AC 2009-1072: PURDUE'S ENGINEER OF 2020: THE JOURNEY

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PURDUE'S ENGINEER OF 2020: THE JOURNEY

Abstract

To remain competitive in a financially uncertain and increasingly changing global economy, engineering companies and businesses need a workforce that is not only technically competent, but that is broadly knowledgeable, adaptable, and nimble. Our studies have shown that the skill sets industry is seeking to survive is becoming ever broader. While the ABET a-k criteria have added to the breadth of most engineering curricula, there are many key skills that are not emphasized in these criteria such as leadership, innovation, entrepreneurship, managing change, etc. Our Engineer of 2020 initiative has served as a catalyst to encourage our faculty to consider what are the critical skills and abilities our graduates are going to need in this new century. The initiative began in 2004 after the release of the NAE publication *The Engineer of 2020: Visions of Engineering in the New Century*. Our previous ABET review had already established that companies are seeking an increasingly broader set of skills in graduates, what we have termed "renaissance engineers." These are engineering graduates that are technically competent, but also broadly knowledgeable about many other areas of both a technical and non-technical nature. But how do you adapt an engineering program to meet the changing needs of graduates of the 21st century? Our first step was to engage our faculty and other constituents (alums, employers, students, etc.) in an extended discussion about what are the target attributes we need to be developing in students. After two years of discussions and at times heated debate, the Purdue's Engineer of 2020 Target Attributes were approved by our faculty. The next stage of our initiative has been to develop methods to advocate curricular change directed at fostering development of the target attributes. Our strategies for fostering change include: *Engineer of 2020 Workshop*, *Engineer of 2020 Seed Grant Program*, *Travel Funds to Strategic Workshops and Conferences*, and *Sharing of Best Practices*. This paper describes the "journey" that has been undertaken thus far and our strategies for developing assessment tools to monitor our progress as we implement the Purdue's Engineer of 2020 initiative in the College of Engineering at Purdue University.

Introduction

Purdue University has a long and widely recognized tradition of educating high quality engineers, and intends to sustain that tradition. Recent national and international trends, validated by surveys of graduating students, indicate that what is required of an excellent engineer now has evolved from past expectations. The attributes that characterized industry and alumni demands of engineering education in the 1970s-1980s have changed substantially in the past two decades. A recent book by Sheppard, Macatangay, Colby and Sullivan[1] delineates many areas where changes are needed in preparing tomorrow's engineers. Therefore, Purdue's College of Engineering has embarked on a journey to redefine engineering education for the 21st century. This process essentially involves two phases: Phase I sought to enumerate the essential attributes of a successful graduating engineer; this phase is now complete. In Phase II, innovative changes to courses and the curriculum will be encouraged so that these attributes can be enhanced. This phase is now underway. Through this process, Purdue's College of Engineering will extend its tradition of excellence while remaining adaptive to changing demands and expectations.

Background

The world that a graduating engineer will enter in the year 2020 will surely be different from the world as it was in the 20th century. Global issues will become much more important, and engineers will need to contribute not only to technology but also to public policy. The National Academy of Engineering prepared a report in 2004 entitled *The Engineer of 2020: Visions of Engineering in the New Century*[2]. That report emphasizes the profound changes that are anticipated for the engineering profession, as well as the opportunities for engineers that future challenges in resource allocation, energy use, and environmental stewardship will provide. The authors sum up their assessment for engineering education this way:

> "If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for a new wave of change. While there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today." [2, p. 5]

A more recent book by Pat Galloway, entitled *The 21st Century Engineer: A Proposal for Engineering Education Reform*[3], emphasizes the need for engineering education to develop "a holistic breed of engineer – one who can work across borders, cultural boundaries, and social contexts and who can work effectively with nonengineers." [3, p. 87] Engineers must become global leaders in their profession. In fact, she says:

> "If engineers are to compete successfully in this global workplace and establish themselves as leaders in solving many of the world's most pressing problems, they must embrace the need for professional innovation and they must do so quickly." [3, p. 1]

