excellent instructor (i.e., high teaching evaluations), a popular mentor, or an author of a widely adopted textbook. Dependence on these metrics as evidence of scholarship in engineering education was probably driven in part by a lack of the more widely accepted forms of scholarship in engineering technical research, such as highly-regarded peer-reviewed journals, highly-competitive extramural funding, and prestigious national and international recognitions. Indeed, the absence of such important elements of infrastructure likely reinforced the perception that teaching was not on par with technical research because it did not have (or attract) these kinds of support.

Growing concerns about the narrow definition often applied to faculty scholarship (i.e., technical research) gained considerable attention when Ernest Boyer, then president of the Carnegie Foundation for the Advancement of Teaching, published his now landmark book, *Scholarship Reconsidered: Priorities of the Professoriate*, in which he broadened and deepened the discussion about the many forms of professorial scholarship beyond simply technical research. (BOYER, 1990). He advocated a model in which he envisioned four kinds of scholarship: *discovery,* being the first to find out, to know, or to reveal original or revised theories, principles, knowledge, or creations; *integration,* making connections across the disciplines, placing the specialties in larger context, illuminating data in a revealing way, and often educating non-specialists as well; *application,* bringing knowledge to bear in addressing significant societal issues; and *teaching,* developing the knowledge, skill, mind, character, or ability of others, and transforming and extending knowledge as well.

For as much as this framework was referenced throughout the 1990s, and even today, it does not appear to have yet moved the professoriate to meaningfully consider a broader definition of scholarship. In engineering, the "scholarship of discovery" is largely equated with technical research, the "scholarship of teaching" is still primarily viewed as excellent teaching or curriculum development, and the scholarships of integration and application are considered mostly technology transfer. The engineering education community still lacks clear explication of what is meant by the scholarship of teaching and learning. If we are to make progress developing the field of educational scholarship, then we must make more clear the role of educational research and development, and researchers and practitioners, in engineering education innovation.

A framework with promise was recently advanced by Borrego, Streveler, Miller, and Smith (2008) based on work by Hutchings and Shulman (1999). The framework emerged as a result of three years of experience with developing, facilitating, and assessing five-day workshops on "Rigorous Research in Engineering Education." The framework characterizes, or represents, educational activities according to four levels of inquiry:

> *Level 1, excellent teaching*, is characterized by the delivery of good content and use of good teaching methods.
> *Level 2, scholarly teaching*, builds on Level 1 and is characterized by efforts involving evidence-gathering of instructional effectiveness informed by best practice and best knowledge, and by inviting colleagues to collaborate in or review the efforts.
> *Level 3, scholarship of teaching*, builds on Level 2 and is characterized by work involving inquiry, particularly about student learning, and by opening one's work to public critique and dissemination in a form that others can build upon it.
> *Level 4, engineering education research*, builds on Level 3 and is characterized by carefully designed studies, questions that are tied to appropriate theoretical frameworks (learning, development, motivation, etc.), and interprets the results in light of theory.

Not too surprisingly, they encountered some tension during the course of their workshops that often occurs whenever the topic of the scholarship of teaching and learning is discussed (BORREGO, 2007b; BORREGO, FROYD, and KNIGHT, 2007; STREVELER and SMITH, 2006). The source of that tension lies largely in that not every engineering faculty member presently is well prepared to do rigorous work at each level, especially Level 4. The emerging research-based model is often perceived as challenging the reform-based practices, standards, and achievements. The dissonance between what constitutes rigorous engineering educational scholarship and the qualifications of the faculty needed to competently conduct such scholarship fuels much of the debate about the field. This dissonance must be resolved. As Borrego et al. summarize:

> The development of engineering education as a field is likely to be impeded if alternative viewpoints are not resolved or at least framed with respect to one another and discussed openly. The key tension identified in this data lies between broad inclusiveness and high standards of research quality. Those subscribing to the reform paradigm feel strongly that if the purpose of engineering education research is to improve engineering education, then a wide audience of all engineering faculty should be targeted. In contrast, a research paradigm is far less inclusive because of high standards and their inevitable consequence of exclusivity are given higher priority than a vast audience or community. What may be viewed as either backlash or a softening of the rigorous research rhetoric since its peak in 2005 could actually be the beginnings of yet another paradigm – a *systems paradigm* for transforming engineering education that values both knowledge building (research) and professional development (reform) as necessary components to achieving lofty goals. If the paradigms of research and reform do indeed lie in direct opposition, then neither may ever dominate before a new paradigm emerges (p. 160).

