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Structuring Capstone Design Assessment to Achieve Student, Faculty, and Employer Priorities

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Rogers joined the university in October, 2008 bringing with him 35 years of industrial experience. His career includes senior leadership roles in engineering, sales, and manufacturing developing products using multidisciplinary teams to convert customer needs to commercially viable products and services. He brings this experience to the university where he leads the effort in developing experiential, multidisciplinary learning.

Rogers co-led the development of an ABET approved year-long Capstone design experience. With a focus on providing students with a broader experience base, the multidisciplinary program applies teams of engineers, business, design, and other students to work with Ohio companies to help them be more competitive and with local non-profits to help them become self-sustaining. Using a formal design process, teams develop new products to meet industries' competitive needs and others to meet the needs of people with disabilities. Students learn to solve open-ended problems and gain skills in critical thinking, professional communication, ethics, and teamwork. Rogers recently expanded this one-year program to a four-year Integrated Engineering and Business (IBE) honors program.

Rogers earned his PhD at the University of Massachusetts, Amherst focused on mechanical engineering and manufacturing and holds the position of Professor of Practice at The Ohio State University.

Work-in-Progress: Structuring Capstone Design Assessment to Achieve Student, Faculty, and Employer Priorities

Abstract

Assessments in capstone design courses typically attempt to measure several technical and professional learning outcomes important to engineering programs. Students, faculty, and employers of graduates will benefit most when these assessments give them accurate measures of knowledge, skills, and abilities (KSAs) that are directly transferable to the professional workplace. This paper identifies technical and professional KSAs judged important to both capstone design courses and the professional workplace, and it presents a structure for assessing these through professional performance reviews and technical design reviews. Performance reviews enable assessment of individual student achievements of either technical or professional nature, ensuring strong human resource development. Design reviews assess the team's design processes and products, ensuring delivery of high quality design products. Implementation of a set of performance and design reviews prepares students for professional practice, enhances achievement of both professional development and solution development, and provides valuable exhibits for students' professional portfolios. The authors of this work-in-progress paper seek collaborators for implementing and testing the proposed assessment structure in capstone design courses.

Introduction

Consider this scenario: An engineering graduate walks into a job interview and hands the interviewer achievement scores for his or her teamwork, communication, problem solving, project management, ethics and professional responsibility, willingness to take risks, motivation to continue learning, and other knowledge, skills and abilities important to the employer. The interviewer smiles upon receiving credible information about this potential employee's preparation for engineering professional work. The interviewer then focuses discussion on performances behind the graduate's scores and on job responsibilities that either fit the individual or that may be particularly challenging for this prospective employee. The interview concludes with both parties confident of the interview's effectiveness and final outcome.

What is different about this picture? What gives the employer and prospective employee confidence in the value of information on the score sheet? In this case, scores were based on evidence from multiple sources: instructor, peers, and outside evaluators. Scores were earned in a capstone design project that simulated actual engineering practice, and scores were based on individual performances of this student. Measures used were tested and validated to ensure that they measure knowledge, skills, and abilities (KSAs) as used in the professional world. In short, validated measures were used by capable instructors who judged performances of individual students under authentic professional experiences—yielding credible scores.

Capstone design courses are common sites of student assessment, but most assessment is focused on ABET (formerly, Accreditation Board for Engineering and Technology) accreditation and awarding grades. Current practices in capstone courses often prevent sound assessment of individual student achievements or are not perceived by stakeholders as valuable assets beyond course grades or program accreditation. Obstacles to achieving the full potential of capstone assessments include:

1. Many assessments are based on group work products that cannot be effectively attributed to individual students.
2. Many assessments are developed by local faculty and not revised and evaluated rigorously to ensure validity and reliability of results.
3. Assessment results are channeled into grades and student work examples for program accreditation, not compiled to meet broader needs of stakeholders including industry.
4. Outcomes being assessed are limited by the number easily assessed in a capstone course, those needed for grading, and those needed for accreditation.
5. Assessment may return less value than instructors or students feel justifies the time invested.

A recent report from the American Society for Engineering Education (ASEE), entitled *Transforming Undergraduate Engineering Education* (TUEE), stated that engineering graduates are not being prepared well for a number of knowledge, skills, and abilities highly sought by the engineering profession[1]. This is consistent with earlier calls for engineering curriculum reform[2]. Some of the industry-valued KSAs are not among those required for engineering program accreditation, and therefore, probably are not being developed and assessed in many engineering programs. Among these are: project management, critical thinking, ability to take calculated risks, and ability to prioritize[1]. Other outcomes listed among ABET requirements and important to the profession similarly lack robust assessments that are defensible to evaluation professionals. Thus, engineering educators need better assessments for use in determining individual student knowledge, skills, and abilities.