She goes on to say:

> "The engineering curriculum can no longer remain as it has for essentially the past 40 years. The subjects of globalization, diversity, world cultures and languages, communication, leadership, and ethics must constitute a core component of the overall engineering education just as physics and mathematics do." [3, p. 87]

Thomas Friedman, in his book *The World is Flat*[4], emphasizes the changes that have occurred in the world toward the end of the last century. The fall of the Iron Curtain, the birth of the internet, the spread of open-source software, and the rise of new economies in eastern Europe, India, and China have made it easier to outsource service jobs to other countries where labor is cheaper. "The global competitive playing field was being leveled. The world was being flattened." [4, p. 8] These trends have increased the importance of preparing our young people to succeed in this new flattened world. In this regard, Friedman comments:

> "America still looks great on paper, especially if you look backward, or compare it only to India and China of today and not tomorrow. But have we really been investing in our future and preparing our children the way we need to for the race ahead? See the next chapter. But here's a quick hint.
> The answer is no." [4, p. 249]

As one illustrative example of the changing demands on graduating engineers, Figure 1 shows two plots of alumni surveys from 1994 and 2000. In these plots, alumni 1-5 years in 1994 (graduates from '89-'93) and alumni 1 and 5 years out in 2000 (graduates of '95 and '99) were surveyed. Two questions were asked regarding each of the 14 outcomes. "How important is this outcome to your company or organization?" "How effective are Purdue graduates in their performance in this outcome area?" The most interesting part of the comparison is that in 1994 the alumni rankings of the importance of the outcomes were very dispersed (e.g., several items such as 3c-global/societal context and 3d-world affairs and cultures were ranked very low, indicating they were deemed unimportant). However, these same outcomes and several others were ranked as considerably more important by 2000. In essence, by 2000 alums seemed to be saying that good technical skills alone are necessary, but no longer sufficient to be successful in the professional workplace. Now employers want the whole package (not just good technical skills, but other professional skills as well). This data shows definitive evidence of industry's trend toward seeking more well-rounded engineers. Thus, an even broader array of attributes is essential to be an effective engineer in the future.

Phase I: Selecting and Adopting Purdue Engineer of 2020 Target Attributes

In the first phase of this process, the attributes that define the Purdue Engineer of 2020 had to be agreed upon throughout the College of Engineering. This process began in November of 2004, when former Dean of Engineering Linda Katehi created a task force to discuss this issue. All task force members were asked to read the NAE report *The Engineer of 2020: Visions of Engineering in the New Century*[2]. In spring of 2005, task force members had discussions with faculty in the various Schools at their faculty meetings. As a result of these discussions and input from surveys, focus groups, and rankings by task force members, industrial advisory committee members, and students, a long list of attributes was drawn up, consisting of 83 attributes in 6 categories.

In August 2005, Lipman Hearne conducted faculty focus groups with 25% of the faculty to discuss future professional settings for engineers, attributes of future engineers, Purdue's performance in these areas, areas in need of change, and obstacles to change. In general, faculty agreed on the need for change, with differences of opinion on the level of urgency in undertaking these changes. Later that month, a workshop for faculty was organized entitled, *Designing Engineering Curricula for the 21st Century*. The keynote address was given by William A. Wulf, then NAE President. Further viewpoints were presented by panels composed of national engineering education leaders and industry leaders. Faculty attendance was overwhelming, with standing room only in the lecture hall. This represented the first widespread conversation between external and internal engineering reform leaders at Purdue about the future of engineering education. A summary of the preliminary work to date in defining the curriculum for the engineer of 2020 was presented at the *Frontiers in Education Conference* and the NAE

Center for the Advancement of Scholarship in Engineering Education (CASEE) meeting in October 2005.