Modeling engineering education innovation as the product of engineering educational research and development reflects a systems perspective, and one that is *inclusive* of both educational research and practice, and educational researchers and educational practitioners. The research-based model reflects our need for deeper understanding about how students learn to become engineers, faculty develop as educators and mentors, and organizations influence and motivate the educational enterprise, and the reform-based model reflects our need for innovative educational development that translates educational and technical research into effective educational practice. Together they reinforce one another and provide meaningful opportunities for educational practitioners and researchers to mutually and synergistically contribute to the advancement of engineering education. Defining the field of educational scholarship more clearly, and the mutually valued and rewarding roles for educational researchers and practitioners, is critical first step to advancing engineering education innovation. (BORREGO, 2007a; FENSHAM, 2003; JESIEK, NEWSWANDER, and BORREGO, forthcoming).

B. Engineering Education Innovation and the Formation of Engineers

Norman Augustine, the retired chief executive officer of Lockheed-Martin, recently remarked (HAGHIGHI et al., 2008), "[…] nearly all the grand challenges potentially to be faced by society as a whole in the next century have significant engineering connotations." Indeed, the U.S. NAE recently asked 17 accomplished engineers, scientists, and medical experts to lead an effort to identify a few grand challenges that could reasonably be accomplished in the next few decades and would substantially advance the human condition. (NAE, 2008b). The 14 (unranked) grand challenges fall into four areas (VEST, 2008b): *manage energy and the environment* (make solar energy economical, provide energy from fusion, develop carbon sequestration methods, manage the nitrogen cycle, provide access to clean water); *improve medicine and health care delivery* (engineer better medicines, advance health informatics); *reduce vulnerability to human and natural threats* (secure cyberspace, prevent nuclear terror, restore and improve urban infrastructure); and *expand and enhance human capability and joy* (reverse engineer the brain, enhance virtual reality, advance personalized learning, engineer the tools of scientific discovery).

These are serious challenges with significant global industrial, environmental, social, and cultural implications. Our success in addressing these and other challenges depends critically on our ability to educate the next generation of engineers. Yet, do we really know who are today's and tomorrow's engineering students, what motivates them, and what attracts them to engineering? What skills, abilities, and attitudes will they need, and what is essential in learning to become an engineer? How can our students learn most effectively, how do they see themselves as they become engineers, and how do we instill the skills to help them grow professionally after graduation?

These issues and others are the focus of a recent special issue of the *Journal of Engineering Education*, "Educating Future Engineers: Who, What, and How," guest edited by Drs. Sheri D. Sheppard, James W. Pellegrino, and Barbara M. Olds. (SHEPPARD, PELLEGRINO, and OLDS, 2008). The motivation for the special issue was twofold: reflection and action. The five editorials, four sponsor commentaries, nine invited papers, and two book reviews describe what educational research in engineering, and related areas of education, cognition, and the learning sciences, currently tell us about how students learn to become engineers. The authors discuss how our educational practices should be guided by the learning styles, motivations, and aspirations of today's and tomorrow's students, but they also remind us that our educational programs should be focused on preparing engineers to tackle the grand challenges of the future. The issue makes clear that we have much to be proud of in the current state of engineering education; however, it also points out that we can do much better.

We need a twin focus in our pursuit of engineering education innovation. Our educational research and development should be *framed* around issues dealing with the formation of engineers and the practice of engineering in a broad societal and global context, and pursued with a *focus* on promoting effective learning environments and educational practices which can be broadly adopted. (FORTENBERRY, 2006; RADCLIFFE, 2006).

C. Building Infrastructure to Sustain Educational R&D

Communities require more than identity and purpose; they require a supportive infrastructue. Sustaining communities of educational researchers and practitioners requires three kinds of infrastructure: physical resources, philosophical structure, and cultural support. Within engineering education these infrastructures are generally better developed and more mature in educational development than they are in educational research.

1) *Physical resources:* Physical resources consists of the usual components needed to conceive, collaborate, conduct, and disseminate the products of academic research and development, among them: i) *well-defined groups, centers, or departments*, in effect, communities of researchers and practitioners within the academic institution who associate, communicate, and collaborate with one another on common research and development interest(s); ii) *supportive professional organizations and recognitions*, such as professional societies that facilitate national and international networking and provide visibility for notable achievements; iii) *adequate fiscal resources for research and development*, and most importantly extramural support from government agencies, industry, and foundations, and especially peer-reviewed and/or highly-competitive sources; and iv) *quality forums for dissemination of knowledge*, such as conferences, symposia, proceedings, and archival journals. These components are generally well developed in many technical fields; however, they are much less evident or mature in engineering educational research and development.