Table 1. KSAs mapped to ABET student outcomes

TUEE KSA	**ABET Student Outcome**	**Relationship**
1. Good communication skills	(3g) communicate effectively	Very similar
2. Physical sciences and engineering science fundamentals	(3a) apply math, science, engineering	Very similar
3. Ability to identify, formulate and solve engineering problems	(3e) identify, formulate, solve engineering problems	Identical
4. Systems integration	(3c) design a system, component or process	Systems integration may be a part of ABET 3c design
5. Curiosity and persistent desire for continuous learning	(3i) recognize need & engage in lifelong learning	Similar
6. Self-drive and motivation		
7. Cultural awareness in the broad sense		
8. Economics and business acumen		Economics may be a part of ABET 3c design
9. High ethical standards, integrity, and global, social, intellectual and technological responsibility	(3f) understand professional & ethical responsibility	Similar but KSA may focus more on application of knowledge
10. Critical thinking		
11. Willingness to take calculated risks		
12. Ability to prioritize efficiently		
13. Project management		
14. Teamwork skills and ability to function on multidisciplinary teams	(3d) function on multidisciplinary teams	Very similar
15. Entrepreneurship and intrapreneurship		

Table 1 lists the top 15 KSAs identified by the TUEE report and maps them to ABET student outcomes[3]. From this table, a number of KSAs surface as outcomes that may need additional attention. Not specifically called out by ABET are outcomes like: self-drive and motivation, cultural sensitivity, critical thinking, willingness to take risks, ability to prioritize, project management, and entrepreneurship/ intrapreneurship. To improve preparation of graduates, outcomes most important to engineering programs and employers should be assessed effectively. Many of these outcomes can be assessed in capstone design courses.

Goals

This paper has three goals:

1. Define requirements for capstone design course assessment that is responsive to the needs of all stakeholders: students, faculty, and employers of graduates.
2. Propose assessment design to achieve greatest value for all stakeholders.
3. Provide examples of possible outputs from well-designed capstone assessments.

Requirements

Requirements for capstone design course assessments are listed below and explained in the following paragraphs. Capstone assessments should:

1. Provide experiences that simulate professional practice
2. Measure outcomes authentic to the engineering workplace
3. Enable efficiencies for students, faculty, and employers

Experience Engineering Practice

Capstone courses often serve as a transition from the academic environment to the professional work environment. To prepare students for the workplace, capstone course practices should simulate to the extent possible the practices used in organizations where engineering projects are conducted. In the workplace, supervisors orient employees to the organization, make work assignments, establish work expectations, provide support for successful outcomes, and evaluate performances. Typically, engineering projects must abide by design controls and undergo scheduled design reviews to ensure that work meets company and regulatory requirements. Individuals undergo performance reviews on a regular basis to facilitate their development and determine rewards.

Design reviews for capstone design projects vary across institutions and engineering programs[4]. Commonly, a two-semester project will have three design reviews: problem review, concept review, and final solution review. Assessment focus shifts according to the review, but it typically examines the adequacy of processes used and quality of products delivered in the corresponding stage of design. Outcomes of the review should be a decision to (a) proceed without changes, (b) make minor refinements and then advance, or (c) make major revisions and undergo another review before advancing. Through these design reviews, students learn to present, assess, and defend their design work before professionals.

Professional performance reviews in capstone courses typically are limited to outcomes specified by ABET student outcomes[3]: teamwork, professional ethics, and lifelong learning. In engineering practice, performance reviews may address issues of personal interactions, professional development, work quality, and work quantity. In many workplaces, peers, supervisor, and subordinates provide input through a 360-degree review of each individual's performance. Professional performance reviews provide individuals valuable information about others' perceptions of their performances as well as opportunities to learn how to: (a) document achievements, (b) assess performances, (c) accept feedback, and (d) plan personal development.

AUTHENTIC ASSESSMENT

For assessment to be authentic, performances must be conducted and observed in contexts that are similar to those in which future performances will occur[5,6]. Therefore, students must be assessed in the context of realistic engineering projects, which are often found in capstone design courses. To match professional practice, most projects should be the responsibility of a team of students with backgrounds suitable for the project, typically requiring multiple engineering disciplines and students or consultants with business and/or social science expertise. Projects should have real stakeholders with whom students interact and some to whom students are accountable. Suitable projects will be constrained by time, finances, safety, legal, social or regulatory requirements, and students' abilities. Students will need to perform independent investigation and gain professional development to complete their project. Projects should offer potential to add significant value to clients, students, and society.