In November and December of 2005, another faculty survey was distributed, polling faculty on their opinions concerning the vision and strategy behind the curriculum reform, and in particular on the list of attributes for the future engineer. Nearly 50% of the faculty participated in this survey. Based on the results of the faculty survey, revisions were made to the list of attributes. In spring 2006, task force members led discussions with the Schools' curriculum committees, faculty committees, ABET coordinators, student groups, and advisory committees to further refine the list. In April 2006, the vision, strategy, and attributes were endorsed by the Engineering Leadership Team, consisting of the dean and associate deans. In October 2006, a proposal to adopt the Purdue Engineer of 2020 Target Program Attributes was distributed to the faculty for consideration. These were adopted by the faculty of the College of Engineering in April 2007.

A list of the 20 target attributes that were finally adopted by the College of Engineering is shown in Fig. 2. These have been organized into three pillars, representing abilities, knowledge areas, and qualities. The 20 attributes are roughly equally divided among the three pillars. Note that although traditional technical knowledge areas are still listed, a majority of the attributes reflect non-technical knowledge and abilities, including leadership, innovation, ethics, multi-disciplinary teaming, and global awareness. Several recent articles[5-12] stress the relevance and practice of teaching these attributes (professional skills) in educating future engineers. Many of these attributes also go beyond the ABET a-k criteria for engineering curricula.

Phase II: Implementation of Target Attributes into the Curriculum

Once the Engineer of 2020 attributes had been adopted, the next phase of the process was to develop mechanisms within the College of Engineering to encourage curriculum innovations that address these attributes. A number of important mechanisms have been established within the College of Engineering to accomplish this goal. The original curriculum reform task force has been remade into a new standing committee within the college, now renamed the Engineer of 2020 committee. That committee has been charged with developing mechanisms to achieve curriculum innovations that enhance these attributes among engineering students. Two primary mechanisms are currently in place: the Engineer of 2020 Annual Workshop, and the Engineer of 2020 Seed Grant Program.

The College of Engineering has hosted an annual Engineer of 2020 workshop since fall of 2007. The first workshop was held on Aug. 28, 2007, and focused on three of the target attributes: innovation, multi-disciplinarity, and continuous learning. Outside experts from industry and academia were invited to present their thoughts on the importance of each of these attributes and on suggestions for how best to include it in the curriculum. Faculty from across the College of Engineering were invited to attend and participate in the discussions. The second workshop was held on Sept. 30, 2008, focusing on the three attributes of leadership, global issues, and ethics. Once again, two outside experts were invited to discuss each attribute, both in a panel session in the morning, as well as in separate break-out sessions in the afternoon. During that workshop, we also had a poster show for the Engineer of 2020 Seed Grant award winners from 2008 (see

next paragraph), providing them an opportunity to discuss their ideas and preliminary results with workshop attendees.

The Engineer of 2020 Seed Grant program is designed to provide seed funding for faculty to try out new and innovative strategies that foster these target attributes. The first round of grants was solicited in fall of 2007, and these first grants were awarded in February 2008. A total of 19 proposals were submitted, of which 5 were selected for funding at a level of $40,000 each. The criteria upon which the proposals were rated included:

1. Significance of the proposed project in relation to current knowledge
2. Grounding of the proposal in current theories and knowledge on teaching and learning
3. Potential impact of the work (its ability to embed the new attributes in all CoE graduates)
4. Potential to gain significant funding beyond the seed grant

The winning proposals selected for 2008 were:

- "Creation of an Instrument to Measure Selected Attitudes in Purdue's Engineer of 2020," Monica Cox, Engineering Education
- "Multidisciplinary Insights for Learning Engineering Aerospace Design," Daniel DeLaurentis, Sean Brophy, Kathleen Howell, Aeronautical and Astronautical Engineering, Engineering Education
- "Spiraling Towards 2020: Project Centered Multidisciplinary Spiral Curriculum as a Model for Developing Purdue's Engineer of 2020," Martin Okos, O. Campanella, Neal Houze, J. Litster, Nate Mosier, David Radcliffe, Bernie Tao, Agricultural and Biological Engineering, Chemical Engineering, Engineering Education
- "The Engineer as an Entrepreneur: Using Case-Driven, Problem-Based Learning to Develop Adaptive Expertise," Joe Sinfield, Robin Adams, Aman Yadav, Civil Engineering, Engineering Education, Education
- "Student's Attitudes and Threshold Concepts Towards Engineering as an Environmental Career: Research by Participatory Design of an Educational Game," Johannes Strobel, Inez Hua, Civil Enginering, Engineering Education, Environmental and Ecological Engineering

