Implications of Research in Engineering Education
for Practice in Engineering Education[1]

This brief paper and invited talk on October 21, 2008 at the 7th ASEE Global Colloquium on Engineering Education focuses on educational research as a means of informing and influencing engineering education practice. I began exploring changes in engineering education about 10 years ago and gave a series of keynote presentations with titles such as "Engineering education: Pressures to change, current trends and future directions." For example, I listed the pressures to change from the following organizations and groups at the Australasian Engineering Education Conference in 1998:

- Legislators (in public institutions)
- National Science Foundation: Career Development Award, Shaping the Future
- Professional Accreditation – ABET: Assessment, Synthesis & Design
- Financial – especially the growing gap between the falling public support and the rising costs
- Employers and Workforce Development Agencies: Workplace Basics, Global Engineer
- University Administration Professional Organizations: Renewing the Covenant, Greater Expectations
- Boyer Commission Reports: Educating Undergraduates in the Research Universities, Scholarship Reconsidered
- Educational Research: Active, Interactive & Cooperative Learning, Inquiry & Problem-Based Learning

Colleagues and I elaborated on this list and offered a summary of models of change we felt were relevant and applicable for engineering education in a 2004 ASEE conference paper (Smith, Linse, Turns & Atman, 2004)

Educational research is just one of many outside forces with implications for the practice of engineering education, however as I argue in this paper it is gaining in prominence and acceptance.

I initially considered starting with a summary of education research areas – cognitive, behavioral, social, and others – that are informing and influencing engineering education practice as well as emerging areas of research that have promise for engineering education, such as complexity theory; and integrated content, assessment and pedagogy design of courses and programs. There is fairly clear evidence that these areas are informing and influencing the practice of engineering education as I elaborate in the following list:

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[1] Author's note: This paper is a work in progress. I invite comments, criticism, and especially, suggestions for improvement.

- Cognition or learning sciences research model of the learner, conceptual understanding, and difficult concepts. Concept inventories, expert-novice differences and adaptive expertise.
- Behavioral, especially mastery model research outcomes and objectives, formative and summative assessment. Student learning outcomes as seen in ABET Criteria 2000 and many other accreditation models
- Social psychology research on active and interactive learning, especially cooperative learning, learning communities, and communities of practice. Social emphasis on student active learning and community as seen in the National Survey of Student Engagement (NSSE)

Rather than try to make the case for a linear relationship between theory, research and practice, I decided to begin by exploring some of the models of the research enterprise:

- Models linking research and practice – Schoenfeld & Burkhardt
- Cycle of knowledge production and improvement of practice – Rand & NSF CCLI
- Pasteur's Quadrant - Stokes

The bulk of the paper focuses on research-based ideas that seem to fit in Pasteur's Quadrant and organizes them around (1) areas where the engineering education community seems to agree based on current practices, (2) emerging areas of agreement, and (3) unresolved issues.

Models of the Research Enterprise

Burkhardt and Schoenfeld (2003) indentified six current models linking research and practice in education:

- Model 1: Teachers read research and implement it in their classrooms
- Model 2: Summary guides
- Model 3: General professional development
- Model 4: The policy route
- Model 5: The long route
- Model 6: Design experiments

The first three models seem to be the ones most commonly embraced by engineering educators and Burkhardt and Schoenfeld argue that achieving significant results from these three approaches is much more complex and difficult than typically appreciated. In their review and analysis of these six models they propose an adaptation of the "engineering approach" (Models 5 and 6) used in other applied fields as having the greatest potential for practical impact. They argue that the engineering approach compared to the other two main research traditions in education – humanities and science – has a key role in making educational research as a whole more useful.