Quality assessment requires that (a) learning targets are clear, (b) purpose is focused, (c) method matches target, (d) sampling is appropriate, and (e) bias and distortion are minimized[7]. For assessment methods to be appropriate for the outcome being assessed, the type of assessment must fit the type of outcome. For example, in the cognitive domain, knowledge is categorized as factual, conceptual, procedural, or metacognitive (see Table 2) [8] . Similarly, social and affective abilities can be categorized.

Table 2. Types of cognitive knowledge development that may be a desired learning outcome

Major Type	Examples
Factual knowledge	Technical vocabulary, elements of a structure, known resources
Conceptual knowledge	Interrelationships among elements that define function
Procedural knowledge	How to do something, methods, criteria for using a process
Metacognitive knowledge	Knowledge of how people think, awareness of one's own thinking

For assessment of outcomes in any category, desired learning may appear at different levels of development. Levels of cognitive knowledge development are summarized in Table 3, with examples.

Table 3. Types of cognitive knowledge development that may be a desired learning outcome

Level of Development	Examples
Remember	Identify, name, list, recall facts or terms
Understand	Describe, illustrate, clarify principles or practices
Apply	Put into practice, execute, use knowledge to achieve an outcome
Analyze	Break into parts, organize, attribute parts in relation to the whole
Evaluate	Check, critique, assess, judge based on criteria
Create	Hypothesize, design, construct from elements a coherent whole

The lowest level, Remember, can be assessed by simple questions that require students to list or recall information. Successively higher levels require more sophisticated assessment methods. For example, assessment of the Apply level requires that students have opportunities to show what they can do with their knowledge in authentic situations. The highest level, Create, requires that students be given the opportunity to create new knowledge based on existing knowledge but requiring synthesis, analysis, and testing or evaluation of their emergent knowledge.

Enable Efficiencies

Assessment is unpopular with most faculty, students, and employers because few feel they receive tangible benefits from the significant effort invested. Faculty perceive extra work in gathering and analyzing data and loss of time that could better be used to achieve course objectives. Students see assessment taking time away from work on the project, and they dislike reviewing peers, resulting in questionable results. Engineering professionals involved in project assessment must sacrifice work time for possible benefits in improved project outcomes and opportunities to observe students in action. For assessment to be valuable to stakeholders, it must deliver accurate measures of student achievement at minimal investment.

Efficient assessment will have the following characteristics:

- Data is gathered as part of normal activities in the capstone course.
- Data processing to obtain useful achievement measures is minimal.
- Individuals learn and gain real value from the assessment process and results.

Assessment Design

Selection of KSAs

Assessment in capstone courses is limited by time and resources, so priority outcomes must be identified. Priority KSAs in engineering graduates were identified by a wide array of industry professionals through the TUEE workshop conducted by ASEE[1]. Workshop participants identified 15 KSAs (listed in Table 4) that are most important in engineering graduates.

Table 4. Priority knowledge, skills, and abilities rated for importance to capstone courses

Knowledge, Skill, or Ability	Importance to Capstone
1. Good communication skills	3.0
2. Physical sciences and engineering science fundamentals	2.0
3. Ability to identify, formulate, and solve engineering problems	3.0
4. Systems integration	2.3
5. Curiosity and persistent desire for continuous learning	1.6
6. Self-drive and motivation	2.3
7. Cultural awareness in the broad sense	1.4
8. Economics and business acumen	2.0
9. High ethical standards, integrity, & global, social, intellectual & technological responsibility	2.7
10. Critical thinking	2.8
11. Willingness to take calculated risks	2.2
12. Ability to prioritize efficiently	2.9
13. Project management	3.0
14. Teamwork skills and ability to function on multidisciplinary teams	3.0
15. Entrepreneurship and intrapreneurship	1.2

Further, a workshop conducted at the 2014 Capstone Design Conference ranked the importance of the 15 KSAs (with 3 = most important) for capstone engineering design courses (as indicated in Table 4) [9]. Results identify four KSAs of top importance to capstone courses: communication, problem solving, project management, and teamwork. Following closely in importance are: ability to prioritize, critical thinking, and ethical standards and responsibility.

Table 5 shows the 15 priority KSAs (ordered by importance to capstone) compared to relevant ABET student outcomes. Based on this information, the most logical set of KSAs to assess in capstone courses includes: communication, problem solving, project management, teamwork, prioritizing, critical thinking, and ethical responsibility. Four of these can directly serve as ABET student outcome assessments. Including less relevant KSAs provides diminishing return on time investment.

