Session 2425

# How Universal are Capstone Design Course Outcomes?

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## Abstract

Capstone design courses are prominent elements of engineering degree programs and are central to the development and assessment of student professional competencies for program accreditation. This paper describes a process for establishing broadly-applicable capstone design course learning outcomes and proposes a set that may become universally applicable across programs and disciplines. These capstone course outcome definitions will guide faculty in creation of improved instructional materials and methods for facilitating engineering-practice-oriented student learning. They also provide a foundation upon which broadly-applicable assessments of student learning can be developed to address the nationwide challenge for capstone course instructors to assess student achievement of important program outcomes.

Capstone course learning outcomes were derived from the attributes of top quality engineers, both upon graduation and five years after graduation, as defined by a team of faculty and industry engineers collaborating across disciplines and organizations. The attributes of top quality engineers include: (1) motivation, (2) technical competence, (3) judgment and decision making, (4) innovation, (5) client/quality focus, (6) business orientation, (7) product development, (8) professional/ethical, (9) teamwork, (10) change management, and (11) communication. These attributes span ABET engineering criteria 3 and 4 requirements.

A set of broadly-applicable capstone course learning outcomes is presented to address needs for developing the attributes of top quality engineers and to match capstone course objectives within engineering curricula.

## Introduction and Objectives

### *Introduction and Rationale*

Capstone design courses occupy strategic positions in engineering baccalaureate degree programs. They provide senior engineering students open-ended project experiences with a variety of realistic requirements and constraints[1,2]. The position of capstone courses in the curriculum, their integrative nature, and their mandatory presence in accredited engineering degree programs make them excellent environments for observing and cultivating students' professional competencies and for documenting student achievement of these in support of program accreditation[3].

Engineering program accreditation criteria established by the Accreditation Board for Engineering and Technology (ABET), in criterion 4, specify the following requirements with regard to engineering capstone project experiences[4]:

"*Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.*"

In recent years, capstone design projects have increased in complexity, duration, and relevance to engineering practice. Motivated by challenging ABET requirements for capstone courses and by industry concerns about workplace preparedness of engineering graduates[5,6], many degree programs across engineering disciplines have adopted industry-sponsored projects, most of which extend over an academic year[7]. At a time when student learning and assessment in capstone courses are increasingly important to program accreditation, capstone course instructors are being challenged by the need to plan, facilitate, and assess student learning where expected capstone course outcomes are uncertain and differ significantly from those of traditional engineering science courses[8].

Establishing suitable capstone course learning outcomes is essential for facilitating and assessing student achievement related to many ABET criterion 3 outcomes. As documented by McKenzie in a national survey with responses from 300 capstone course instructors, most instructors believe that ABET criteria 3 and 4 outcomes can be assessed in capstone courses, but faculty need help in developing suitable assessments[8]. To date, the creation of engineering design assessment tools[9,10] has been uncommon and specialized. User-friendly assessments require clear outcome statements, performance criteria, and performance tasks that are integrated into an assessment and evaluation system[11]. Broadly-applicable, clearly articulated, capstone course learning outcomes are a crucial foundation for both assessing and improving student learning in capstone design courses.

For decades, people have defined performance expectations of engineers in varying detail and format and for different purposes. Employers of engineers establish performance metrics to guide promotion and salary scales. Faculty define engineering competencies that guide curriculum design and assessment for specific engineering program accreditation. Professional societies and licensing bodies define standards and guidelines for professional engineers and criteria for graduates of accredited degree programs[4,12,13,14]. Others among industry, academic, government, and public constituencies have sought to derive broad-based definitions of desired attributes of engineering graduates[6,15,16,17]. These typically are specific to organizations or disciplines, are too exhaustive for use in academic programs, or are not available to engineering faculty in forms that support capstone engineering design course instruction and assessment.

*Research Questions and Objectives*

The following research questions are important to the development of a versatile capstone course assessment and evaluation system:

- What capstone course learning outcomes support the objectives of capstone courses in engineering curricula and embody relevant preparation of engineering graduates who will enter engineering practice?
- To what extent is this set of learning outcomes universally applicable across engineering disciplines and institutions so as to justify standardized assessments?

In order to answer these questions, we must clarify the broader preparation of engineering graduates and their expected performance when engaged in engineering practice. This leads to three objectives addressed in this paper:

1. Describe a top quality engineer of any discipline five years after graduation with a baccalaureate engineering degree.
2. Establish a set of attributes that describe a top quality engineer of any engineering discipline at the time of graduation from a BS engineering degree.
3. Define a set of student learning outcomes for capstone design courses consistent with course objectives and attributes desired in BS engineers upon graduation.

