2006-1444: ASSESSMENT FRAMEWORK FOR CAPSTONE DESIGN COURSES

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Assessment Framework for Capstone Design Courses

Abstract

This paper describes a framework for developing and implementing assessment instruments in capstone engineering design courses. The framework provides a structure for aligning learning outcomes, methods for examining performance related to these outcomes, and providing feedback that improves student learning in these outcome areas. The framework incorporates three different perspectives—that of the educational researcher, the student learner, and the professional practitioner. The paper concludes by highlighting which framework components inform different steps in a methodology currently being used to create sound, broadly-applicable, and efficient assessment instruments for capstone design courses.

Introduction

Engineering design is recognized as a vehicle for cultivating many of the practical skills needed for engineering practice[1]. A number of assessment approaches have been proposed for measuring achievement of engineering design outcomes[2]. Researchers have reported on important educational questions, but their methods are disconnected from practical day-to-day use in the workplace or the design studio[3,4,5,6]. Authors who have explored issues in program assessment have used design journals and student portfolios to assess design team skills as well as attributes of design products[7,8,9]. There are also some assessment tools that are highly student-centered and provide real-time feedback[10]. However, these are not wrapped around long-term project work.

A national survey of capstone engineering design instructors indicates that most use a collection of custom-designed, single-purpose assessments that are not well-integrated with one another and are largely untested for reliability or validity[11]. This led participants in the Transferable Integrated Design Engineering Education (TIDEE) consortium to shift their focus from articulation between 2-year and 4-year programs[12,13,14] to capstone course assessment[15,16]. In 2004, TIDEE received a National Science Foundation grant to develop transferable assessment for capstone engineering design courses. This research project responds to the need for a deeper, richer, more rigorous definition of the knowledge, behaviors, and attitudes that are important to engineering practice.

The assessment framework presented here was informed by a review of published literature on design assessment[2] and input from a ten-member focus group that met twice over the last two years[17]. The focus group brought together diverse perspectives related to engineering practice, engineering design education, and assessment. Disciplines of mechanical engineering, civil and environmental engineering, industrial engineering, bioengineering, and educational assessment were represented in the focus group. Employers included private educational institutions, public universities, minority-serving universities, a major corporation, and the National Academy of Engineering.

Guiding Principles

Ideally, achievement targets in capstone engineering design courses must be meaningful to classroom researchers, to professional practitioners who evaluate engineering programs, and of course to engineering students. Researchers depend on a clearly conceptualized cognitive model that reflects the latest understanding of how learners represent knowledge and develop expertise in the domain[18]. Researchers also expect alignment between the cognitive model and the methods used to observe performance as well as the protocol for interpreting results. Professional practitioners expect to see course outcomes that are responsive to the diverse roles played by an engineering professional[19]. Prominent roles in capstone courses include those of analyst, designer, problem solver, communicator, collaborator, achiever, and self-grower[16]. Students respond best to explicit learning targets that involve authentic challenges connected with knowledge mastery, reasoning proficiency, product realization, and professional expectations[20]. These three perspectives have been synthesized for use by multiple audiences in Figure 1. The next three sections of the paper explore the subcomponents in the three primary regions in the framework—model, observation, and interpretation.

