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The heart of the capstone experience is the project itself. There are a variety of projects used in capstone design: projects sponsored by industry with or without a fee, service learning projects, student competitions, campus projects, 'paper designs,' and faculty projects. The project management can range from being managed completely by the faculty advisor or the project sponsor to those that are completely managed by the student team. Teams can be allowed to fail or the faculty project advisor can ensure successful completion. Projects may emphasize creativity and/or communication and/or technical depth. This paper evolved from a panel discussion of capstone projects at the Capstone 2010 Design Conference and notes the distinct differences between project types.

Keywords: project selection; project management, program assessment; capstone design

Susannah Howe, Kevin Caves, Carsten Kleiner, Glen Livesay, Judith Shaul Norback, Renee Rogge, Cameron Turner and Tristan Utschig	1174–1185	Nifty Ideas and Surprising Flops in Capstone Design Education
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Following good design practice, capstone design instructors often try out new teaching strategies and activities in their capstone courses, hoping to find useful tools to support student learning. Some of these ideas are a riotous success; others fall completely flat. The "Nifty Ideas and Surprising Flops" panel session at the 2010 Capstone Design Conference featured eight such ideas—some of them nifty, some of them floppy, and some with aspects of both—presented in a rapid-fire manner with rich discussion. Several of the ideas addressed oral presentations in capstone courses: scoring rubrics utilizing engineering executive input, voice-over narratives, and elevator pitches. Two of the ideas focused on mentoring: graduate student mentors for capstone teams, and vertical mentoring. The other three ideas covered a design "boot camp", broader impacts essays, and back-of-the-envelope calculations. This paper provides additional detail about the eight different ideas, including how they were implemented, to what extent they were successes or flops, and how they have been modified as a result. Capstone instructors are encouraged to try out their own versions of these ideas, leveraging the successes and learning from the flops presented here.

Keywords: capstone design pedagogy; oral presentation; engineering executive input; elevator pitch; engineering broader impact; preparation for capstone design; capstone design mentoring; design calculations

Angela Shartrand and Phil Weilerstein	1186–1191	Strategies to Promote Entrepreneurial Learning in Engineering Capstone Courses
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Capstone courses offer opportunities for students to apply their knowledge and skills directly by working on teams and solving real problems within external constraints and limited time frames. As such, capstone courses offer unique opportunities to acquire and apply entrepreneurial skills in the context of the design process. This article examines what is distinctive about an entrepreneurial approach to capstone design and describes strategies used by faculty to promote entrepreneurial learning within the context of the senior capstone design experience. Implications of these different approaches for engineering students' acquisition of entrepreneurial skills and experiences are addressed.

Keywords: capstone; entrepreneurship; innovation

Marie Paretti, Richard Layton, Stephen Laguette and Greg Speegle	1192–1205	Managing and Mentoring Capstone Design Teams: Considerations and Practices for Faculty
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This paper presents the findings from a panel session at the 2010 Capstone Design Conference in Boulder, Colorado in which panelists and participants had a lively discussion about practices associated with managing and mentoring student teams. The three broad topics discussed at the session were the methods of assigning teams, product versus process learning objectives for design teams, and non-technical aspects of team performance (e.g. race and gender dynamics, professional and interpersonal communication). For each topic, the paper describes the wide variety of views and approaches (some contradictory) that were explored regarding each topic, as well as the factors affecting choice of approach. In addition, the paper highlights three themes that recurred across the topics: 1) clear learning objectives for capstone or any project-based activity are central to effectively designing and mentoring teams; 2) faculty participants do care deeply about their students and take steps to act in ways that benefit students, and 3) both positive and negative aspects of student attitudes and behaviors may reflect faculty attitudes and behaviors, implying that we should examine and act to improve our departmental cultures if we hope to affect student

performance. The results of this discussion point strongly to the need for more research on teaming in capstone courses to better understand the relationships among curricular environment, student development, and learning outcomes.