Table 5. KSAs compared to ABET student outcomes

TUEE KSA	ABET Student Outcome	Relationship
3.0 Good communication skills	(3g) communicate effectively	Very similar
3.0 Ability to identify, formulate and solve engineering problems	(3e) identify, formulate, solve engineering problems	Identical
3.0 Project management		
3.0 Teamwork skills and ability to function on multidisciplinary teams	(3d) function on multidisciplinary teams	Very similar
2.9 Ability to prioritize efficiently		
2.8 Critical thinking		
2.7 High ethical standards, integrity, and global, social, intellectual & technological responsibility	(3f) understand professional & ethical responsibility	Similar but KSA focuses more on application of knowledge
2.3 Systems integration	(3c) design a system, component or process	Systems integration may be a part of ABET 3c design
2.3 Self-drive and motivation		
2.2 Willingness to take calculated risks		
2.0 Physical science and engineering fundamentals	(3a) use math, science, and engineering	Very similar
2.0 Economics and business acumen		Economics may be a part of ABET 3c design
1.6 Curiosity and persistent desire for continuous learning	(3i) recognize need & engage in lifelong learning	Similar
1.4 Cultural awareness in the broad sense		
1.2 Entrepreneurship and intrapreneurship		

Characterization of KSAs

Assessments for the selected KSAs must be developed to fit the outcomes. Therefore, a first step is a contextualized definition of each priority KSA. Besterfield-Sacre and colleagues created definitions of ABET outcomes at different levels in Bloom's Taxonomy, but these were not specific to the capstone course context[10]. Table 6 presents outcomes definitions for these KSAs, with specific reference to a team-based project context. Table 6 also identifies each KSA as a knowledge, skill, or ability based on its characterization in the TUEE report[1]. Finally, the definition is used to determine how people and the project might be impacted by performance of the outcome in the capstone course. These impacts are useful to suggest types of evidence that might be sought for assessing the outcome's achievement.

Table 6. Outcome definitions for seven priority KSAs in capstone project context

KSA	Outcome Definition	Impacts of Outcome
Communication (skill)	With a communication goal in mind, the student engages and effectively exchanges information about technical and professional subjects with teammates and/or project stakeholders using appropriate oral, written, and graphical means.	*People*: understanding and emotions *Project*: information integrity
Problem Solving (skill)	When encountering a team or project related problem, the student identifies and correctly defines the problem, formulates an effective approach, and produces a viable solution.	*People*: confidence *Project*: progress and viability
Project Management (skill)	When managing a project, the student plans activities, pursues and allocates resources, and guides outcome-focused work to achieve an on-time, within-budget delivery of high-quality products as specified.	*People*: task assignments *Project*: progress, completion, efficiency
Teamwork (ability)	When working on a multidisciplinary team, the student prizes and ensures team success by purposefully building team harmony, member productivity, team synergies, and competently communicated achievements.	*People*: feelings, productivity *Project*: output quantity and quality
Prioritization (skill)	When facing a situation in which prioritization is needed, the student identifies competing demands and relevant factors for prioritization, then makes evaluations to determine those most deserving attention.	*People*: productivity *Project*: focus of attention
Critical Thinking (skill)	When needing to make a critical judgment, the student perceptively states a project-related question and clearly asserts a reasoned conclusion that addresses alternative perspectives, key assumptions, and supporting evidence in context.	*People*: understanding *Project*: defensibility
Ethical Standards and Responsibility (ability)	When facing an issue with ethical or professional dimensions, the student identifies and appropriately applies relevant ethical or professional principles or standards in ways that demonstrate integrity and responsible behavior towards colleagues, clients, and society in general.	*People*: ethics and responsibility *Project*: legal and societal acceptability

ASSESSMENT VENUE

The venue for assessment in capstone courses must be selected carefully to (a) obtain data that best demonstrates individual students' achievements of the outcome, (b) give authenticity to the assessment, and (c) minimize unnecessary work. To identify the best sources of data for an outcome, the 27 workshop participants at the 2014 Capstone Conference were asked to rate a list of common capstone course work products as sites for assessing the 15 priority KSAs[9]. Table 7 shows eleven top scoring work product sites, when ratings were not weighted by the importance of the KSA. Results suggest that the work products that have the greatest potential as assessment sites are the final design (perhaps with a business plan), the problem definition and its process documentation, idea generation documentation, lists of work yet to be done, and a project management review. In each of these cases, an assessment must be crafted to determine individual student achievement of the targeted outcome.