The cyclic model of knowledge production and improvement of practice was introduced in a Rand report on mathematics proficiency (RAND, 2003), see Figure 1, and adopted and adapted a bit by the National Science Foundation's Course, Curriculum and Laboratory Improvement (CCLI) program.
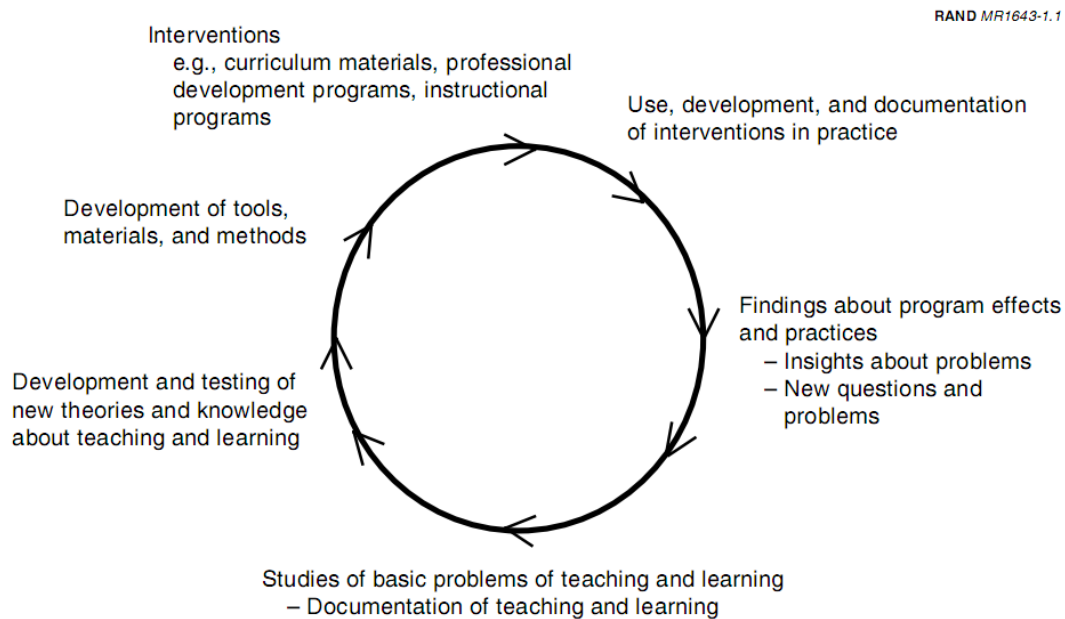

Figure 1.1—Cycle of Knowledge Production and Improvement of Practice

Figure 1 Rand Report - Cycle of Knowledge Production and Improvement of Practice

The NSF CCLI program adapted this cyclic model as noted in a recent Program Solicitation (NSF, 2008):

> The CCLI program is based on a cyclic model of the relationship between knowledge production and improvement of practice in undergraduate STEM education. The model is adapted from the report, "Mathematical Proficiency for All Students" (see http://www.rand.org/publications/MR/MR1643/). In this model, research findings about learning and teaching challenge existing approaches, thus leading to new educational materials and teaching strategies. New materials and teaching strategies that show promise give rise to faculty development programs and methods that incorporate these materials. The most promising of these developments are first tested in limited environments and then implemented and adapted in diverse curricula and educational institutions. These innovations are carefully evaluated by assessing their impact on teaching and learning. In turn, these implementations and assessments generate new insights and research questions, initiating a new cycle of innovation.

Schoenfeld and Burkhardt and the NSF CCLI program both embrace Donald Stokes' (1997) *Pasteur's Quadrant*, in which, according to Burkhardt and Schoenfeld (2003) "Stokes argues that better insights come from situating inquiry in arenas of practice where engineering is a major concern. Stokes' motivating example is Pasteur, whose work on solving real world problems contributed fundamentally to theory while addressing pressing problems."(p. 5). Figure 2 provides a summary of Stokes' framework.

Research Inspired By:

Use (Applied)

		No	Yes
Understanding (Basic)	**Yes**	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	No		Pure applied research (Edison)

Stokes, Donald. 1997. Pasteur's quadrant: Basic science and technological innovation. Wash, D.C., Brookings.

Figure 2 Stokes - Pasteur's Quadrant

Major developments in educational research and their implications for the practice of engineering education

This section focuses on three areas, which fit in Pasteur's Quadrant, where there seems to agreement among engineering educators in terms of the practice of engineering education – Outcomes, Inquiry, and Engagement; four areas where there seems to be emerging agreement – Cognitive model of the learner; Integrated approach to course and program design; Importance of a broader range of knowledge, skills and attributes; and Scholarly approach to engineering education through the scholarship of teaching and learning (SoTL) and engineering education research; and finally, suggested areas where research is needed due to lack of agreement – BS or MS as first professional degree, Breadth and depth, Fundamentals and applications, Technical training or liberal arts education.