Keywords: capstone design; student teams

Angela R. Bielefeldt, Mandar M. Dewoolkar, Kevin M. Caves, Bruce W. Berdanier and Kurtin G. Paterson 1206–1220 Diverse Models for Incorporating Service Projects into Engineering Capstone Design Courses

There are a variety of ways in which service projects have been incorporated into senior engineering capstone design courses. Some of these experiences fulfill the rigorous definition of service-learning (SL) and others meet some but not all of the true SL requirements. Many students and faculty find service projects particularly motivating, and educational theory indicates that motivation is a crucial ingredient for higher-order learning. Different course models from civil, environmental, and biomedical engineering, ranging from a single semester to a full calendar year, are compared and contrasted. Most of these courses and/or service projects are optional capstone projects for students, but in other cases all students are required to complete service projects for the capstone design course. Reflection exercises are an important component of SL projects, and a variety of structured and semi-structured reflection exercises have been incorporated into these capstone design courses. Data indicate that service projects are effective at teaching students both a depth and breadth of technical and non-technical skills. SL projects may be particularly superior for increasing students' understanding of sustainability, cultural competency, and sense of civic responsibility. It is particularly difficult to balance educational outcomes for the students with benefits for the community/client partners in single semester courses. Projects for local communities or individuals seem to yield the most tangible results for partners in a one-semester time span, while international projects with a development focus offer an array of logistical and cultural challenges. The instructors must devote time and attention to developing relationships with partners in advance of the course and follow-up to help ensure optimal outcomes for the partners. The lessons learned from these courses may help others effectively incorporate service projects into their own capstone design courses.

Keywords: appropriate technology; assessment; assistive technology; capstone; community engagement; design; service-learning

Alan Parkinson, Holt Zaugg and Isaku Tateishi 1221–1230 Global Virtual Teams: A New Frontier for Capstone Design

As engineering becomes more global in nature, engineering design is increasingly being accomplished through global virtual (GV) teams. These types of teams are usually defined as being geographically dispersed, spanning several different countries and time zones, being composed of team members with little prior association, and communicating through electronic means. GV teams overlay a number of new challenges on top of the usual challenges for design teams. This paper will review some of the efforts taking place at universities in the U.S. with GV teams, including our own experience. We propose a 'three ring' Venn diagram as a framework for understanding the issues associated with GV teams. We discuss these rings in some detail and provide recommendations for establishing successful GV teams.

Keywords: global virtual teams; cross-cultural teams; global engineering; global competence

Paul Kauffmann and Gene Dixon 1231–1237 Vetting Industry Based Capstone Projects Considering Outcome Assessment Goals

One goal of capstone projects is that they simulate a challenging design experience similar to what is expected of a BS graduate engineer. Consequently industry originated capstone projects are very valuable since they are based on real world problems and technical challenges. Capstone projects are also a critical part of the assessment process for most engineering programs. The challenge arises in how to evaluate the potential of an industry based project in providing assessment information related to program learning outcomes. This paper provides an example of a vetting process used successfully to accomplish this complex evaluation of alternatives.

Keywords: assessment; capstone project; industry project

Gregg M. Warnick and Robert H. Todd 1238–1245 Importance of Providing Intellectual Property to Sponsoring Companies When Recruiting Capstone Projects

Since nearly the inception of the Capstone program at Brigham Young University (BYU) in 1990, it has been our practice to provide intellectual property (IP) rights to project sponsoring companies. This policy has helped BYU successfully recruit and complete 577 Capstone projects from throughout the world. Providing IP rights to sponsoring companies enables BYU to identify appropriate design and build projects even in more difficult economic times, enabling our students to be taught the design process and learn the practice of engineering. This paper provides an overview of BYU's Capstone program and its intellectual property history and policy including the experiences gained by students working on industry-sponsored projects with intellectual property. Also presented are recent survey findings demonstrating the importance of providing intellectual property to sponsoring companies when recruiting Capstone projects.

Keywords: intellectual property; capstone; industry; sponsor; project; design; agreement; NDA; BYU

R. Keith Stanfill and Oscar D. Crisalle 1246–1258 Mentoring the Project Coach: Effective Propagation of Pedagogical Techniques, Resources, and Know-How