## Methods

The development of capstone course outcomes is part of a larger effort of the Transferable Integrated Design Engineering Education (TIDEE) consortium of institutions to enhance engineering design education. Having previously defined learning outcomes, developed instructional materials, and created and evaluated assessments for the first two-years of engineering curricula, TIDEE project faculty have begun developing a comprehensive assessment and evaluation system for capstone engineering design courses[5,18,19]. Figure 1 illustrates this larger system that will enable engineering educators to prepare graduates better able to practice engineering. Defining the profile of a top quality engineer and establishing a broad set of capstone course learning outcomes are early steps in the development of an assessment and evaluation system.

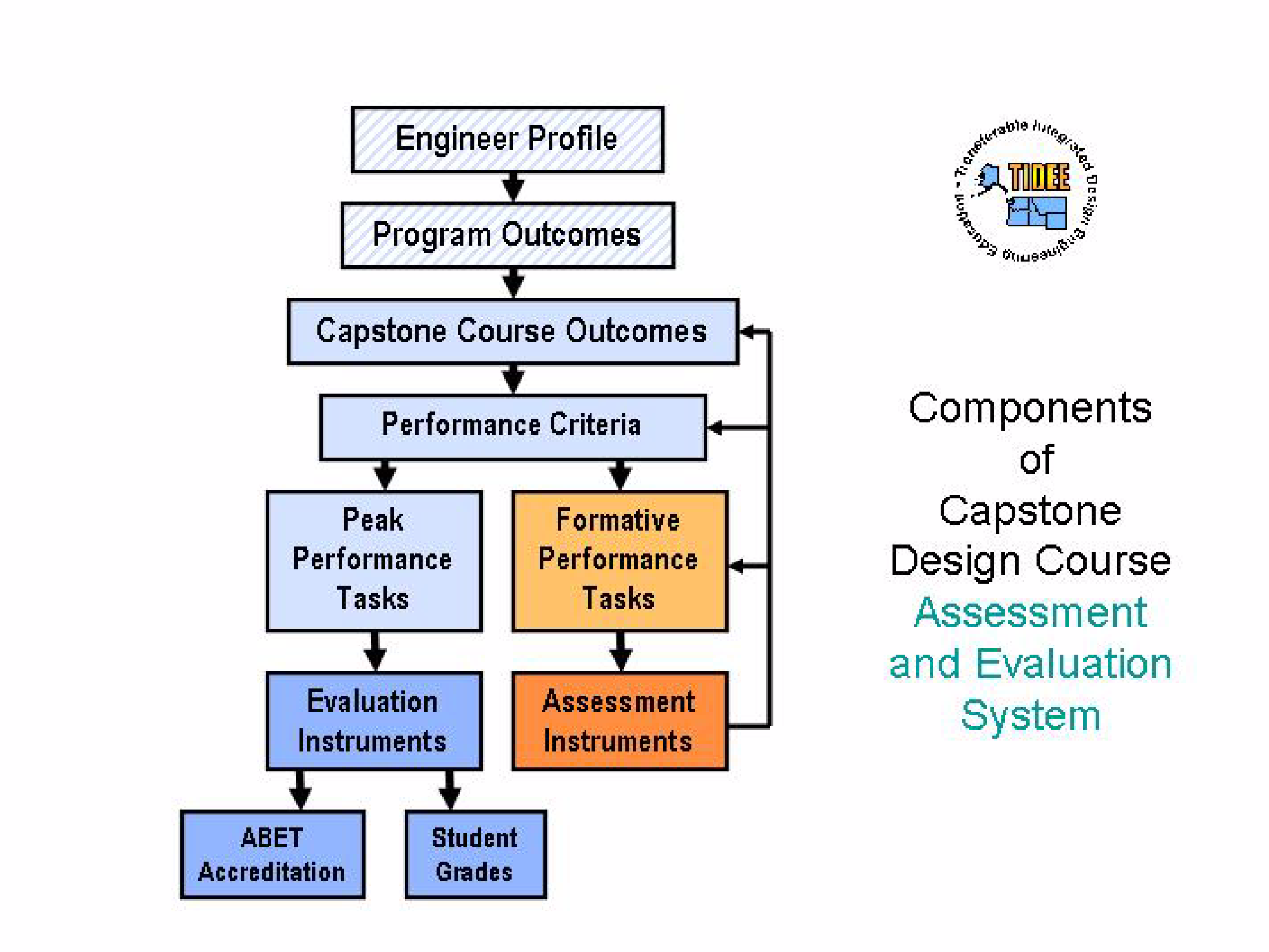


Figure 1. Capstone Design Course Assessment and Evaluation System

*Profiles of Top Quality Engineers*

Profiles of top quality engineers were defined in Fall 2002 through a series of steps, engaging a broad set of collaborators and drawing from several information sources.