The global engineering education community appears to be doing best in creating well-defined groups and supportive professional societies. Many U.S. institutions and/or engineering colleges have centers for teaching and learning (e.g., PSU, 2008) and research groups (CAEE, 2008), and some have academic departments focused on engineering education. (CLEMSON, 2008; PURDUE, 2008; UTAH STATE, 2008; VIRGINIA TECH, 2008). Similar groups appear internationally as well. (UCPBL, 2008; SJTU, 2008). Professional societies, organizations, and education-related agencies have created new platforms and awards to recognize engineering educational innovations. (ASEE, 2008; IFEES, 2008; IUCEE, 2007; NAE, 2008c; REES, 2008; SEFI, 2008).

Support for conducting educational research and forums for the dissemination of research results are the least well developed. Historically, sources of support for education came mostly from internal (institutional) sources. They were seldom peer-reviewed and often in small amounts and short duration. The U.S. NSF has made progress to boost the amount and prestige of engineering educational research (GABRIELE, 2005); however, the consistency of support and award amounts still do not compare favorably with technical research.

Similarly, while most engineering education conferences provide ample venues for disseminating educational developments, similar venues for educational research are not as plentiful. However, sessions on engineering educational research are appearing more regularly at international engineering education conferences, and indeed sometimes appear as entire tracks of papers. (ASEE, 2008). The community-driven Research on Engineering Education Symposium (REES) is rapidly building a global network of researchers in the field. (BORREGO, FROYD, and KNIGHT, 2007; REES, 2008). A number of journals are now explicitly encouraging submissions focused on engineering educational research. Two primary sources for engineering educational research may be found in the *Journal of Engineering Education,* which repositioned in 2003 to focus exclusively on publishing engineering educational research (LOHMANN, 2003, 2005), and the Web portal Annals of Research on Engineering Education, which serves as a gateway to access engineering educational research articles in a number of engineering education journals (and closely related fields). (NAE, 2008d; SMITH, 2006).

2) *Philosophical structure:* Consider a conversation that often occurs between two engineering educators who meet for the first time. After the usual pleasantries, the following exchange typically takes place: "*What is your discipline?,*" "Aerospace Engineering," "*And what is your specialty?*," "Gas Dynamics." In that brief exchange, the questioner very likely knows much more about his or her fellow engineering educator other than his or her discipline and specialty. The questioner has a pretty good idea of the nature of the problems studied and their professional and societal significance, and if the questioner comes from a related discipline and specialty (e.g., mechanical engineering, fluid dynamics), he or she may even have some appreciation of the research methods, practices, and recent results.

Contrast this dialogue with a similar conversation in engineering education. Many engineering faculty would be surprised to hear a colleague say that his or her discipline is "engineering education," and probably would not have the presence of mind to ask about his or her specialty. The typical conversation focuses on what they each may teach or perhaps their latest curriculum projects. It is highly unlikely they would frame their conversation around educational research interests or specialties. The absence of a means to classify engineering education research problems in a more rigorous way, categorize research methods, practices, and results within those classifications, and communicate cogently about these problems with those inside and outside the community is a major hindrance to the advancement of the field. (STREVELER and SMITH, 2006). Such a structure is still largely absent in engineering educational research.

A recent effort in the United States, funded by the NSF, created the first taxonomy for engineering educational research. (SPECIAL REPORT, 2006; BORREGO, 2007b; BORREGO et al., 2008). It divided engineering education research into five categories: *engineering epistemologies,* engineering thinking and knowledge within social contexts now and into the future; *engineering learning mechanisms,* engineering learners' developing knowledge and competencies in context; e*ngineering learning systems*, institutional culture, institutional infrastructure, and epistemology of engineering educators; *engineering diversity and inclusiveness*, diverse human talents as they relate to social and global challenges and relevance of our profession.; and *engineering assessment*, assessment methods, instruments, and metrics to inform engineering education practice and learning.