A common obstacle faced by faculty serving as coaches for student teams in multidisciplinary capstone design courses is the lack of teaching paradigms that can serve as a guide when making pedagogical and team-management decisions. We have addressed this challenge by creating a document entitled IPPD Coach Guide—A Resource for Mentoring Project Teams that compiles a set of best practices and catalogs resources available in our Integrated Process and Product Design program, with the goal of enhancing the coach's effectiveness in directing the evolution of the design project and assisting students in reaching all learning objectives. The guide serves as a tool that enables the propagation of pedagogical techniques, identifies available administrative and material resources, and archives the program's historically acquired know-how. This paper describes the mechanics followed to arrive at the generation of the guide, including the methodology used for harvesting collective knowledge from the most experienced faculty coaches, using techniques ranging from a directed faculty-retreat event to systematic idea mapping exercises, and including management approaches such as a challenge-question environment and the adoption of affinity-group analysis. The guide can also be used to recruit and train new coaches, to establish policies, and to serve as a contextual framework for extramural program reviews. A brief overview of the contents of the guide is provided including succinct representative examples of the material. The guide may serve as an example tool that could be of utility to other capstone design courses interested in promoting improved uniformity in quality of pedagogical delivery and increased coach effectiveness.

Keywords: capstone design; product and process design; multidisciplinary design; mentoring; senior engineering design; capstone design pedagogy

Mark Steiner, Junichi Kanai, Cheng Hsu, Richard Alben and Lester Gerhardt 1259–1272 Holistic Assessment of Student Performance in Multidisciplinary Engineering Capstone Design Projects

Capstone design courses are commonly employed in engineering schools to culminate students' learning experiences, as called for by the Accreditation Board for Engineering and Technology (ABET). Although widely considered one of the best practices of engineering education, these courses continue to challenge the field. Capstone courses are challenging not only because they involve open-ended design that may require researching untried approaches while at the same time being accountable to sponsors'

particular requirements; but also due to their multidisciplinary nature and the dynamics of student teams. These challenges are reflected in the problem of giving each project the relevant advising and each student a fair final grade. In this paper we present a holistic approach to advising and evaluation of individual students in multidisciplinary teams that was developed and has proven to work at Rensselaer. The approach adopted a two-person, often multidisciplinary, instructing team design, coupled with 'mentors' from sponsoring companies, to coach the students; and developed dedicated rubrics to measure student performance concerning adherence to design process, team participation, and communication skills. These new rubrics added to the traditional methods, which include group reports and student peer evaluations. The new team teaching design also separated the duties associated with coaching and judging, to make advising and evaluation more effective and objective. Our internal reviews and students' peer evaluations showed that a high degree of consistency in grading has been achieved with the implementation of the new design. Finally, we submit that the basic structure of the holistic approach—i.e., blending objectives with due process and evaluation from multiple sources, is consistent with practices in industry that students will face after graduation.

Keywords: capstone design; pedagogy; engineering education

Kenneth J. Reid and John K. Estell 1273–1280 Incorporation of Poverty Alleviation in Third World Countries in a First-Year Engineering Capstone Course

The engineering curriculum at Ohio Northern University includes a one year introduction to engineering course sequence culminating in a one quarter first-year capstone design course. A requirement for projects to involve the design of a poverty alleviation device was recently introduced. The initial implementation required student teams to identify an impoverished country (using the World Bank's definition) and address a specific need of the population. The project requirements include following and documenting the engineering design process, preparation of a proposal, regular verbal and written status reports, and both development and presentation of a prototype. The poverty alleviation requirement has allowed students to directly experience multiple learning outcomes as specified in ABET assessment criteria including understanding engineering in a global and societal context, along with criteria typically found in a capstone course such as the ability to function in teams and to communicate effectively. Quantitative and qualitative assessment of the project showed that students felt the experience related to societal and realistic constraints. Based on the evaluation of data from the initial offering of this course, recommendations for both course improvements and future research are presented.

Keywords: first-year engineering; capstone; international; poverty; poverty-alleviation

Michael W. Glier, Susanne R. Schmidt, Julie S. Linsey and Daniel A. McAdams 1281–1294 Distributed Ideation: Idea Generation in Distributed Capstone Engineering Design Teams

This paper documents two studies in distributed idea generation at Texas A&M. The first study is a controlled two-factor experiment wherein three-person groups of mechanical engineering capstone design students generate solutions to a simple design problem using either brainstorming or a modified 635 method in either a distributed or collocated team. Eight groups participated in the experiment; two were assigned to each of the four experimental conditions. The ideas produced are evaluated in terms of quantity, quality, novelty, and variety, using a series of metrics described in the paper. The modified 635 method produced the highest quantity of non-redundant ideas; the team's distribution had no significant effect on the number of ideas they produced. Distributed teams using the modified 635 method generated the highest quality ideas, while collocated teams using the same method produced the most variety. Collocated brainstorming teams generated the most novel ideas. The other study presented in this paper documents the performance of two globally distributed Mechanical Engineering capstone design teams. These student teams are composed of members from Texas A&M College Station and Texas A&M Qatar in Doha Qatar. The two teams participate in a controlled ideation experiment to generate possible solutions to their respective design problem; a third team with all its members in College Station also participates in the experiment. The teams generate ideas using the modified 635 method. This experiment confirms that the modified 635 method is a viable ideation technique for distributed teams and seems to confirm that the quantity of ideas generated with the method is not dependent on the team's distribution. Furthermore, instructors for the globally distributed teams observe that the teams performed on par with typical collocated capstone design teams.