Step 1 was defining the profile of a top quality engineering graduate five years after receiving a baccalaureate degree, thereby articulating an educational objective (or orienting a compass for engineering education). ABET Engineering criteria 3 and 4 provide a minimum set of engineering attributes for consideration because they are required for all accredited engineering programs and appear explicitly or implicitly in all published engineering program outcomes. Other outcomes examined include those defined by broad industry-academic-government constituencies: skills defined by the Industry-University-Government Roundtable for Enhancing Engineering Education[6], Iowa State University's competencies developed with Development Dimensions International[17], and desired engineer capabilities published by professional societies[12,14]. Synthesis of these engineering traits produced a first draft set of ten attributes of a top quality engineer.

Step 2 drew input from a diverse team of collaborators to check for broad applicability and comprehensiveness of proposed attributes of top quality engineers. A diverse team of forty university and ten industry collaborators was formed from the 150 respondents to McKenzie's survey[8] identifying themselves for collaboration on capstone design assessments and from regional and national friends of the TIDEE project. All were invited to review the ten proposed attributes of a top quality engineer five years after graduation. Fifteen respondents ranked the attributes, identified missing elements, and suggested other revisions. Synthesis of this input produced a revised list of eleven attributes of a top quality engineer, each attribute further delineated by two or three performance factors.

Academic and industry collaborators were again invited to review the revised list of attributes and performance factors for the purpose of defining their relevance to engineers of all disciplines at graduation and afterward. Twenty six respondents rated the importance of thirty factors to engineers both at graduation and five years after graduation. They also indicated whether the importance of an attribute is universal across all engineering disciplines or if it depends heavily upon discipline. Overall, respondents were very favorable about the completeness of the attributes list, and few offered suggestions for revisions to attributes or factors. Synthesis of this feedback produced profiles of the top quality engineer at both BS graduation and five years after graduation.

### *Capstone Course Outcomes*

A set of ten learning outcomes was defined to articulate the student learning that can be achieved in capstone design courses toward preparation of the top quality engineering graduate. Care was taken to define outcomes broadly enough to extend beyond the product-oriented outcomes commonly found in capstone design courses[8]. Ten preliminary outcomes were defined and pilot tested in two capstone design courses in two different disciplines and institutions in fall 2002. Subsequent to the semester, and after the eleven attributes of a top quality engineer were defined, the ten capstone course outcomes were refined further to achieve greater generality and to align better with the engineer profile attributes. The resulting ten course outcomes are suitable for a typical capstone engineering design course.

## Results

### *BS and BS+5 Attributes of Top Quality Engineers*

Attributes of the top quality engineer are presented in Table 1. This set of attributes and performance factors was derived from collaborator feedback and was used to obtain importance ratings from collaborators. Every attribute and factor was rated by over 80% of respondents: at least moderately important for some or all disciplines at both graduation and five years afterward.

Table 1. Attributes and Performance Factors for Top Quality Engineers*

**1. Motivation— Motivated and takes action to complete assignments on time**
- Accepts responsibility needed for an assignment
- Maintains focus to complete important tasks on time amidst multiple demands
- Takes necessary initiative and appropriate risks to overcome obstacles and achieve objectives

**2. Technical Competence— Competent in knowledge and tools of engineering**
- Demonstrates knowledge of fundamentals of mathematics, statistics, physical and life sciences in engineering problem solving
- Demonstrates knowledge of engineering sciences, experimental methods, engineering economics, and information technology required in engineering problems
- Demonstrates ability to use contemporary tools of engineering to analyze and solve engineering problems

**3. Judgment and Decision Making— Able to make sound engineering decisions**
- Recognizes key issues when addressing engineering problems
- Draws evaluation criteria from diverse sources and evaluates alternatives against these criteria and associated risks
- Makes decisions rationally and checks viability of decisions

**4. Innovation— Contributes creativity to engineering activities**
- Thinks creatively (independently and cooperatively) and searches broadly to identify and formulate innovative approaches
- Models and supports actions that enhance innovation

**5. Client/Quality Focus— Pursues highest quality as defined by customers**
- Establishes successful relationships with internal and external clients to understand their needs and to achieve or exceed agreed-upon quality standards
- Monitors achievement, identifies causes of problems, and revises processes to enhance satisfaction

**6. Business Orientation— Seeks business success for engineering products**
- Can articulate the factors that drive business success in today's marketplace
- Adapts efforts to appropriately support changing business needs of organization for which work done
- Estimates economic costs and benefits anticipated for engineering alternatives

**7. Product Development— Creates engineering products with realistic, responsible constraints**
- Develops engineering products and processes that meet needs of society in the context of global, social, political, and environmental constraints
- Designs technological products that are manufacturable and maintainable
- Applies state-of-the-art technologies in development of new products

**8. Professional/Ethical— Practices and promotes professional performance**
- Exhibits integrity and ethical behavior in engineering practice and relationships
- Participates in discipline-appropriate professional societies to establish standards and ensure that engineers comply with professional codes and standards