Table 7. Scoring of common capstone work products as possible assessment sites for KSAs

KSA	Problem definition process	Problem definition + solution specs	Idea generation process	List of ideas generated for solution	Analysis for cost, performance, risks	Prioritized list of design work needed	Physical or virtual prototype	Final design fully specified, explained	Business plan	Documentation of teamwork skills	Project management review
Good communications skills	1	1	1					1	1	1	1
Identify, solve engg probs	1		1	1			1	1			
Project management					1	1		1	1		1
Teamwork skills (multidisc)	1	1	1			1		1	1	1	1
Prioritize efficiently	1	1				1		1	1		1
Critical thinking	1		1	1	1		1	1	1		
Ethics, integrity, responsibility		1						1	1	1	1
Sum	**5**	**4**	**4**	**2**	**2**	**3**	**2**	**7**	**6**	**3**	**5**

For authenticity, assessments must correspond to common practices in the engineering workplace that assess either performances of people or their engineering work. The authors propose using two different forms of assessment, one focusing on individual student performances and the other on team project achievements. These two assessment forms, defined below, are scheduled as shown in Figure 1.

(a) *Individual Student Performance Reviews*. Individual students engage in personal performance reviews that address goal setting, performance appraisal, and performance documentation. These exercises develop skills vital to the engineering student for successful teamwork and project completion, as well as personal career development.

(b) *Team Project Achievement Reviews*. Teams engage in formal technical design reviews of work (processes and products) achieved during a designated stage of their design: problem definition, concept selection, and solution realization. Technical design reviews are conducted to identify weaknesses and guide improved designs[4].

(c)

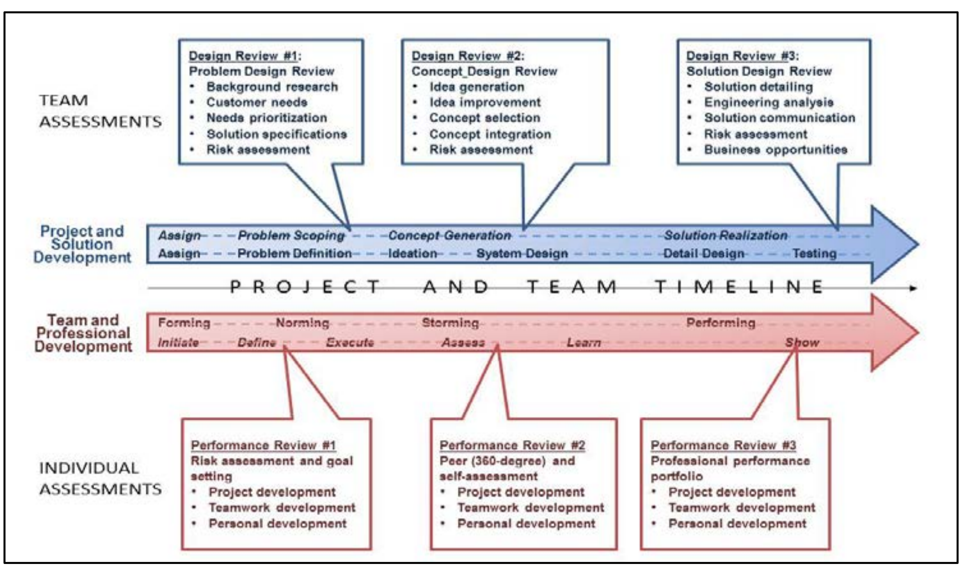

Figure 1. Timeline for performance reviews and design reviews across a capstone project

Illustrative Assessments

This section describes details behind each of the assessments proposed for capstone design courses. A context for the assessment is defined, assessment instructions (assignment) are given, and scoring factors identified.

INDIVIDUAL ASSESSMENTS

PERFORMANCE REVIEW #1: RISK ASSESSMENT AND GOAL SETTING

Context: Students have engaged in their project and worked with their team to understand the challenges they face. Now they need to take responsibility for committing to important goals for the duration of the project.

Assignment: For each of three areas – Project development, Teamwork development, and Personal development

(a) Identify two potential failures and two potential successes, then score each for its importance (H/M/L) and likelihood of occurring (H/M/L).

PROJECT DEVELOPMENT Potential Failure	Importance (H/M/L)	Likelihood (H/M/L)	PROJECT DEVELOPMENT Potential Opportunity	Importance (H/M/L)	Likelihood (H/M/L)
TEAMWORK DEVELOPMENT Potential Failure	Importance (H/M/L)	Likelihood (H/M/L)	TEAMWORK DEVELOPMENT Potential Opportunity	Importance (H/M/L)	Likelihood (H/M/L)
PERSONAL DEVELOPMENT Potential Failure	Importance (H/M/L)	Likelihood (H/M/L)	PERSONAL DEVELOPMENT Potential Opportunity	Importance (H/M/L)	Likelihood (H/M/L)

(b) Define three specific measureable goals (one for each area) that you commit to achieve during the remainder of your team project. Then explain your rationale for these choices and define specific actions you will take to achieve these goals.