Educational Objectives and Mastery, and Student Learning Outcomes

Educational objectives, mastery and, more broadly, student learning outcomes have been fully embraced by the engineering education community.

My first exposure to educational objectives was reading Ralph Tyler's 1949 *Basic principles of curriculum and instruction*, in which he addressed the following questions: (1) What educational purposes should the school seek to attain? (2) What educational experiences can be provided that are likely to attain these purposes? (3) How can these

educational experiences be effectively organized? And (4) How can we determine whether these purposes are being attained? Tyler devotes about one-third of the book to the sources, identification, and framing of objectives.

Benjamin Bloom completed a PhD at the University of Chicago, served as a research assistant in the Office of the University's Board of Examinations under Tyler's supervision, and eventually succeeded Tyler as University Examiner. In 1956 Bloom and colleagues published the *Taxonomy of educational objectives, Handbook 1: The cognitive domain*. (Bloom, et.al., 1956).

Many engineering educators have explored the idea of objectives as well as student's mastery of educational objectives. Most influential for me was the work and publications of Jim Stice, University of Texas at Austin. Stice convinced me of the importance of carefully identifying and specifying objectives through a series of articles, workshops and follow-up conversations in the early 1980s. Robert Mager (1997) and Norman Grondlund's (2000) ideas were also explored by many engineering educators during the 60s and 70s. John Heywood (2005) provides an excellent summary of the development of educational objectives in his extraordinary synthesis of work in engineering education.

The rest of the story as they say is history. Educational objectives, especially student learning outcomes, are now part of the fabric of the engineering education community and are showing up in university accreditation systems as well. Although the 1956 version of Bloom's Taxonomy of Educational Objectives is widely used by engineering educators, I recommend considering the adoption of the updated and revised taxonomy (Anderson & Krathwohl, 2001).

A recent example of broadening the application of taxonomies is the Engineering Education Research Colloquies, and the research agenda that was derived from the synthesis of the conversations (Steering Committee of the National Engineering Education Research Colloquies, 2006):

- Engineering Epistemologies
- Engineering Learning Mechanisms
- Engineering Learning Systems
- Engineering Diversity and Inclusiveness
- Engineering Assessment

There are of course drawbacks to using taxonomies, which highlight differences, as articulated by Lee Shulman in his 2002 *Change* article "Making differences: A table of learning," and like all tools we need to use them with care.

Inquiry

The idea of inquiry was articulated by John Dewey and he saw it as part of an ideal school (Dewey, 1915):
- a "thinking" curriculum aimed at deep understanding

- cooperative learning within communities of learners
- interdisciplinary and multidisciplinary curricula
- projects, portfolios, and other "alternative assessments" that challenged students to integrate ideas and demonstrate their capabilities.

Jerome Bruner built on Dewey's idea of inquiry and was one of the first North American psychologists to embrace a cognitive approach to education and educational psychology. Bruner's (1960) summary of a ten-day meeting of thirty-five scientists, scholars, and educators to discuss how education in science might be improved was enthusiastically welcomed and sold over 400,000 copies within four years. Bruner argues, "Mastery of the fundamental ideas of a field involves not only the grasping of general principles, but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own." (p. 20). Bruner's (1961) article "Acts of Discovery" articulated some of the heuristics of discovery as well as how to learn them.

Joseph Schwab (1964) and others also advocated an inquiry approach and articulated some details on using inquiry as a teaching approach. Schwab argues, "Scientific knowledge of any given time rests not only on the facts but on *selected* facts – and the selection rests on the conceptual principle of the enquiry. Moreover, the knowledge won through inquiry is not knowledge merely of the facts but of the facts interpreted." (p. 14).

Inquiry and inquiry-based or guided approaches are evident in many aspects of engineering education today, including problem-based and project-based learning (Smith, 2000, 2002; Smith, Sheppard, Johnson and Johnson, 2005). Furthermore, a recent National Research Council (2000) report, *Inquiry and the National Education Standards* provides guidance for teaching and learning using an inquiry approach.

Prince and Felder (2006, 2007) took a more comprehensive approach by looking at inductive instructional methods and their Figure 3 provides an excellent summary of the features of common inductive instructional methods – inquiry, problem-based, project-based, case-based, discovery and Just in Time Teaching (JiTT).