More details about some of these projects and progress made to date will now be provided. In the first project by Monica Cox, the purpose of the research is to identify the observable outcomes of Purdue's Engineer of 2020 for three targeted attributes: (1) leadership, (2) ability to recognize and manage change, and (3) ability to synthesize engineering, business, and social perspectives. The review of the current and relevant literature resulted with an interview protocol. The protocol included 16 open-ended questions for the industry experts. The purpose of the interviews are fourfold: (1) to assess the leadership styles of the industry experts using a standardized leadership survey (2) to solicit relevant descriptions of each of the aforementioned attributes, (3) to assess the importance of the attribute in engineering (in relation to experts' field), and (4) solicit real life examples of how such attributes can be utilized in the field to

compile a portfolio of case studies. Analysis of the interviews along with the case studies and their comparisons to leadership styles will be one of the deliverables. The end goal of this project is to develop and pilot test a quantitative tool that will assess the three targeted attributes of Purdue University undergraduate engineering students.

In “Spiraling Towards 2020,” a project-based spiral curriculum was proposed by the Biological and Food Processing Engineering (BFPE) program and the School of Chemical Engineering at Purdue University, primarily to address the problem of fewer students enrolling in engineering, both nationally and at Purdue University. The specific objectives of the project include: A) to critically evaluate project centered and spiral curricula from other institutions and their ability to be transferred to the Purdue environment; B) to develop, teach and evaluate two prototype courses in BFPE and Chemical Engineering that demonstrate the integration of a select number of targeted Engineer of 2020 attributes in practice; C) to design a prototype project based spiral curriculum that incorporates the target attributes of the Engineer of 2020 into the BFPE program; D) to develop a "lessons learned" data base to guide the College of Engineering in wider adoption of spiral curriculum by a) forming a College of Engineering advisory group who will assist in assessing outcomes, b) progressively evaluating the operation of courses using reflective instruments by faculty and students with assessment by advisory group, and c) presenting results at regional and national meetings; and finally E) to seek funding from outside sources such as from foundations, USDA, and NSF. To date, two prototype standalone project based classes were developed: one course for the sophomore year in the BFPE program and one course for the senior year in the Chemical Engineering program. The project based courses served as the teaching model since students had to seek out information to solve the problems. Students received information through just-in-time project related lectures and hands on guided tutorials to complete two projects with their teams. Subsequent projects in subsequent project based courses apply the spiral model where projects are proposed to build in sophistication and complexity as the students must apply knowledge from other courses throughout the curriculum. This integration and continual reinforcement should provide the students a powerful link between engineering principles and their application and impact for real world problems. Since the prototype project based courses focused on a hands-on real-life problem, the course at the sophomore level also served to increase attraction and retention of the undergraduate students while providing a way for graduate students to gain first hand teaching, mentoring, and course development experience. In addition to developing the technical knowledge of the students, the project based courses also were found to be an applicable model to deliver training in other key 'soft skill' competencies that will make the students better prepared for leadership roles in responding to the global technological, economic, and societal challenges. Specific training, evaluation and feedback was given in the prototype courses to develop students' abilities to be strong in: leadership, teamwork, communication, innovation & strong work ethic, and curious & persistent learners. Assessment of the prototype project based courses was done through formative and summative measures. Initial feedback showed that the students enjoyed the course and the ability to see the bigger picture. The students also self-reported an increase in technical and non-technical skills. Future work will focus on increasing the multidisciplinary aspect of the course which will better prepare students for the workforce.