PROJECT DEVELOPMENT Goal	Rationale for Goal and Actions to Achieve Goal
TEAMWORK DEVELOPMENT Goal	Rationale for Goal and Actions to Achieve Goal
PERSONAL DEVELOPMENT Goal	Rationale for Goal and Actions to Achieve Goal

Scoring: *Ability to prioritize efficiently*

Performance Review #2: Peer (360) and self-assessment

Context: Students have engaged in a team-based project through nearly half of its duration, after having set performance goals weeks ago. This provides an opportunity for obtaining both peer and self-assessment data with regard to important knowledge, skills, and abilities being used in the project.

Assignment: For each of three areas – Project development, Teamwork development, and Personal development:

(a) Rate each team member (including yourself) on his or her personal demonstrations of the knowledge, skill, or ability listed. Insert team member names at the top of each column and fill all unshaded rows of those columns.

	Team Member Name or Initials						
Knowledge, Skill or Ability							
Project Development							
Engineering problem solving							
Managing work tasks							
Systems integration							
Business value creation							
Responsibility to stakeholders							
Project documentation							
Teamwork Development							
Building team cohesion							
Interpersonal communications							
Doing work with teammates							
Team-centered individual work							
Resolving differences constructively							
Building team member capabilities							
Personal Development							
Self-drive and motivation							
Critical thinking							
Prioritizing							
Taking calculated risks							
Oral communication							
Personal integrity and responsibility							

(b) Write a performance assessment for each member with regard to each area listed: Project development, Teamwork development, and Personal development. For each performance assessment,

i. Identify a strength the person exhibits and explain how this has impacted the team
ii. Identify an area to improve and suggest specific steps to achieve the improvement.

Scoring: Levels of performance for KSAs, communication and critical thinking in written assessments

PERFORMANCE REVIEW #3: PROFESSIONAL PERFORMANCE PORTFOLIO

Context: Students have engaged in a team-based project nearly to the point of completion, after having set personal performance goals and received peer feedback. This assessment invites students to provide information to demonstrate achievement of earlier goals, possibly with help from peer feedback. Student responses and information from teammates provide data for a personal performance portfolio that may be useful for career advancement.

Assignment: For each of three areas – Project development, Teamwork development, and Personal development:

(a) Rate each team member (including yourself) on his or her personal performances of the knowledge, skill, or ability listed. Insert team member names at the top of columns and fill all unshaded cells of those columns.

	Team Member Name or Initials						
Knowledge, Skill or Ability							
PROJECT DEVELOPMENT							
Engineering problem solving							
Managing work tasks							
Systems integration							
Business value creation							
Responsibility to stakeholders							
Project documentation							
TEAMWORK DEVELOPMENT							
Building team cohesion							
Interpersonal communications							
Doing work with teammates							
Team-centered individual work							
Resolving differences constructively							
Building team member capabilities							
PERSONAL DEVELOPMENT							
Self-drive and motivation							
Critical thinking							
Prioritizing							
Taking calculated risks							
Oral communication							
Personal integrity and responsibility							

(b) For each team member (including self),
   i. Write a short summary of his or her most significant contributions to **project** development and its impact on the project's success
   ii. Write a short summary of her or his most significant contributions to **teamwork** development and its impact on the team's success.

(c) Describe your accomplishments of three goals you set for yourself early in the project, one each for project development, team development, and personal development. Specifically: State the goal, describe your steps to proactively achieve the goal, and explain how your goal achievement impacted the project, team, or your personal growth.

Scoring: performance levels of KSAs listed, teamwork, professional growth, project contribution level

TEAM ASSESSMENTS

DESIGN REVIEW #1: PROBLEM DESIGN REVIEW

Context: Students have engaged in a team-based project to the point at which they have researched the project and established a formal definition of the needs and requirements for a valuable solution. This design review is vital to ensure that the problem is well understood and the definition establishes specific requirements that can be used to judge design decisions. This review is conducted at the team level, determining their readiness to proceed to find appropriate solutions.

Assignment: Prove the rigor and quality of your design efforts to this stage of the project.

(a) Give evidence for strong design processes and resulting work products from:
   i. Identifying and prioritizing needs of project stakeholders
   ii. Defining a solution vision statement (need, solution, impact)
   iii. Establishing specifications or requirements for the desired solution

(b) Identify the risks you perceive as you proceed to the next stage of design:
   i. Listing anticipated points of project failure
   ii. Identifying steps to avoid or handle these problems

Scoring: problem definition, team progress, solution potential

DESIGN REVIEW #2: CONCEPT DESIGN REVIEW

Context: Students have engaged in a team-based project to the point at which they have generated solution ideas and selected their "best" solution concept. This design review is vital to ensure that the solution space (possible solutions) has been fully explored, concept selection is based on established requirements, and concept integration is effective. This review is conducted at the team level, determining their readiness to proceed to develop and evaluate a final solution.