Keywords: idea generation; ideation, distributed teams; capstone design; brainstorming; method 635

Gregg L. Fiegel and Jay S. Denatale 1295–1307 Civil Engineering Capstone Design: Team Formation, Preparation, and Performance

The following paper describes our experiences working with student design teams in a new two-quarter capstone course in civil engineering. Each student completes a survey that defines his or her academic coursework, industrial experience, status with respect to Engineer-In-Training (EIT) certification, current grade point average, and experience with computer-aided design software. The course instructors use this information to subdivide the class into six-person teams, ensuring that each team has a comparable degree of background and experience. The teams are multi-disciplinary in that each member is assigned a specific civil engineering role that relates to his or her elective coursework and industrial experience. After forming teams, the students complete a three-part, month-long lesson on communication. The lesson includes presentations and activities that focus on team building, active listening, communication styles, and assertiveness. These lessons are described in the paper. The intent of the lessons is to prepare the students to successfully interact and work together over the six-month course sequence. The approach to forming and preparing student teams has proven successful, as evidenced by peer evaluations and by project assessments completed by faculty members and local engineering professionals.

Keywords: capstone design; civil engineering; communication styles; multi-disciplinary; design team

Jay McCormack, Steve Beyerlein, Patricia Brackin, Denny Davis, Michael Trevisan, Howard Davis, Jennifer Lebeau, Robert Gerlick, Phillip Thompson, M. Javed Khan, Paul Leiffer and Susannah Howe 1308–1323 Assessing Professional Skill Development in Capstone Design Courses

The capstone engineering design course provides students an opportunity to create a product or process as well as the opportunity to improve professional skills and workplace behaviors. The latter are often difficult to teach and assess in a project-based course. To encourage students to be aware of, to prepare for, and to engage in project-based professional skill development, the Transferable Integrated Design Engineering Education (TIDEE) consortium developed the Integrated Design Engineering Assessment and Learning System (IDEALS) that includes course materials, assessment instruments and companion scoring rubrics that target professional development. In the IDEALS assessment instruments, professional skills include professional responsibility and an ability to pursue lifelong learning related to twelve specific abilities/attributes that are technical, interpersonal, and individual in nature. The IDEALS professional skills assessments consist of a progression of two formative assessments (Professional Development Planning and Professional Development Progress) and one summative assessment (Professional Development Achieved) that are used to prepare for, monitor, and summarize student professional development during the capstone course. A companion instructional module and scoring rubric is provided with each assessment instrument in an instructor-friendly web-based format that helps the instructor guide student development. The professional skills assessment instruments were piloted at six colleges and universities throughout the United States that differ with respect to size, geographic location, student demographic, and public or private status. The results of these pilot implementations, inter-rater agreement studies, student perceptions, and faculty perceptions of the assessment instruments are included in this paper. Results indicate that use of the instruments is perceived by students as value-added within the capstone program, are perceived by instructors as helpful in monitoring student growth as well as in program assessment, and show sufficient scoring consistency for reliable use.

Keywords: formative assessment; summative assessment; program assessment; professional skills; lifelong learning; professional development

Ben Sherrett and John P. Parmigiani 1324–1332 Implementation of the House of Quality as a Tool to Assess Products of Design in a Capstone Design Course