In the project entitled “Multidisciplinary Insights for Learning Engineering Aerospace Design,” the principal investigators are currently developing a multi-player game version of AAE 251

Introduction to Aerospace Engineering, a sophomore-level design course taught to approximately 200 students every year. In the 3D virtual world, a portion of the AAE 251 students work as a team, perform engineering analysis, and collaboratively design aerospace vehicles. To facilitate the learning that traditionally took place in the classroom, a series of video clips have been developed that can be viewed during the game play (Fig. 3, bottom left picture) for the AAE 251 students as well as via web browser for non-players. With the PE 2020 grant, approximately 45 independent lecture topics (delivered as over 200 short video clips) will be made available by May 2009. The contributing experts include Professor Longuski and Professor Howell on spacecraft and mission design, Professor DeLaurentis (AAE) on Aircraft Design, and Professor J. Mark Thom from Aviation Technology on Aircraft Engines. In addition, in-game presentations by students are made available to the students for their resources, to the instructors for grading, and to education researchers for team-learning assessments.

In 2009, 10 proposals for Engineer of 2020 Seed Grants were received. Using the same criteria as in 2008, 5 of these proposals were selected to receive $40,000 to carry out the proposed work. The winning proposals were:

- "Incorporating Sustainability Concepts into the Engineering Curriculum," Stephen Hoffman, Chip Blatchley, Inez Hua, Larry Nies, Civil Engineering, Environmental and Ecological Engineering
- "Measuring and Modeling Purdue's Engineer of 2020 Attributes using a Neural Network Model of Student Success," P. K. Imbrie, Teri Reed-Rhoads, Engineering Education
- "Assessing Engineer of 2020 Attributes through Transformative Global Experiences," Brent K. Jesiek, Demetra Evangelou, Dianne Atkinson, Yating Chang, E. Daniel Hirleman, Engineering Education, Electrical and Computer Engineering, Mechanical Engineering, Global Engineering Program
- "Creating Frameworks for Learning and Assessing Leadership, Cross-disciplinary Learning on Multidisciplinary Teams, Ethics and Design," William Oakes, Carla Zoltowski, Scott Schaffer, Leonard Harris, Engineering Education, EPICS Program, Education, Philosophy
- "Development and Assessment of 'Ethics in Engineering Practice': A New Technical Support Elective," Rodney Trice, Matthew Krane, Materials Engineering

Besides these primary initiatives, other steps have been put in place to encourage curriculum innovation. An Engineer of 2020 Website has been established to disseminate information about the seed grants and workshops, and to provide a forum where curriculum ideas can be shared and discussed. Regular faculty luncheons and workshops are expected to offer opportunities for sharing of best practices. Travel grants are available from the College of Engineering to allow faculty to attend national and international conferences to share ideas.

Another important piece of this effort is assessment. During the 2007-2008 academic year, each of the Schools was asked to have their faculty and their industrial advisory boards rank the importance of each of the Engineer of 2020 target attributes within their pillar (Abilities, Knowledge Areas, and Qualities). Each school was then asked to discuss these rankings in the

context of how well their programs are providing opportunities for their students to learn the top-ranked attributes. Based on these discussions, each school will develop implementation plans for those attributes that need more attention. Progress towards Purdue's Engineer of 2020 will be part of each school's annual assessment report to the dean.

Uniquely positioned to help with the Engineer of 2020 activities is the relatively new School of Engineering Education, which was established at Purdue in 2004. As the first such department dedicated to the art and science of engineering education, it has the expertise in education theory and epistemology to aid efforts to update the engineering curriculum. Many of the seed grant proposals were co-written by members of the Engineering Education faculty. And several key members of the Engineer of 2020 committee are faculty in the School of Engineering Education. The engineering education research that Engineering Education faculty are currently conducting can help inform the curriculum reform efforts that the Engineer of 2020 initiative supports.