Assignment: Prove the rigor and quality of your design efforts to this stage of the project.

(a) Give evidence for strong concept generation processes and resulting work products:
   i. Identifying solution ideas from diverse existing and original ideas
   ii. Selecting ideas that best meet solution requirements
   iii. Integrating ideas into a solution concept shown to best meet solution requirements

(b) Identify the risks you perceive as you proceed to the next stage of design:
   i. Listing anticipated points of project failure
   ii. Identifying steps to avoid or handle these problems

Scoring: concept generation, team progress, solution promise

Design Review #3: Solution Design Review

<u>Context</u>: Students have completed a team-based project in which they produced their final solution and obtained evidence for its satisfaction of requirements. This design review is vital to ensure that the solution is technically credible and meets expectations of stakeholders. This review is conducted at the team level, determining their readiness to move the final solution into additional refinement, testing, or implementation.

<u>Assignment</u>: Prove the rigor and quality of your design efforts to this stage of the project.

(a) Give evidence for strong <u>design</u> <u>processes</u> and resulting <u>work products</u>:
  - i. Analyzing the solution for engineering soundness
  - ii. Detailing and refining the solution to establish its final state
  - iii. Testing and evaluating how well the solution meets solution requirements and its intended uses

(b) Identify the risks you perceive as the solution proceeds to be implemented by others:
  - i. Listing anticipated points of project failure
  - ii. Identifying steps you recommend to avoid or handle these problems

<u>Scoring</u>: solution definition and testing, team progress, solution value

Performance Portfolios

The proposed assessments produce resources that contribute to a professional performance portfolio. Students' responses to assessment questions record their understanding and performances that may be worthy exhibits in a portfolio. In addition, peer and self-assessment ratings, combined with an instructor's rating of the student in KSA performances, provide additional direct measures of the student's contributions. Figure 2 illustrates a sample performance summary that might be generated from the assessments.