Whether these five categories withstand the test of time, or expand to represent engineering educational research efforts beyond the U.S. remains to be seen, but they form the basis for developing the body of knowledge and communities of practice in engineering educational research. They provide a means for researchers to begin to specialize, to develop theories, methods, and practices appropriate to the classifications studied, engage in structured discourse, and to communicate with others in related fields in search of underlying or overarching principles and observations.

3) *Cultural support:* A current research initiative by the *European Journal of Engineering Education* and the *Journal of Engineering Education* entitled, "Advancing the Global Capacity for Engineering Education Research," is conducting information-gathering sessions at ten international engineering education conferences. (DE GRAAFF and LOHMANN, 2008; BORREGO, JESIEK, and BEDDOES, 2008). The purpose of the sessions is twofold: identify key international issues to advancing engineering educational research, and build a global network among regional communities of scholars. Preliminary observations from sessions involving largely American, Australian, European, and Chinese engineering

faculty have yielded interesting national differences. (BORREGO, JESIEK, and BEDDOES, 2008). In the United States, disciplinary and departmental structures and rewards are powerful, whereas in Europe disciplinary boundaries are less critical. Europeans are more concerned about crossing national (European Union) boundaries than disciplinary ones. Australians exhibit a bit of both the U.S. and European viewpoints; they are less concerned about disciplinary boundaries, but they are very concerned about rewards and recognitions. In China, the academic hierarchy is very powerful. Faculty members there are likely to defer to higher-ranking colleagues and administrators in making their decisions. Thus, conferences, publications, resources, etc. which recognize, say, the American need for clear disciplinary/departmental identity may not be viewed as supportive in the European multi-/inter-disciplinary culture; similarly, recognitions aimed at supporting individual faculty may not inspire action in China but they may resonate well in Australia. No doubt additional depth of understanding and a more complete picture will emerge from the sessions involving Africa, India, Russia, and South America.

Because faculty members are embedded within local, regional, or national higher education systems, their professional success is largely determined by the "value systems" of that infrastructure. Thus, one's success internationally will be significantly determined by the value systems "back home". Understanding the various value systems internationally, therefore, becomes important as one seeks to build a global community in engineering educational research and development. Community building efforts that do not recognize, support, and validate the value systems of local, regional, or national higher education systems are not likely to be sustainable.

Overall, our challenge is to build a *multi-dimensional* infrastructure, one that provides physical resources, philosophical structure, and cultural support. This will not be an easy task; it requires a well-balanced infrastructure. Only when all three are well developed and mutually reinforcing will engineering educational scholarship have reached a level of maturity consistent with many other established fields.

CONCLUSION

Today's highly-competitive global economy coupled with the growing list of serious global challenges, such as sustainability, security, and health, are straining the capacity of our society's institutions to keep pace, whether it is industry, government, or education. It is a time in which many local, regional, national, and international institutions, organizations, and agencies are engaged in far-reaching discussions with potentially profound and long-lasting changes. It is a time in which we, in higher education and engineering education in particular, must be adaptive, innovative, and entrepreneurial. This is easier said than done. John Bransford, co-author of the highly influential book, *How People Learn* (NRC, 2000), describes this aptly: "The hard part of being adaptive and innovative is that often it forces us to change ourselves, our environments, or both. These changes can evoke strong emotions and take us away from our momentary efficiencies and comfort zones by forcing us to unlearn old skills, [and] tolerate momentary chaos and ambiguity in order to move forward..." (BRANSFORD, 2007).

If we wish to assure global engineering excellence, we need to remember that excellence is seldom the result of happenstance; it is more often the result of vision, planning, and commitment. We need a new vision for engineering education innovation, one based upon a solid foundation of educational research and tightly linked to educational practice. We need to develop plans to build the necessary infrastructure to create and sustain a global community of educational researchers and practitioners, and we need the will to follow through. Assuring global engineering excellence depends critically on our ability to rapidly advance the global capacity for educational research and development. The question is: are we ready?

ACKNOWLEDGMENTS

The author wishes to express his genuine appreciation to several colleagues for their thoughts and comments to help improve this article, specifically, Drs. Maura Borrego, Richard Felder, Norman Fortenberry, Jeffrey Froyd, Erik de Graaff, Roger Hadgraft, David Radcliffe, and Karl Smith.

NOTAS

1 An invited paper for the commemorative issue of the Brazilian Journal for Engineering Education celebrating the 35th anniversary of the Brazilian Society for Engineering Education. Not for quotation or circulation without written permission from the author. 25 July 2008.

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3 ABET, Inc. is the U.S. organization which accredits engineering programs.

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