Perhaps a fitting anecdote that illustrates the early impact of the Engineer of 2020 efforts to date can be found in the area of environmental engineering. The Division of Environmental and Ecological Engineering was recently established to bring together faculty from across the College of Engineering who work in all facets of environmental engineering. It currently offers a minor in Environmental and Ecological Engineering. Some of the DEEE faculty feel very strongly that an environmental focus is an essential requirement for a future engineer. Therefore, they are developing elective courses in environmental engineering to be made available to all engineering students, easy-to-use modules that all senior design courses could incorporate in their classes across the College of Engineering, and a multi-disciplinary capstone course that all College of Engineering students would take. These efforts would clearly embed many of the Engineer of 2020 target attributes into the engineering curriculum in the College of Engineering.

Conclusion

Purdue's College of Engineering has embarked on a journey to define and develop the Engineer of 2020. This engineer of the future will not only be technically competent, but also be aware of the wider context within which engineering is practiced. This includes innovation, leadership, global awareness, ethics, etc. At Purdue, 20 target attributes that define the Engineer of 2020 have been adopted by all the Schools of Engineering. These target attributes are organized into three pillars, representing abilities, knowledge areas, and qualities. A series of surveys, focus groups, and discussions with faculty, alumni, corporate advisory boards, and students helped to converge on this particular list. Now that these attributes have been agreed upon, the next phase is to develop mechanisms to implement these attributes within the curriculum. At the moment, two primary mechanisms are in place: Engineer of 2020 workshops and Engineer of 2020 seed grants. The workshops bring in outside speakers with expertise in particular areas related to the target attributes. The intent is for the faculty to engage in a conversation with experts on how best to incorporate these attributes into their courses. The seed grants are designed to provide resources with which faculty can develop and test new ideas in pedagogy so as to integrate these attributes into the curriculum. So far, two rounds of seed grants have been funded, and the fruits of those efforts are expected to be disseminated in the next year or so. Purdue Engineering is on an exciting journey to recreate engineering education for 2020 and beyond.