Table 1. Features of Common Inductive Instructional Methods

Method → Feature ↓	Inquiry	Problem-based	Project-based	Case-based	Discovery	JiTT
Questions or problems provide context for learning	1	2	2	2	2	2
Complex, ill-structured, open-ended real-world problems provide context for learning	4	1	3	2	4	4
Major projects provide context for learning	4	4	1	3	4	4
Case studies provide context for learning	4	4	4	1	4	4
Students discover course content for themselves	2	2	2	3	1	2
Students complete & submit conceptual exercises electronically; instructor adjusts lessons according to their responses	4	4	4	4	4	1
Primarily self-directed learning	4	3	3	3	2	4
Active learning	2	2	2	2	2	2
Collaborative/cooperative (team-based) learning	4	3	3	4	4	4

1 – by definition, 2 – always, 3 – usually, 4 – possibly

Figure 3 Prince & Felder (2006) Table 1.

Student Engagement

Student engagement or involvement in learning is the third area that I think the engineering education community has fully embraced. The idea of the importance of student involvement was advanced by many, including John Dewey, and in the 70s and 80s was supported by research by Astin (1993), Light (1992) and many others. The 1984 report from the National Institute on Education, *Involvement in learning: Realizing the potential of American higher education* made a very strong case for the importance of student involvement.

One of the most common ways that engineering faculty have embraced student involvement is through the use of cooperative learning. Cooperative learning has been part of the landscape of engineering education for the past almost 30 years. The conceptual cooperative learning model was introduced to the engineering education community in 1981 (Smith, Johnson, & Johnson, 1981a, 1981b) and was continually refined and elaborated for engineering educators (Felder, 1995; Prince, 2004; Smith, 1995; Smith, Sheppard, Johnson, & Johnson, 2005) and higher education faculty in general (Johnson, Johnson, & Smith, 1991; Johnson, Johnson, & Smith, 1998; Johnson, Johnson, & Smith, 2000, 2006, 2007; MacGregor, Cooper, Smith, & Robinson, 2000; Millis & Cottell, 1997; Smith, 1996, 1998; Smith, Cox, & Douglas, 2008). The influence of foundational work on cooperative learning can be seen in the University of Delaware Problem Based Learning model (Allen, Duch, & Groh, 1996 ; Duch, Groh, & Allen, 2001), the SCALE-UP model at North Carolina State (Beichner, Saul, Allain, Deardorff, & Abbot, 2000), the Technology Enhanced Active Learning (TEAL) model at MIT (Dori & Belcher, 2005; Dori, et.al, 2003) and many others.

Cooperative learning and its underlying theoretical framework, social interdependence theory, have been systematically studied in engineering education for over 50 years; the first study with engineering students was conducted at MIT in 1948 (Deutsch, 1949).

Engineering faculty began embracing cooperative learning shortly after it was introduced in engineering education conferences and journals in 1981 and its use continues to grow. Furthermore, there is ongoing work to refine social interdependence theory (Johnson & Johnson, 2005) as well as continual refinement of cooperative learning practices for faculty.

The empirical and theoretical evidence supporting cooperative learning is vast and I'll only provide a brief summary. During the past 90 years, over 350 experimental studies have been conducted in college and adult settings comparing the effectiveness of cooperative, competitive, and individualistic efforts. These studies have been conducted by a wide variety of researchers in different decades with different learner populations, in different subject areas, and in different settings. More is known about the efficacy of cooperative learning than about lecturing, the fifty-minute class period, the use of instructional technology, or almost any other aspect of education. From this research you would expect that the more students work in cooperative learning groups the more they will learn, the better they will understand what they are learning, the easier it will be to remember what they learn, and the better they will feel about themselves, the class, and their classmates. The multiple outcomes studied can be classified into three major categories: achievement/productivity, positive relationships, and psychological health. Cooperation among students typically results in (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and (c) greater psychological health, social competence, and self-esteem. Please see Smith, Sheppard, Johnson and Johnson (2005) and Johnson, Johnson & Smith (1998, 2007) for details.

Details on the key research-based elements of cooperative learning – positive interdependence, individual and group accountability, face-to-face promotive interaction, teamwork skills, and group processing – as well as implementation of the three main types of cooperative learning – Informal Cooperative (Active) Learning, Formal Cooperative Learning and Cooperative Base Groups – are available in Smith, Sheppard, Johnson & Johnson (2005) and in extensive detail in Johnson, Johnson & Smith (2006).