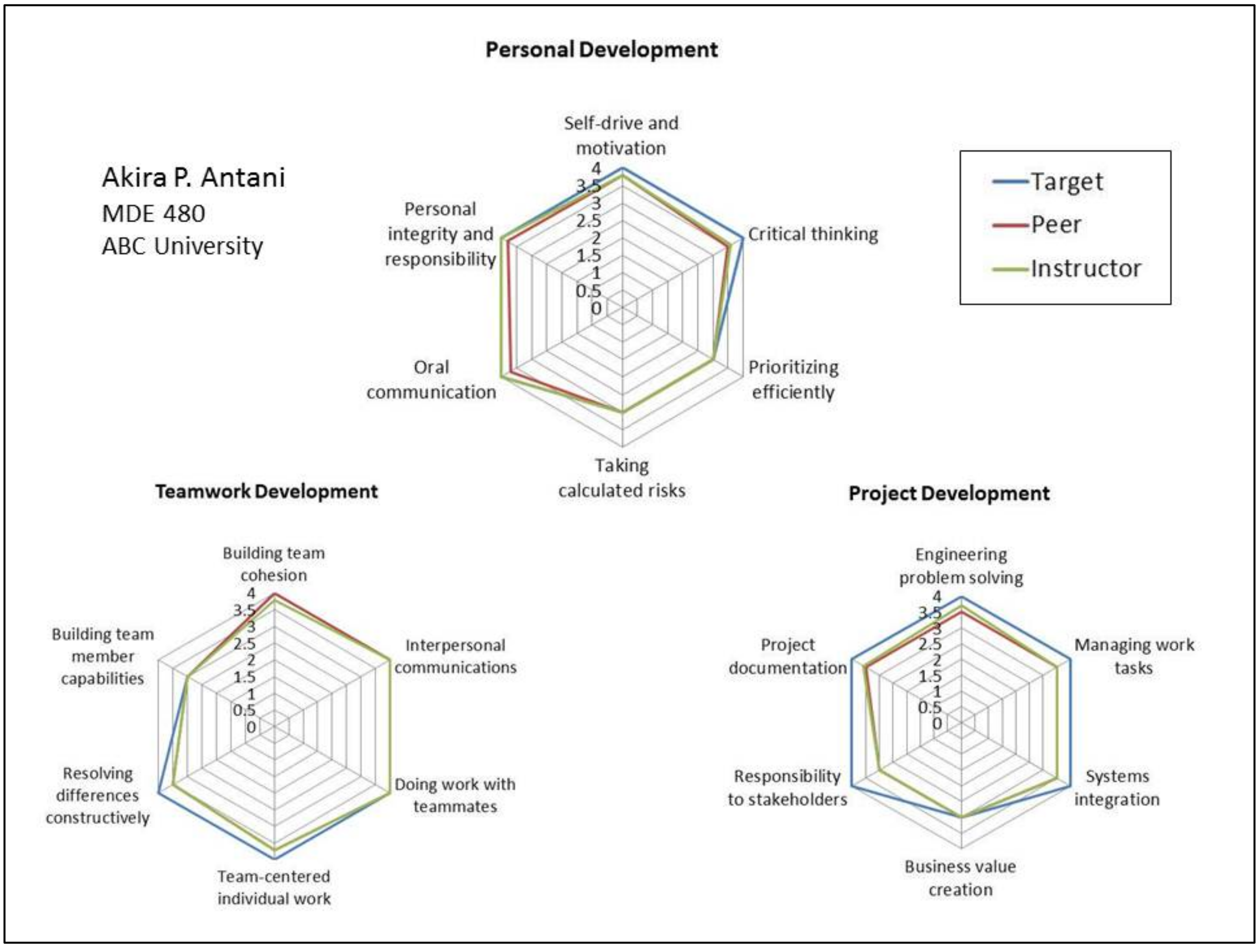

Figure 2. Personal performance summary

Summary

Six assessments were defined to address a set of knowledge, skills, and abilities identified by industry leaders as vital for engineering graduates, and judged relevant to capstone courses by capstone instructors. Configured as professional performance reviews and technical design reviews, the assessments align with common practices in the workplace and fit naturally into capstone design courses at three project milestones: at the end of problem definition, concept selection, and final design development. The performance reviews provide individual student performance data that spans project development, teamwork development, and personal development—all crucial to the capstone course and student preparation for professional life. Because KSA assessments are based on direct evidence of student performances as well as peer and self-assessments of these performances, resulting performance measures can be used with confidence.

The technical design reviews provide critical feedback on the processes and products of the team's design activity. The reviews search for weaknesses that could lead to project failure, and they help students learn how to justify and document their design work. Design reviews help students deliver high quality design solutions in the capstone class and create a skill useful in their professional lives.

The proposed assessments provide students, faculty, and potential employers tangible value that motivates each of their personal investments to ensure that assessments are completed well. Specific items of value include:

FOR STUDENTS

- Students are coached to define and pursue goals that address opportunities and threats to project, team, and personal success.
- Students receive peer feedback on 18 knowledge, skills, or abilities important to their capstone course, guiding them to improved performance in their project work.
- Students learn how to give and receive feedback on their work.

FOR FACULTY

- Faculty have assessments to be administered annually to measure student achievement, useful in benchmarking performance for making program improvements and useful for program accreditation.
- Faculty obtain student performance data on project quality as well as individual student achievements, useful for grading and coaching student performance.
- Faculty see improved student performances as students understand what is expected and respond to feedback that enables them to perform better to expectations.

FOR EMPLOYERS

- Potential employers of students have opportunities to give feedback to students and faculty so that student preparation in valuable KSAs meets employer expectations.
- Potential employers may receive assessment data shared by students interviewing for positions, providing reliable measures of student preparation for engineering careers.

The proposed series of performance reviews and design reviews should be applicable to capstone design courses of different durations and with different preparatory design experiences. If students enter the capstone design course with previous design experiences, they enter into a more advanced level of design that requires rigor in both personal development and design. If they enter with no previous design experience, the three-stages of reviews serve as building blocks to establish understanding of design and professional development before the "final exam" occurs. In either case, students are mentored by the structure of the reviews and the feedback they receive. By the time they engage in the final reviews, they possess the understanding of expectations and personal confidence from practice that lead to high levels of performance.

Everyone benefits from a well-designed set of assessments for KSAs. As these are developed, tested, and adopted, the nation stands to benefit from better prepared graduates from engineering programs.

Future Work

The assessment structure presented in this paper is derived from an overall need for improved effectiveness and efficiency of capstone design course assessment, while considering specific requirements and constraints of individual capstone design classes. The set of proposed assessments seeks to assess achievement and provide feedback for improving students' professional development and design solution development. This model for capstone design assessment requires substantive testing under varied capstone course conditions, instructor skills and motivations, and student characteristics before it can be adopted confidently by engineering programs across the nation for their capstone design courses.

The authors desire to implement the proposed assessment structure in a diverse set of capstone design courses to test its practicality and effectiveness in assessing students' achievements. If implemented in a yearlong capstone design course, three performance reviews and three design reviews would be conducted around natural project milestones of problem definition, concept selection, and final design submittal. The set of assessments would be evaluated with respect to ease of implementation, student performance enhancement, time investment required by students and instructors, ease and reliability of scoring, and value perceived by all stakeholders. The capstone design community is invited to contact the authors to explore opportunities to collaborate in this effort.

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