**9. Teamwork— Builds and maintains effective teamwork**
- Shows sensitivity and respect for perspectives and contributions of people from different cultures and backgrounds
- Builds and maintains trusting, productive working relationships and resolves conflicts productively
- Performs as an effective team player who assists and values individual and team successes

**10. Change Management— Prepares self and others for change and professional growth**
- Anticipates change and remains flexible to respond to changes in organizations and society
- Applies ongoing self-assessment, planning, and effort to continue to grow professionally and deal constructively with change
- Helps others grow professionally and respond to change

**11. Communication— Exchanges information to meet needs of audience**
- Listens and observes attentively and effectively to assess audience information needs
- Organizes and expresses thoughts clearly and concisely, both in speaking and writing, with necessary supporting materials to achieve desired understanding and impact
- Keeps stakeholders informed about matters that affect their work while protecting necessary confidentiality

*For each of the eleven attributes, performance factors are designated as bulleted items.

Table 2 addresses the question about which attributes and performance factors are **universal** at graduation (BS) and/or five years later (BS+5) for the top quality engineer and whether the attributes and performance factors are discipline specific. In this table, a performance factor is labeled "highly universal" (HU) when at least 75% of respondents rated it "essential for all disciplines," and it is labeled "moderately universal" (MU) when 75% of ratings were either "essential for all disciplines" or "moderately important for all disciplines." The attribute is considered "universal" when one or more of its performance factors is universal. The following attributes are considered universal at either BS or BS+5 points in time:

- Highly universal: Motivation, judgment & decision making, professional/ethical, teamwork, and communication
- Moderately universal: Innovation, client/quality focus, business orientation, and change management

Table 2. Universality of Attributes and Performance Factors

| ATTRIBUTE | PERFORMANCE FACTORS | BS | BS+5 |
|---|---|---|---|
| **Motivation** | Accepts responsibility needed for an assignment | **HU** | **HU** |
| | Maintains focus to complete important tasks amidst . . . | | **HU** |
| | Takes necessary initiative and appropriate risks . . . | *MD* | MU |
| **Technical Competence** | Demonstrates knowledge of fundamentals of math . . . | | |
| | Demonstrates knowledge of engineering sciences, . . . | *HD* | |
| | Demonstrates ability to use contemporary tools . . . | | |
| **Judgment & Decision Making** | Recognizes key issues when addressing engineering problems | *MD* | **HU** |
| | Draws evaluation criteria from diverse sources, evaluates . . . | *MD* | MU |
| | Makes decisions rationally and checks viability of decisions | *MD* | **HU** |
| **Innovation** | Thinks creatively . . . to identify, formulate innovative approaches | *MD* | |
| | Models and supports actions that enhance innovation | | MU |
| **Client/Quality Focus** | Establishes successful relationships with internal, external . . . | | MU |
| | Monitors achievement, identifies causes of problems, revises . . . | *MD* | |
| **Business Orientation** | Can articulate the factors that drive business success . . . | *MD* | |
| | Adapts efforts to appropriately support changing business . . . | *MD* | |
| | Estimates economic costs and benefits anticipated . . . | *MD* | MU |
| **Product Development** | Develops engineering products, processes that meet needs . . . | *MD* | |
| | Designs technological products that are manufacturable . . . | *MD* | |
| | Applies state-of-the-art technologies in development . . . | *MD* | *MD* |
| **Professional/ Ethical** | Exhibits integrity and ethical behavior in engineering . . . | **HU** | **HU** |
| | Participates in discipline-appropriate professional societies . . . | *MD* | |
| **Teamwork** | Shows sensitivity and respect for perspectives . . . | MU | MU |
| | Builds, maintains trusting, productive working relationships . . . | | **HU** |
| | Performs as an effective team player who assists and values . . . | MU | **HU** |
| **Change Management** | Anticipates change and remains flexible to respond . . . | MU | |
| | Applies ongoing self-assessment, planning, and effort . . . | | MU |
| | Helps others grow professionally and respond to change | *MD* | |
| **Communication** | Listens and observes attentively and effectively . . . | | **HU** |
| | Organizes and expresses thoughts clearly and concisely . . . | | **HU** |
| | Keeps stakeholders informed about matters that affect . . . | | **HU** |

As shown in Table 2, some performance factors are important in only selected disciplines. Here "highly disciplinary" (HD) means that over 75% of respondents ranked it "essential," but more were "essential for some disciplines" than "essential for all disciplines." In contrast, "moderately disciplinary" (MD) means over 75% of respondents ranked it "moderately important" or "essential" and more were for "some disciplines" than for "all disciplines." Attributes with one or more performance factors that are discipline specific at the time of the BS degree are:

- Moderate discipline dependence in **multiple** factors: Judgment & decision making, business orientation, and product development
- Moderate discipline dependence in **one** factor: Motivation, innovation, client/quality focus, professional/ethical, and change management

The essential role of individual performance factors for top quality BS and BS+5 engineers is displayed in Figure 3. Here the label "essential" is given to a factor if at least 75% of respondents rated it either "essential for all disciplines" or "essential for some disciplines."