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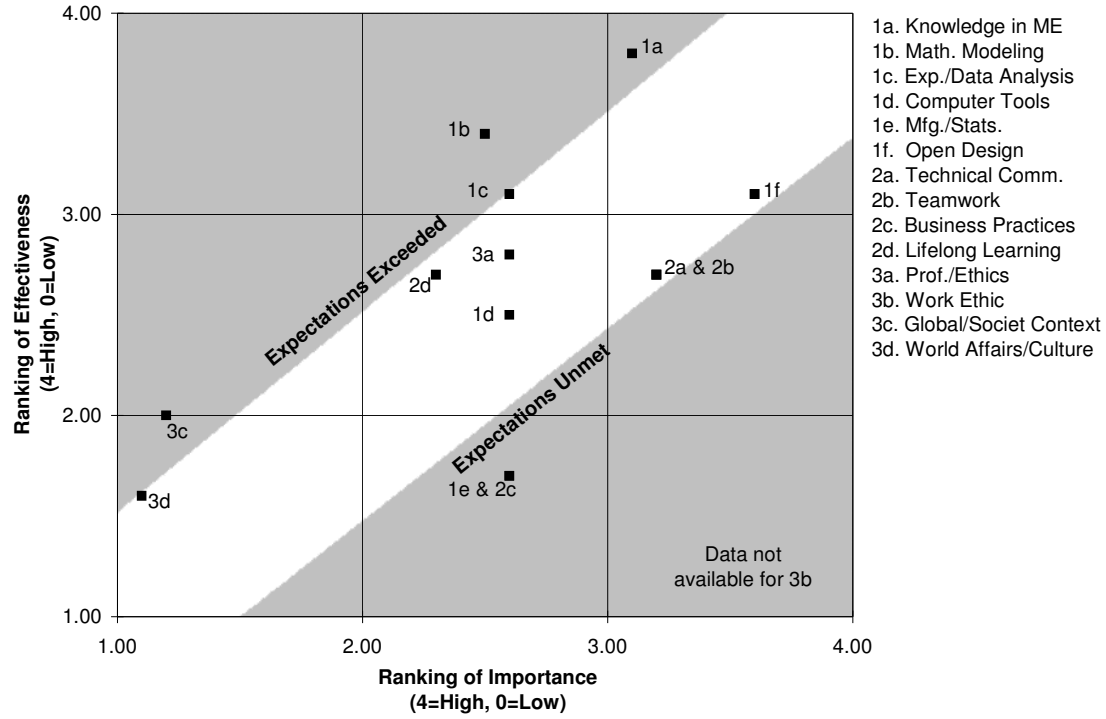
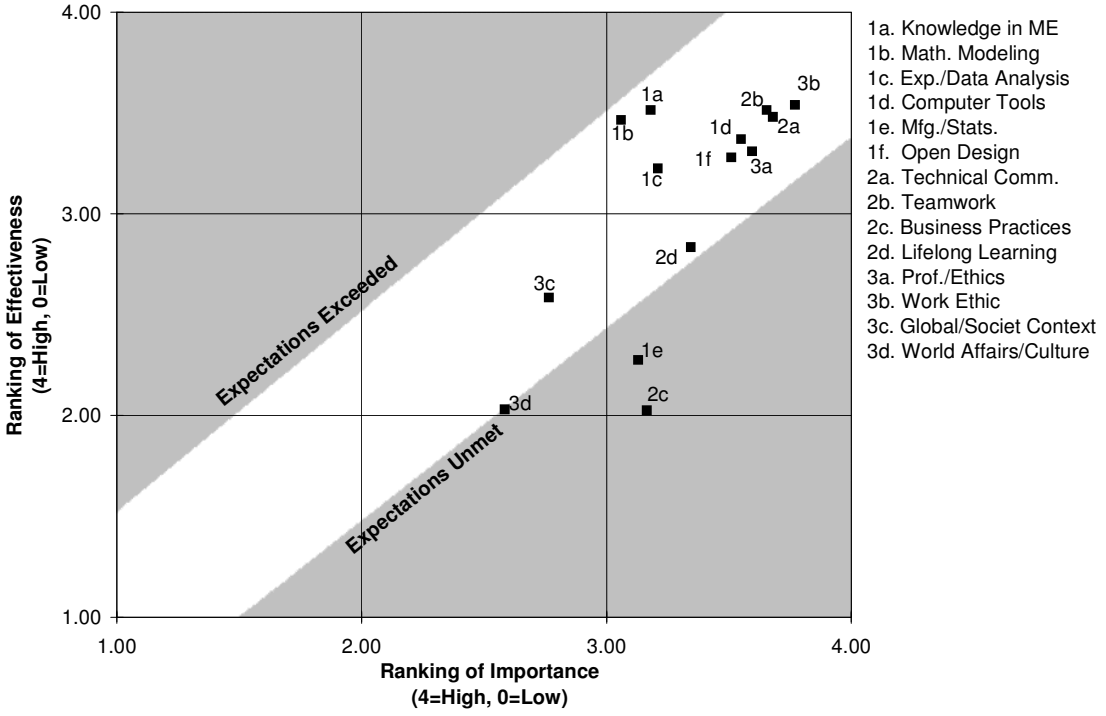


a) 1994 Alumni Survey (1-5 Years Out, 352 Responses, 35% Return)



b) 2000 Alumni Survey (1 and 5 Years Out, 156 Responses, 35% Return)

Figure 1. Scatter Plots of Importance versus Effectiveness of ME Program Objectives as ranked in a 1994 Alumni Survey and a 2000 Alumni Survey.