The project titled The National Survey of Student Engagement (NSSE, 2003) deepens our understanding of how students perceive classroom-based learning, in all its forms, as an element in the bigger issue of student engagement in their college education. The NSSE project conceives that student engagement is not just a single course in a student's academic career, but rather a pattern of his or her involvement in a variety of activities. The annual survey of freshmen and seniors asks students how often they have, for example, participated in projects that required integrating ideas or information from various sources, used e-mail to communicate with an instructor, asked questions in class or contributed to class discussions, received prompt feedback from faculty on their academic performance, participated in community-based projects, or tutored or taught other students. Student responses are organized around five benchmarks

1. Level of academic challenge: Schools encourage achievement by setting high expectations and emphasizing importance of student effort.

2. Active and collaborative learning: Students learn more when intensely involved in educational process and are encouraged to apply their knowledge in many situations.
3. Student-faculty interaction: Students able to learn from experts and faculty serve as role models and mentors.
4. Enriching educational experiences: Learning opportunities inside and outside classroom (diversity, technology, collaboration, internships, community service, capstones) enhance learning.
5. Supportive campus environment: Students are motivated and satisfied at schools that actively promote learning and stimulate social interaction.

The NSSE project is grounded in the proposition that student engagement, the frequency with which students participate in activities that represent effective educational practice, is a meaningful proxy for collegiate quality and, therefore, by extension, quality of education.

My sense, based on the practice of engineering education, is that there is widespread agreement about outcomes, inquiry and engagement. If you disagree or have other candidates where we agree, please contact me.

In the next section I argue that there is emerging support among engineering educators for the following four areas: Cognitive model of the learner; Integrated approach to course and program design; Importance of a broader range of knowledge, skills and attributes; and Scholarly approach to engineering education through the scholarship of teaching and learning (SoTL) and engineering education research;

Cognitive Model of the Learner

Physics education researcher Joe Redish (2000) provides an insightful comparison of the model of the student that most physics education researchers hold – the cognitive model with that held by many physics faculty – the broadcast model. It seems to me that many, if not most, engineering faculty implicitly embrace the broadcast model.

The Cognitive Model.

- Students build their knowledge by processing the information they receive (constructivism).
- What students construct depends on the context—including the students' mental states.
- Producing significant conceptual change is difficult and can be facilitated through a variety of known mechanisms.
- Individuals show a significant variation in their style of learning along a number of dimensions.
- For most individuals, learning is most effectively carried out via social interactions.

The Broadcast Model.

1. Previous knowledge is not relevant. (Students are blank slates.)
2. Knowledge is binary. (You either know it or you don't.)
3. The student is idealized. (Students possess good motivation, independence, a knowledge of what to do, and a willingness to do it.) If the student differs from this ideal image, it's their fault.
4. The student is assumed to be metacognitive. (Students learn from their mistakes.)
5. Scientific thought and rational thinking are taken to be natural—even obvious.

Redish argues that the implicit presence of the broadcast model in colleges and universities as well as structures in the system help explain why it is so difficult to change.

The increased emphasis in engineering education on conceptual understanding, and especially difficult concepts, by researchers such as Ruth Streveler, Ron Miller, Paul Steif and many others is beginning to compel colleagues to embrace a cognitive model of the learner. Also, there are lots of connections between the cognitive model of the learner and taking an integrated approach to course and program design.

Integrated Approach to Course and Program Design

Wiggins and McTighe's (1998) Backward Design approach, which they introduced in their book *Understanding by Design*, is gaining acceptance in engineering education for course and program design. Wiggins and McTighe list three stages in the process:

Stage 1. Identify Desired Results. During this stage they argue that we need to think carefully about what we want students to know, be able to do, and what modes of thinking or habits of mind we want them to develop as a result of instruction. During this stage they recommend subjecting the student learning outcomes to the following filters:

> Filter 1. To what extent does the idea, topic, or process represent a big idea or have enduring value beyond the classroom?
> Filter 2. To what extent does the idea, topic, or process reside at the heart of the discipline?
> Filter 3. To what extent does the idea, topic, or process require uncoverage?
> Filter 4. To what extent does the idea, topic, or process offer potential for engaging students?