Table 3. Summary of Essential Attributes and Performance Factors

| ATTRIBUTE | PERFORMANCE FACTORS | BS | BS+5 |
|---|---|---|---|
| **Motivation** | Accepts responsibility needed for an assignment | E | E |
| | Maintains focus to complete important tasks amidst . . . | | E |
| | Takes necessary initiative and appropriate risks . . . | | E |
| **Technical Competence** | Demonstrates knowledge of fundamentals of math . . . | E | |
| | Demonstrates knowledge of engineering sciences, . . . | E | E |
| | Demonstrates ability to use contemporary tools . . . | E | |
| **Judgment & Decision Making** | Recognizes key issues when addressing engineering problems | | E |
| | Draws evaluation criteria from diverse sources, evaluates . . . | | E |
| | Makes decisions rationally and checks viability of decisions | | E |
| **Innovation** | Thinks creatively . . . to identify, formulate innovative approaches | | E |
| | Models and supports actions that enhance innovation | | E |
| **Client/Quality Focus** | Establishes successful relationships w internal, external clients . . . | | E |
| | Monitors achievement, identifies causes of problems, revises . . . | | E |
| **Business Orientation** | Can articulate the factors that drive business success . . . | | E |
| | Adapts efforts to appropriately support changing business . . . | | E |
| | Estimates economic costs and benefits anticipated . . . | | E |
| **Product Development** | Develops engineering products, processes that meet needs . . . | | E |
| | Designs technological products that are manufacturable . . . | | E |
| | Applies state-of-the-art technologies in development . . . | | |
| **Professional/ Ethical** | Exhibits integrity and ethical behavior in engineering . . . | E | E |
| | Participates in discipline-appropriate professional societies . . . | | |
| **Teamwork** | Shows sensitivity and respect for perspectives . . . | E | E |
| | Builds and maintains trusting, productive working relationships . . . | E | E |
| | Performs as an effective team player who assists and values . . . | E | E |
| **Change Management** | Anticipates change and remains flexible to respond . . . | | E |
| | Applies ongoing self-assessment, planning, and effort . . . | | E |
| | Helps others grow professionally and respond to change | | E |
| **Communication** | Listens and observes attentively and effectively . . . | | E |
| | Organizes and expresses thoughts clearly and concisely . . . | E | E |
| | Keeps stakeholders informed about matters that affect . . . | | E |

From Table 3 note that all except one factor are classified as "essential" for either BS or BS+5 top quality engineers; "Participates in discipline-specific professional societies" is not labeled "essential," although it is rated at least "moderately important for some disciplines" by over 80% of respondents. As expected, the "essential" label for a factor occurs more frequently at the BS+5 time, indicating higher performance expectations five years after graduation than at graduation. Note, however, that some technical competence factors become less essential after five years.

Interpreting results presented in Tables 2 and 3, the following statements are made regarding the profile of top quality engineers:

- All of the eleven attributes are essential for top quality engineers some time during their first five years after receiving the baccalaureate engineering degree.
- Accepting responsibility is universally essential for graduates, and after five years even greater focus and initiative are essential for engineers in all disciplines.
- Technical competence in fundamentals is highly discipline specific and yet essential at graduation; some of it becomes less essential after five years.
- Decision making is important for engineers in some disciplines at graduation, but decision making becomes universally essential after an additional 5 years.
- Innovation is important in some engineering disciplines at graduation, and the need for practicing innovation becomes more universal across disciplines after five years.
- The importance of quality and client focus is moderate in some engineering disciplines at graduation; it becomes more essential in all disciplines later.
- A business orientation is moderately important in some engineering disciplines at graduation, but it becomes more universally important after five years.
- In selected engineering disciplines graduates are expected be able to develop a new product; five years later product development is essential in a variety of scenarios.
- Ethics is universally essential for engineers at graduation and after five years; some disciplines also expect involvement of engineers in professional societies at graduation.
- Teamwork is universally important for engineers at graduation, and it becomes increasingly essential for all disciplines after five years.
- Professional development is important across disciplines for engineers at graduation, although somewhat discipline-specific; self-assessment and professional development are universally important five years after graduation.
- Communication capabilities become universally essential and broad five years after graduation; they are less extensive but important at graduation.