While serving a vital role in the undergraduate curriculum, capstone design courses face a variety of challenges. These challenges include lack of student value & utilization of course objectives & assessment tools, sponsor retention & funding issues, and large instructional demands. Many of these challenges may be addressed by placing a larger and more genuine emphasis on assessing the product of the design project, not only the process by which the design occurs. Oregon State University's (OSU) Mechanical, Industrial, and Manufacturing Engineering capstone course currently organizes, manages, and evaluates capstone projects using the House of Quality (HoQ). In general, the HoQ is a tool used to relate project requirements to design performance specifications. Additionally, at OSU the HoQ serves as (i) a contract between students, sponsors, course instructors, and faculty advisers detailing exactly what is required from the design project, (ii) a guiding tool to allow students to self-monitor their progress throughout the course, and (iii) an objective means of evaluating the students' performance in terms of the product produced by their capstone design projects. This paper describes the OSU course, introduces the HoQ, and presents a time-line of the implementation of product assessment at OSU. Key changes are shown during the move from a purely process based assessment framework to the current state where 50% of total points in the design implementation term of the capstone course are awarded based on the student design team accomplishing design product metrics per sponsor defined design requirements. In addition, the authors report on the course instructor's perception regarding the effect of implementing the HoQ in the OSU capstone course. Finally, conclusions and implications of the work are presented.

Keywords: capstone design; product assessment; house of quality; quality function deployment

Section II

Contributions in: Students Performance, Problem-based Learning, Control Systems, and Industry Needs

Ali Yalcin and Autar Kaw 1333–1342 Do Homework Grading Policies Affect Student Learning?

A significant amount of teaching assistant and instructor time is allocated to grading homework assignments, especially in large enrolment courses. However, the benefits of such a time-consuming activity are unknown and not well documented. Our goal is to examine the impact that different homework grading policies have on students' final examination performance. We are interested not only in the overall student performance, but also in the performance of specific student subgroups with varying backgrounds, as well as the impact of homework on the type of learning that takes place in the course. The study was conducted in a Numerical Methods course at the University of South Florida over a period of three years encompassing data from over 300 Mechanical Engineering students. Statistical analysis of data regarding the impact of homework grading policies on student subgroups based on several factors is presented. Our results indicate that there is no statistically significant difference in student examination performance when homework is graded versus when homework is assigned but not graded. However, certain grading policies did seem to put some subgroups of students at a disadvantage. While grading homework may not be critical in improving student examination performance, it is important to ensure that students practice the concepts.

Keywords: homework; grading policy; student performance

J. C. F. de Winter and D. Dodou 1343–1351 Predicting Academic Performance in Engineering Using High School Exam Scores

This study investigated the extent to which high school exam scores predict first-year grade point averages (GPA) and completion of Bachelor of Science (B.Sc.) programs at a Dutch technical university. It was hypothesized that, of the exam scores, those for mathematics and physics would be the strongest predictors of academic performance. Factor analysis of high school exam scores was performed for a cohort of 1,050 students. Regression analysis of the extracted factors was conducted to predict first-year GPA and B.Sc. completion. The results showed that the Natural Sciences and Mathematics factor (loading variables: physics, chemistry, and mathematics) was the strongest predictor of first-year GPA and B.Sc. completion, the Liberal Arts factor was a weak predictor, and the Languages factor had no significant predictive value. Differences were identified across the B.Sc. programs, with programs that relied strongly on Natural Sciences and Mathematics enrolling better-performing students. Women entered university with higher average exam scores than men, but gender was not predictive of first-year GPA and was a weak predictor (with an advantage for women) of B.Sc. completion. These findings may prove valuable in the development of predictors of academic performance in engineering.

Keywords: engineering; academic performance; predictors; natural sciences; mathematics.

Ning Fang 1352–1361 Tree of Dynamics: A Modified Concept Mapping Approach to Improving Students' Conceptual Understanding in Engineering Dynamics

This paper presents a modified concept mapping approach, called the "Tree of Dynamics," in which the relationships among concepts are represented by "tree" structures including roots, trunks, branches, leaves, and fruits, instead of by using linking words or phrases, to enhance students' perception of the relationships among concepts and also to add fun to student learning. The modified approach was implemented in an Engineering Dynamics course that the author of this paper taught in a recent semester. A total of 76 undergraduate engineering students participated in hands-on active learning activities in which students constructed a series of "Trees of Dynamics" that focus on improving students' understanding of the relationship among seven key Dynamics laws/principles. Both qualitative and quantitative methods (including pre-test-post-test, correlation analysis, and questionnaire survey) were employed in assessing student learning outcomes. The results of assessments show that the average learning gain for all student participants was 64.2%. Compared with the average pre-test score, the average post-test score increased 1.45 standard deviations. Moderate correlation ($r = 0.309$, $p = 0.029$) existed between students' conceptual understanding (gained from "tree"-constructing activities) and their problem-solving skills (measured from exams in which students were required to apply mathematics to generate a numerical solution to Dynamics problems). A total of 71% of the surveyed students agreed or strongly agreed that the "Tree of Dynamics" helped them to understand the hierarchical relationships among dynamics principles and associated equations.