My experience working with faculty on Stage 1 is that when these four filters are applied one-quarter to one-third of the material in a typical course disappears from the syllabus.

Stage 2. Determine Acceptable Evidence. This stage involves deciding what evidence we need to convince ourselves, our colleagues and the students that they have achieved the desired results identified in Stage 1. Wiggins & McTighe argue for broadening the types of assessment beyond quiz and test items (simple, content-focused test items) to include

academic prompts (open-ended questions or problems that require the student to think critically, and performance tasks or projects (complex challenges that mirror the issues or problems faced by graduates, and are authentic)

Stage 3. Plan Learning Experiences and Instruction. Finally, they argue we need to consider what pedagogical approaches are most likely to help student's achieve the desired results.

The Backward Design Approach, that is, "begin with the end in mind" is radically different from the conventional approach of choosing topics to cover, but I think it is gaining traction in the engineering education community. Also it is well aligned with a learner-centered as contrasted with a teacher-centered approach to education (Barr and Tagg, 1995; Campbell and Smith, 1997).

Several higher education researchers and practitioners have embraced the integrated content-assessment-pedagogy model, including Bransford, Vye and Bateman (2002), Fink (2003) and Pellegrino (2006).

In addition to making an emphatic argument for the integration of content, assessment and pedagogy, Pellegrino (2006) reminds us of some important principles about learning and understanding:

- The first important principle about how people learn is that students come to the classroom with preconceptions about how the world works which include beliefs and prior knowledge acquired through various experiences.
- The second important principle about how people learn is that to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
- A third critical idea about how people learn is that a "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Felder and Brent (2003) make a compelling case for the integrated design of courses as shown in their Figure 1. Another great feature of the Felder and Brent model is they remind us to keep students at the center of our thinking about the course.
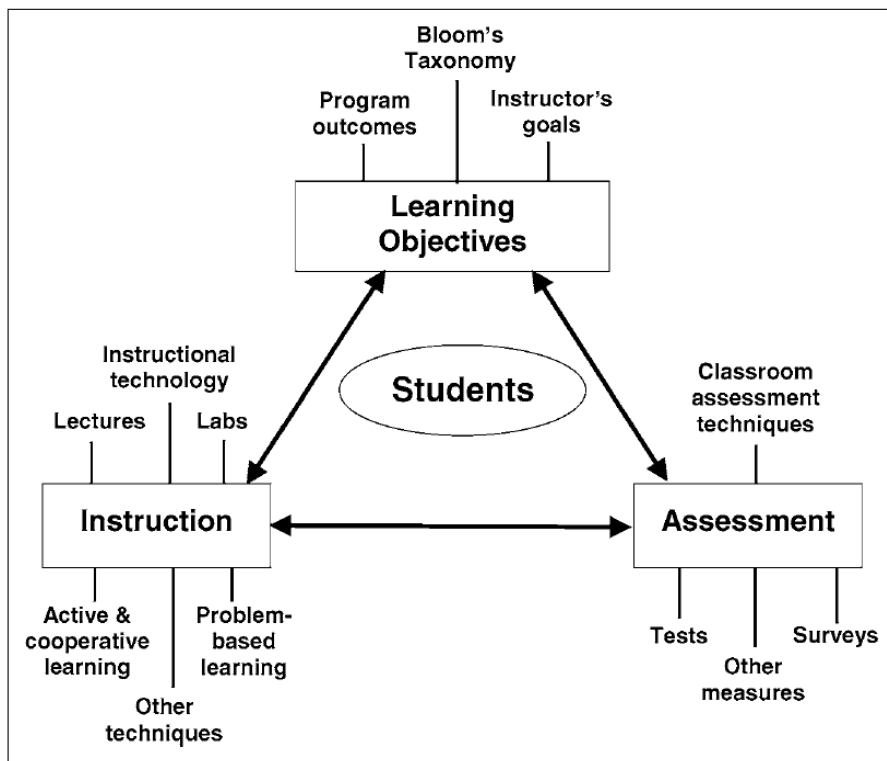
Figure 4 Felder and Brent (2003) Figure 1 - Elements of Course Design

Jim Duderstadt (2008) claims, "It could well be that faculty members of the twenty-first century college or university will find it necessary to set aside their roles as teachers and instead become designers of learning experiences, processes, and environments." I agree wholeheartedly as do the scholars listed above.