This summary profile of a top quality engineer provides useful insights for engineering educators and capstone design course instructors. First, the breadth of attributes shown important to engineering practice reinforces the importance of providing students comprehensive capstone project experiences. Comparisons of profiles at graduation and five years later reveal greater discipline-dependence at graduation and greater uniformity in important attributes at the later time when engineers have greater responsibility and independence. Universally essential expectations of all engineers at graduation include four attributes or performance factors: (1) accepting responsibility for an assignment, (2) exhibiting integrity and ethical behavior, (3) being an effective team player who respects others, and (4) remaining open and flexible to change. These expectations should shape the outcomes of engineering degree programs and, specifically, capstone design courses, where they can be addressed directly.

*Capstone Course Outcomes*

Ten capstone design course learning outcomes are presented and defined in Table 4. These outcomes include high-level integrative outcomes (perform professionally), significant achievements (produce quality design products), and others which may identify specific levels of achievement or desired growth in skills. They are comprehensive in types of outcomes and in the domain of development (e.g., cognitive, affective, social, etc.) that is addressed.

Table 4. Capstone Design Course Learning Outcomes and Definitions

| Outcome | Definition |
|---|---|
| 1. Perform Professionally | Perform professionally—exhibiting integrity, accepting responsibility, taking initiative, and providing leadership necessary to ensure project success. |
| 2. Produce Quality Design Products | Produce design products that meet important performance requirements while satisfying relevant societal and professional constraints. |
| 3. Establish Relationships for Quality Performance | Establish relationships and implement practices with team members, advisors, and clients that support high performance and continuous improvement. |
| 4. Manage Project Schedule and Resources | Plan, monitor, and manage project schedule, resources, and work assignments to ensure timely and within-budget completion. |
| 5. Apply Knowledge, Research and Creativity | Utilize prior knowledge, independent research, published information, patents, and original ideas in addressing problems and generating solutions. |
| 6. Make Decisions Using Broad-Based Criteria | Make design decisions based on product design requirements, product life-cycle considerations, resource availability, and associated risks. |
| 7. Use Contemporary Engineering Tools | Demonstrate effective use of contemporary tools for engineering and business analysis, fabrication, testing, and design communication. |
| 8. Test and Defend Product Performance | Test and defend performance of a design product with respect to at least one primary design requirement. |
| 9. Communicate for Project Success | Use formal and informal communications with team, advisor, and clients to document and facilitate progress and to enhance impact of design products. |
| 10. Pursue Needed Professional Development | Assess and pursue personal professional growth in concert with project requirements and personal career goals. |

The ten capstone course outcomes were checked for alignment with two sets of criteria—attributes (and performance factors) of top quality engineers and ABET criteria— to determine their versatility and relevance to design educators' needs. As shown in Table 5, each learning outcome was checked for relevance to performance factors categorized as "universal," "discipline-specific," and otherwise "important" to top quality engineers. In this matrix, weights are applied to performance factors based on their level of universality, discipline-specificity, and importance (1 = moderate, 2 = essential). Each of the ten outcomes is assigned a score (with 1 = low match, 2 = high match) for its alignment with the corresponding performance factor.

Table 5. Alignment of Capstone Course Outcomes with Attributes of Top Quality Engineers