Keywords: concept mapping; "Tree of Dynamics"; active learning; conceptual understanding; engineering dynamics

Liliana Fernández Samacá, Kirsten Mølgaard Nielsen, José Miguel Ramírez and Anette Kolmos 1362–1373 Comparison of PBL Curricula within Control Engineering Education

During the last twenty years, various forms of PBL have been implemented in diverse educational programs and national policy regulations, and to different extents, ranging from a single course level to an integrated PBL curriculum. This has resulted in a variety of PBL curriculum practices. In this article, a comparison of two PBL cases will be described in order to study the advantages and

disadvantages of the two systems. One case presents a single level comprised of two courses and the other one is an integrated PBL curriculum, and both are focused on control engineering courses. The PBL approaches are compared based on an analysis of the study guidelines, the technical curriculum, the themes of the project, the project introduction and specification given by staff, as well as student outcomes in the form of technical skills and skills related to specification requirements, project organization and structuring based on a study of written project proposals and student reports delivered. The results show that both the PBL curricula formulated the same technical learning outcomes, modeling and control methods; however, in the curriculum practice there are differences related to the scope of curriculum objectives, knowledge, independence of the student work, supervision management, and students' preconditions related to PBL.

Keywords: PBL Project Based Learning; Control Engineering Education

R. Aguilar, V. Muñoz and E. J. González 1374–1382 Laboratory Approach for Teaching and Learning Intelligent Control

This paper introduces a laboratory approach for teaching and learning an Intelligent Control course delivered to Automation and Industrial Electronics Engineering students. It integrates methods from Control Theory and Artificial Intelligence. Students initially develop a simulated plant controller using the Matlab fuzzy toolbox and the Simulink program. They then apply their design to interconnected tanks in an actual plant. Other experiments include the expert control of an elevator panel using the CLIPS shell and Linux in real time. This is complemented by the design and implementation of a Neural Network for the identification of a proposed plant. A survey of students' opinion about the approach and the impact of the approach to learning were assessed.

Keywords: laboratory education; fuzzy control; expert control systems; neurocontrol

Jean-Sébastien Deschênes 1383–1393 Integration of Local Industry Theme Examples in Process Control Education: a Case from North-Eastern Quebec

A set of realistic applications inspired by local industries were integrated in a process control course at UQAR. The course employs a multidisciplinary approach, integrating notions from various fields of engineering through theme examples such as wastewater treatment, pulp and paper making, and mineral grinding (mining industry). Laboratories involving these processes were realized using a simulation software designed for process control education. A fourth laboratory comprising the use of an industrial programmable controller was also part of the course. Feedback and comparative appreciation from the students is included.

Keywords: control systems; process control education; simulation software; local regional industry

Joy Watson and Jed Lyons 1394–1411 Aligning Academic Preparation of Engineering Ph.D. Programs with the Needs of Industry

Engineering doctoral programs in the United States are frequently designed to prepare graduates to become original researchers and work in academia. However, the majority of engineering Ph.D. graduates are being employed in industry, this leads to the question of how well doctoral programs are preparing students to meet the needs of industry. The purpose of this exploratory study discussed in this paper is to determine the skills and skill levels needed by engineering Ph.D.s working in industry so that effective strategies may be developed to align student preparation with industry needs. A review of a sample of job solicitations was performed to create a list of possible skills that are essential for engineering Ph.D.s working in industry. A survey was administered to a sample of Ph.D.s in industry to understand the level of different skills needed in their organization and the amount of preparation they received as doctoral students. Survey results indicated that learning and working independently, working in teams, written and oral communication, and solving problems are the most important skills for Ph.D. engineers in industry. Marketing products/processes, managing others, identifying customer needs and writing peer reviewed papers are some of the least important skills for entry-level engineering Ph.D.s. The essential skills for industry and the level of doctoral preparation are, in general, well aligned. Results suggest that one of the most significant areas for improvement in preparing doctoral students is related to teamwork.

Keywords: Ph.D.; industry; skills; survey; teamwork