Importance of a Broader Range of Knowledge, Skills and Attributes

Evidence of increased emphasis on a broader range of knowledge, skills, and attributes (or habits of mind and modes of thinking) for engineering graduates abounds. Several studies – Boeing and RPI's *The Global Engineer* (Boeing, 1997), NAE's *Engineer of 2020* (2005), Purdue Future Engineer (Jamieson, 2007), *The 21st-Century Engineer* (Galloway, 2007, *Engineering for a Changing World* (Duderstadt, 2008) – have begun to articulate the knowledge, skills, and habits of mind that are needed for students to perform satisfactorily in an interdependent world (Smith, 2008). The *Purdue Future Engineer,* for example, is focused on a much broader range of student learning outcomes as shown in Figure 5 (Jamieson, 2007).
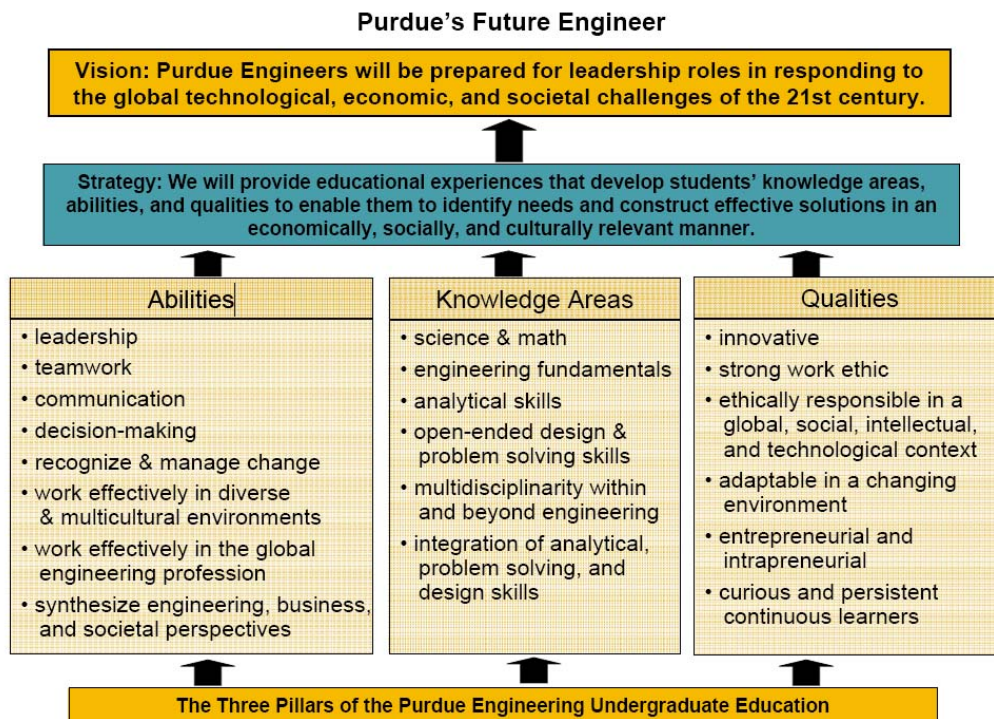
Purdue's Future Engineer

Vision: Purdue Engineers will be prepared for leadership roles in responding to the global technological, economic, and societal challenges of the 21st century.

Strategy: We will provide educational experiences that develop students' knowledge areas, abilities, and qualities to enable them to identify needs and construct effective solutions in an economically, socially, and culturally relevant manner.

Abilities
- leadership
- teamwork
- communication
- decision-making
- recognize & manage change
- work effectively in diverse & multicultural environments
- work effectively in the global engineering profession
- synthesize engineering, business, and societal perspectives

Knowledge Areas
- science & math
- engineering fundamentals
- analytical skills
- open-ended design & problem solving skills
- multidisciplinarity within and beyond engineering
- integration of analytical, problem solving, and design skills

Qualities
- innovative
- strong work ethic
- ethically responsible in a global, social, intellectual, and technological context
- adaptable in a changing environment
- entrepreneurial and intrapreneurial
- curious and persistent continuous learners

The Three Pillars of the Purdue Engineering Undergraduate Education

Figure 5. The Purdue Pillars of Engineering Undergraduate Education

Scholarly Approach to Engineering Education through the Scholarship of Teaching and Learning (SoTL) and Engineering Education Research