| | Weight* | | | Capstone Outcome Number* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FACTORS (of Engineer Profile Attributes)** | **A** | **B** | **C** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| Accepts responsibility needed for . . . | **2** | 0 | 2 | 2 | | | | | | | | | |
| Maintains focus to complete . . . | 0 | 0 | 1 | | | | 1 | | | | | | |
| Takes necessary initiative, appropriate risks . . . | 0 | 1 | 1 | | | | | | | | | | |
| Demonstrates knowledge of math . . . | 0 | 0 | 1 | | | | | 1 | | | | | |
| Demonstrates knowledge of engineering sci . . . | 0 | 2 | 2 | | | | | 1 | | | 1 | | |
| Demonstrates ability to use contemporary . . . | 0 | 0 | 1 | | | | | | | 2 | | | |
| Recognizes key issues . . . | 0 | 1 | 1 | | | | | | | | | | |
| Draws evaluation criteria from diverse . . . | 0 | 1 | 1 | | | | | | 2 | | | | |
| Makes decisions rationally and checks . . . | 0 | 1 | 1 | | | | | | 2 | | | | |
| Thinks creatively . . . | 0 | 1 | 1 | | | | | 2 | | | | | |
| Models, supports actions that enhance innov | 0 | 0 | 1 | | | | | | | | | | |
| Establishes successful relationships . . . | 0 | 0 | 1 | | | 2 | | | | | | | |
| Monitors achievement, identifies causes . . . | 0 | 1 | 1 | | | | | | | | | | |
| Can articulate factors that drive business . . . | 0 | 1 | 1 | | | | | | | | | | |
| Adapts efforts to appropriately support chg . . . | 0 | 1 | 1 | | | | | | | | | | |
| Estimates economic costs and benefits . . . | 0 | 1 | 1 | | | | | | | 1 | | | |
| Develops engineering products, processes . . . | 0 | 1 | 1 | | 2 | | | | | | | | |
| Designs techn. products that are manuf . . . | 0 | 1 | 1 | | 2 | | | | | | | | |
| Applies state-of-the-art technologies . . . | 0 | 1 | 0 | | | | | | | | | | |
| Exhibits integrity and ethical behavior . . . | **2** | 0 | 2 | 2 | | | | | | | | | |
| Participates in discipline appropriate prof . . . | 0 | 1 | 0 | | | | | | | | | | |
| Shows sensitivity, respect for perspectives . . . | 1 | 0 | 2 | | | 1 | | | | | | | |
| Builds and maintains trusting, productive . . . | 0 | 0 | 2 | | | 2 | | | | | | | |
| Performs as an effective team player . . . | 1 | 0 | 2 | | | 2 | | | | | | | |
| Anticipates change, remains flexible . . . | 1 | 0 | 1 | | | | | | | | | | |
| Applies ongoing self-assessment, planning . . . | 0 | 0 | 1 | | | | | | | | | | 2 |
| Helps others grow professionally, respond . . . | 0 | 1 | 1 | 1 | | | | | | | | | |
| Listens and observes attentively . . . | 0 | 0 | 1 | | | | | | | | | 1 | |
| Organizes and expresses thoughts . . . | 0 | 0 | 2 | | | | | | | | | 2 | |
| Keeps stakeholders informed about matters . . . | 0 | 0 | 1 | | | | | | | | | 2 | |
| Weighted Scores for Outcomes based on Wt **A** | | | | 8 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Weighted Scores for Outcomes based on Wt **B** | | | | 1 | 4 | 0 | 0 | 4 | 4 | 1 | 2 | 0 | 0 |
| Weighted Scores for Outcomes based on Wt **C** | | | | 9 | 4 | 12 | 1 | 5 | 4 | 3 | 2 | 7 | 2 |
| TOTAL SCORES FOR OUTCOMES | | | | 18 | 8 | 15 | 1 | 9 | 8 | 4 | 4 | 7 | 2 |

*Key to Column Headings:
A = Universally essential at BS; B = Discipline specific but essential at BS; C = Essential at either BS or BS +5.
1 = Perform professionally; 2 = Produce quality design products; 3 = Build team/client relationships; 4 = Manage project resources; 5 = Employ knowledge, research, creativity; 6 = Make decisions from broad criteria; 7 = Use contemporary tools; 8 = Test and defend performance; 9 = Communicate for projects success; 10 = Pursue professional development.

Weighted sums at the bottom of the Table 5 show that all of the proposed outcomes align with at least one performance factor of importance. One of the capstone outcomes— Perform Professionally— aligns with the two performance factors that are universally essential (universality = 2). Each of the other capstone course outcomes aligns with one or more performance factors and all performance factors align with at least one course outcome. Thus, the proposed capstone course outcomes comprise a viable set to address the attributes and performance factors for top quality engineers.

Capstone course learning outcomes are compared to ABET criteria 3 outcomes in Table 6. An "X" indicates that a capstone course outcome overlaps the corresponding ABET outcome. As seen, every ABET criterion 3 outcome is addressed by a capstone course outcome; some capstone outcomes address multiple ABET outcomes. It should also be noted that ABET criterion 4, quoted earlier, is addressed by the breadth of three capstone course outcomes: (1) perform professionally, (2) produce quality design products, and (6) make decisions from broad criteria. Thus, these ten capstone course learning outcomes will enable faculty to use capstone design courses to provide at least one measure of student achievement of every ABET criterion 3 outcome.

Table 6. Comparison of Capstone Design Course Outcomes to ABET Criterion 3 Outcomes

| | Capstone Outcome Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **ABET Engineering Criterion 3 Outcomes** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| a) an ability to apply knowledge of mathematics, science, and engineering | | | | | X | | | | | |
| b) an ability to design and conduct experiments, as well as to analyze and interpret data | | | | | | | | X | | |
| c) an ability to design a system, component, or process to meet desired needs | | X | | | | | | | | |
| d) an ability to function on multi-disciplinary teams | | | X | | | | | | | |
| e) an ability to identify, formulate, and solve engineering problems | | | | | X | | | | | |
| f) an understanding of professional and ethical responsibility | X | | | | | | | | | |
| g) an ability to communicate effectively | | | | | | | | | X | |
| h) the broad education necessary to understand the impact of engineering solutions in a global/societal context | | | | | | X | | | | |
| i) a recognition of the need for and an ability to engage in life-long learning | | | | | | | | | | X |
| j) a knowledge of contemporary issues | | | | | | X | | | | |
| k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice | | | | | | | X | | | |

## Conclusions

Profiles for top quality engineers at graduation and five years later identify approximately thirty capabilities (grouped under eleven attributes) that are important for engineering educators to consider. At graduation, two attributes (motivation and professional/ethical) are universal and essential, and two more (teamwork and change management) are moderately important across all disciplines. Technical competence is essential but dependent on discipline. Other attributes are moderately important or essential for selected disciplines at graduation: judgment and decision making, innovation, client/quality focus, business orientation, and product development. At graduation, some communication skills are essential. As engineers gain five years of experience after graduation, the attributes they need become more uniform across disciplines and become more essential for success. This realization suggests that the baccalaureate engineering education needs to lay a foundation for all of these attributes to prepare graduates for success over their first five years after graduation.