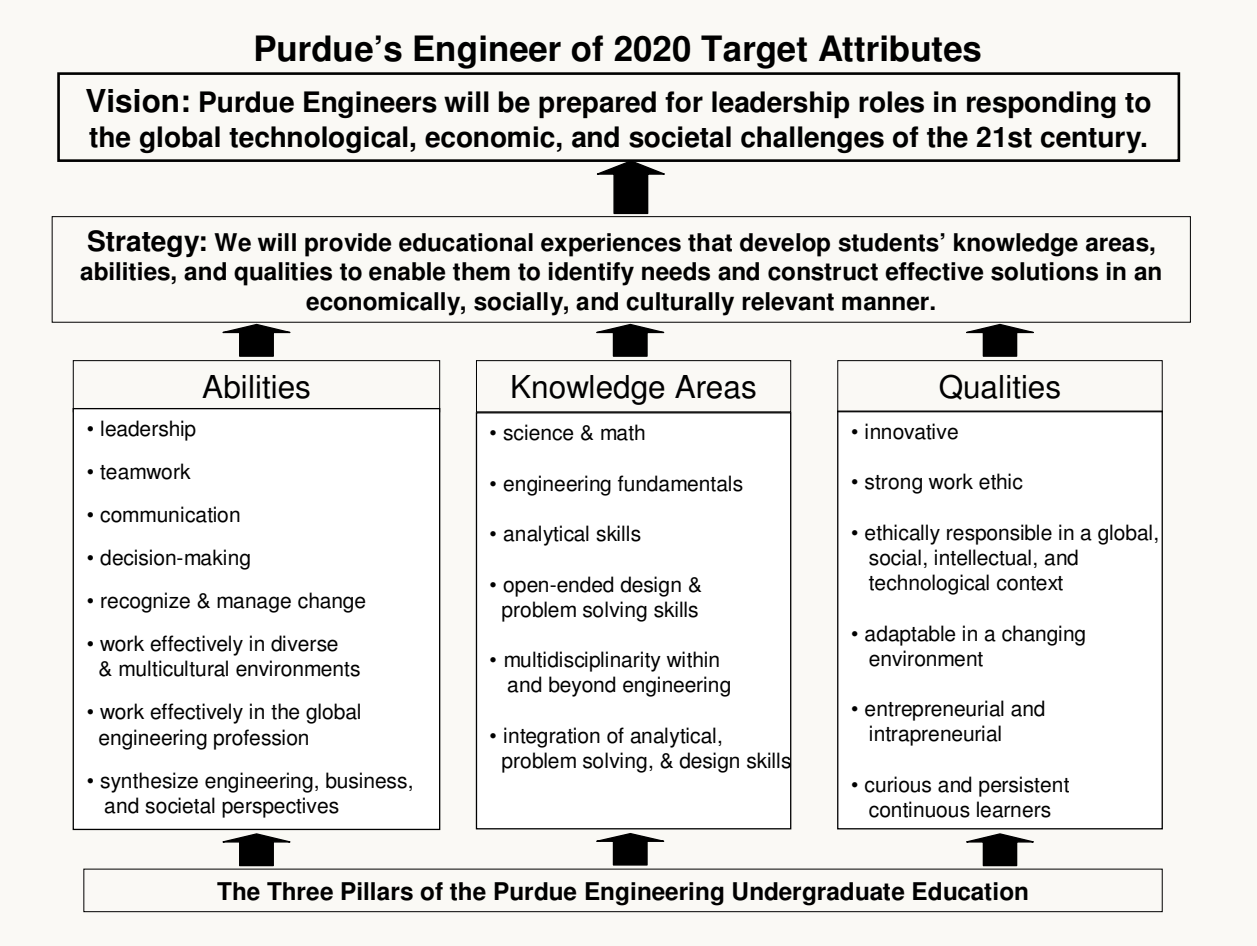


Figure 2. Purdue's Engineer of 2020 Target Attributes, arranged in three pillars representing abilities, knowledge areas, and qualities.

Figure 3. Screenshots of the Virtual World Designed for Engineering Design Education. "Expert Videos" (Shown Left Bottom) Allow Students to Access Videos "in Time" and "on Demand."