Boyer's (1990) report *Scholarship Reconsidered* redefined the landscape of scholarship in higher education. Boyer argued for expanding scholarship beyond discovery to include integration, translation and teaching. Hutching and Shulman (1999) contrasted "teach as taught" with three levels on inquiry within education and Streveler, Borrego and Smith (2007) expanded on the list by adding a forth level, engineering education research

- Teach as Taught ("distal pedagogy")
- Level 1: Effective Teacher
- Level 2: Scholarly Teacher
- Level 3: Scholarship of Teaching and Learning (SoTL)
- Level 4: Engineering Education Research

Borrego, Streveler, Miller and Smith (2008) elaborated on these levels of inquiry

Level of inquiry	Attributes of that level
Level 1: Excellent teaching	Involves the use of good content and teaching methods
Level 2: Scholarly Teaching	Good content and methods *and* classroom assessment and evidence gathering, informed by best practice and best knowledge, inviting of collaboration and review.
Level 3: Scholarship of Teaching	Is public and open to critique and evaluation, is in a form that others can build on, involves question-asking, inquiry and investigation, particularly about student learning.
Level 4: Rigorous Research in Engineering Education	Also is public, open to critique, and involves asking questions about student learning, but it includes a few unique components. (1) Begin with a *research* question not an *assessment* question. Assessment questions often deal with the "what" or "how much" of learning, while research questions more often focus on the "why" or "how" of learning (Paulsen, 2001). (2) Tying the question to learning, pedagogical, or social theory and interpreting the results of the research in light of theory. This will allow for the research to build theory and can increase the significance of the findings. For example, studies about teaching thermodynamics can be redesigned to become studies, based on cognitive theory, which can help explain why certain concepts in thermodynamics are so difficult to learn. (3) Paying careful attention to design of the study and the methods used. This will enable the study to hold up to scrutiny by a broad audience, again creating a potential for greater impact of results.

Table 7. Levels of rigor in inquiry representation. Reproduced from Streveler, Borrego, and Smith (2007). The authors credit Hutchings and Shulman (1999) for levels 1–3.

The emergence of increased emphasis on a scholarly approach to engineering education is indicated by numerous developments, including the ASEE Year of Dialogue, the National Academy of Engineering's Center for the Advancement of Engineering Education and especially the Annals of Research on Engineering Education (Smith, 2006), the rigorous research in engineering education project (Streveler and Smith, 2006; Streveler, Borrego and Smith, 2007; Borrego, Streveler, Miller & Smith, 2008), the repositioning of the *Journal of Engineering Education* "to serve as an archival record of scholarly research in engineering education (Lohmann, 2008a) and the global emphasis on engineering education research (Lohmann, 2008b).

Unresolved Issues

In this final section I suggest the following areas where research, dialogue, and consensus-building is needed due to lack of agreement – BS or MS as first professional degree, Breadth and depth, Fundamentals and applications, Technical training or liberal arts education.

Conclusion

Although there is agreement on many educational research-based aspects of engineering education, I think we need to be mindful that the existence of panaceas is unlikely. Mastery, inquiry and student engagement are good ideas, but as Nel Noddings (2006, 2007) reminds us we have a tendency in education to take good ideas and try to universalize them. The push to extremes of mastery and inquiry almost destroyed these good ideas, and I have similar worries currently about student engagement. Bruner argued, for example, that students can't learn everything by discovery, which implies making inquiry an integral part of a student's education and not exclusively inquiry.

Boyer (1990) challenged us in 1990 to consider broadening the definition of scholarship beyond the scholarship of discovery to include the scholarship of integration, application, and teaching. In a subsequent paper, Boyer (1996) encouraged all of us to make connections across these forms of scholarship by embracing the scholarship-of-engagement:

> The scholarship of engagement means connecting the rich resources of the university to our most pressing social, civic and ethical problems, to our children, to our schools, to our teachers and to our cities.

Finally, Judith Ramaley (2000) argues that we also need to bring a scholarly approach to change:

> Achieving transformational change is a scholarly challenge best dealt with by practicing public scholarship, which is modeled by the leader and encouraged in other members of the campus community. Like all good scholarly work, good decision making by campus leadership begins with a base of scholarly knowledge generated and validated by higher education researchers, (page 75).

Acknowledgements

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