Capstone design courses provide an excellent environment for developing in students many of the broad set of attributes of a top quality engineer. The ten capstone course outcomes defined in this paper offer a distinct set of outcomes that address top engineer attributes and yet satisfy ABET requirements. These ten outcomes encompass learning in areas judged important at graduation and those that become more important during the next five years. Including these in capstone design courses will position students to succeed after graduation and to progress rapidly in their engineering careers.

Addressing the posed research questions, one may conclude that the ten capstone course learning outcomes fit objectives of capstone courses while also preparing engineering graduates for success in engineering practice. Furthermore, of the ten learning outcomes, two are aligned closely with universal performance factors, and five others are aligned with essential but discipline-specific performance factors for top quality engineering graduates. The remaining three outcomes align with otherwise essential performance factors. Thus, they span the universal and discipline-specific attributes essential to a broad set of disciplines.

The work reported here is based on responses from a diverse but limited team of engineers. A more extensive survey is required to increase the reliability of the conclusions stated here. With broader input, a greater degree of confidence can be placed on individual attributes and factors for top quality engineers, and capstone course outcomes can be tested with greater assurance.

**Bibliography**


1. Todd, R., Magleby, S., Sorensen, D., Swan, B., and Anthony, D. (1995). "A Survey of Capstone Engineering Courses in North America", *Journal of Engineering Education*, 84 (2): 165-174.
2. Dutson, A., Todd, R., Magleby, S., and Sorensen, C. (1997). "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses", *Journal of Engineering Education*, 86 (1): 57-64.
3. Davis, D., Beyerlein, S., Trevisan, M., McKenzie, L., and Gentili, K. (2002). "Innovations in Design Education Catalyzed by Outcomes-Based Accreditation", ABET Conference on Assessment.
4. ABET. (2003). Engineering Criteria, Accreditation Board for Engineering and Technology. www.abet.org.
5. National Science Foundation. (1996). *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*, NSF Report 96-139.
6. Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE). (1997). *ABET Criteria: Industry Expectations of New Engineers*.
7. Moore, D. and Farbrother, B. (2000). "Pedagogical and Organizational Components and Issues of Externally Sponsored Senior Design Teams", *Proceedings of 2000 Frontiers in Education Conference*.
8. McKenzie, L. J. (2002). End-of-Program Assessment: An Investigation of Senior Capstone Design Assessment Practices. Doctoral Dissertation, College of Education, Washington State University, Pullman, WA.
9. Napper, S. and Hale, P. (1999). "Using Design Projects for Program Assessment", *Journal of Engineering Education*, 88(2): 169-172.
10. Rizkalla, M. and Yokomoto, C. (2001). "Redesigning and Assessing the ECE Capstone Design Course for EC 2000", *Proceedings of the 2001 ASEE Annual Conference & Exposition*.
11. Stiggins, R. (2001). *Student-Involved Classroom Assessment (3rd ed.)*. Upper Saddle River, NJ: Prentice Hall.
12. NSPE. (2003). "Code of Ethics for Engineers." National Society of Professional Engineers, www.nspe.org.
13. NCEES. (2003). National Council of Examiners for Engineering and Surveying. "www.ncees.org.
14. IEEE. (2002). "Attributes of the 21st Century Engineer." www.-cseg.inaoep.mx/~jmc/21st.html.
15. Partis, A. (2002). "10 Attributes of a Professional Software Engineer." www.thundernet.com/alpartis/articles/engineer.shtml.
16. Boeing. (2003). "Boeing Attributes of an Engineer." www.boeing.com/companyoffices/pwu/attributes/attributes.html.
17. Hanneman, L., S. Mickelson, L. Pringnitz, and M. Lehman. (2002). "Constituent-Created, Competency-Based, ABET-Aligned Tools for the Engineering Experiential Education Workplace", ABET Conference on Assessment.
18. Davis, D., Gentili, K., Trevisan, M., and Calkins, D. (2002). Engineering Design Assessment

Processes and Scoring Scales for Program Improvement and Accountability, *Journal of Engineering Education* 91(2): 211-219.
19. Gentili, K., D. Davis, and S. Beyerlein. (2003). "Framework for Developing and Implementing Engineering Design Curricula." Proceedings of 2003 Annual Conference of American Society for Engineering Education.

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