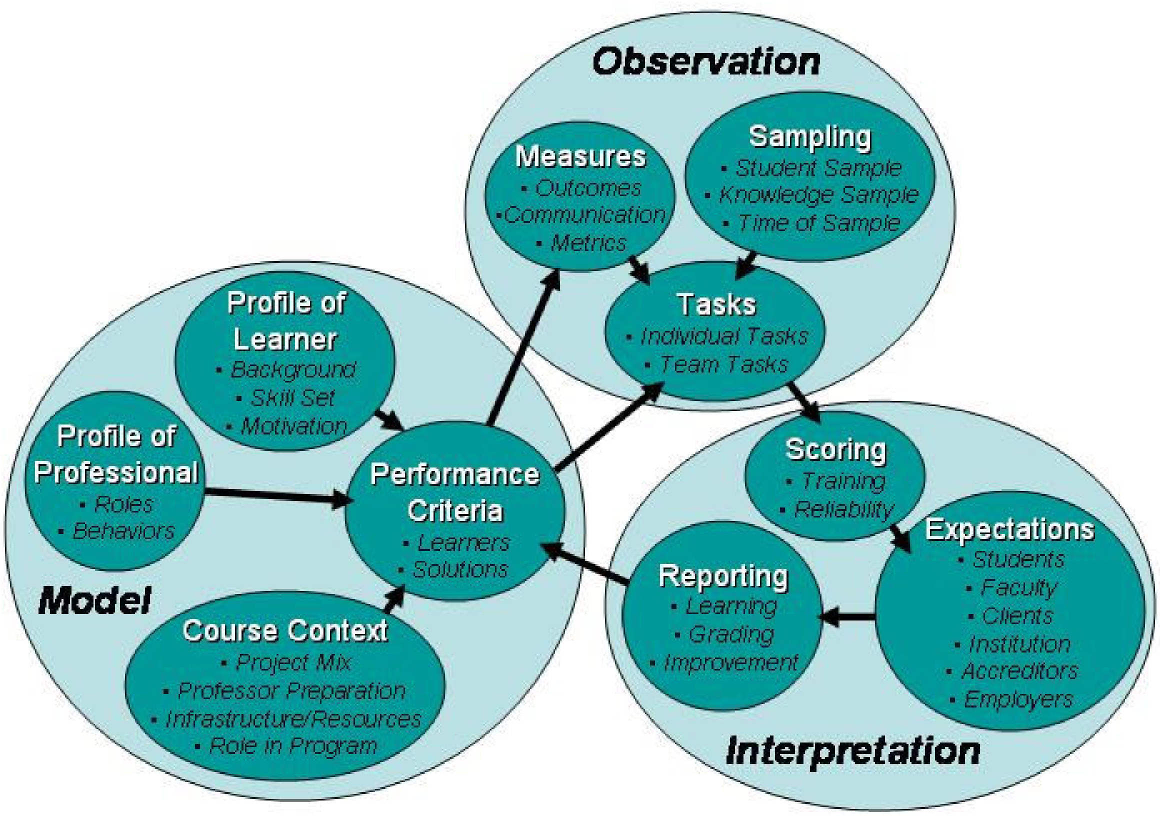

Figure 1. Components of Assessment Framework

The researcher perspective is endorsed by the National Academy of Sciences and requires three elements of the "assessment triangle"[18]. These include a cognitive model that is appropriate for the discipline under study, an appropriate method for conducting performance measurement, and a coherent system for interpreting results. All three elements need to work together to produce sound measurements that in turn shed light on the nature of knowledge construction in the discipline as well as pedagogical approaches that are effective or ineffective. The importance of aligning learning outcomes, measurement methods, and data analysis in engineering education research was underscored by Olds, Moskal, and Miller in their recent article in the *Journal of Engineering Education*[21]. Since integrity in measurement is foundational to classroom research, program evaluation, and assessment for learning, the three large circles evident in the framework are a reminder about the benefits and the requirements of a balanced "assessment triangle".

The professional practitioner perspective reflects the broad array of knowledge, skills, and attitudes expected in the current and future engineering workplace[19]. Because these individuals typically interact with engineering programs through accreditation visits as well as industry advisory boards, it is common to map assessment targets to ABET criteria[22,23,24]. This mindset is both convenient and appealing to faculty who teach design classes that emulate project work found in engineering practice[25]. Efforts to identify and classify professional behaviors for entry-level engineers has prompted much dialogue between academia, industry, and government[15,19,26]. For these reasons, care was taken to embed professional expectations for behavior, rigor in measurement, and alignment with accreditation standards throughout the assessment framework.

The student perspective permeates the K-12 assessment literature. One of the most respected references is that by Stiggins[20] which outlines five attributes of quality assessment which apply to any educational setting. These include: (a) clearly communicated purposes, (b) clear and appropriate targets, (c) target and method matching, (d) appropriate sampling, and (e) elimination of bias and distortion. It is essential that all participants and users of an assessment understand why it is being conducted and how the results will be used. Ideally, students will value the performance criteria as much as their teachers, being motivated to improve future performance based on the feedback they receive. Teachers have a special obligation to choose assessment instruments that match measurement methods to targets that have been mutually agreed upon. Teachers also need to consider uniform administration and frequency of sampling to ensure fairness and reliability across different courses. Finally, latent sources of bias should be identified and eliminated to avoid inaccurate conclusions that could misguide learners.

Model: Conceptualizing Design

Professional Profile – In defining terminal behaviors for capstone design students it is useful to begin with an expert profile that describes the high level performance found in engineering practice. Over the last five years, such a profile has been created through various TIDEE surveys, focus groups, and workshops[11,15,16]. This effort resulted in ten roles shown in Table 1. A set of five complementary professional behaviors has been identified for each role[15].

Table 1: Roles and Holistic Behaviors of an Engineer

Technical Roles	Holistic Technical Behaviors
Analyst	When conducting engineering analysis, the engineer adeptly applies principles and tools of mathematics and science to develop understanding, explore possibilities and produce credible conclusions.
Problem Solver	When facing an engineering problem, the engineer produces solutions that properly address critical issues and assumptions and that are conceptually and contextually valid.
Designer	When facing an engineering design challenge, the engineer develops designs that satisfy stakeholder needs while complying with important implementation, societal, and other constraints.
Researcher	When conducting applied research, the engineer designs and conducts studies that yield defensible results and answer important applicable research questions.
Interpersonal Roles	**Holistic Interpersonal Behaviors**
Communicator	When exchanging information with others, the engineer prepares, delivers, and receives messages that achieve desired outcomes.
Collaborator	When working with others in joint efforts, the engineer supports a diverse, capable team and contributes toward achievement of its collective and individual goals.
Leader	When providing needed leadership, the engineer promotes shared vision to individuals, teams, and organizations and empowers them to achieve their individual and collective goals.
Professional Roles	**Holistic Professional Behaviors**
Self-Grower	Motivated for lifelong success, the engineer plans, self-assesses, and achieves necessary personal growth in knowledge, skills, and attitudes.
Achiever	When given an assignment, the engineer demonstrates initiative, focus, and flexibility to deliver quality results in a timely manner.
Practitioner	Driven by personal and professional values, the engineer demonstrates integrity and responsibility in engineering practice and contributes engineering perspectives in addressing societal issues.

No matter what stage of development an individual is in, expert profiles raise the bar on one's performance. They inspire novices to accept the challenge of purposefully elevating personal skills. They help teachers prioritize, communicate, and facilitate learning outcomes that are aligned with long-term behaviors within the profession/discipline. They remind even the most talented professionals that there are multiple dimensions of professional practice and that ongoing personal development in all dimensions is needed to stay abreast of new knowledge, technology, and ever increasing societal challenges. The engineering profile can be a unifying force in the engineering community, encouraging all members (learners, teachers, and practitioners) to engage in dialogue about their profession/discipline and to walk the talk of continuous self-improvement toward a shared ideal.

Course Context – There are many similarities among capstone design courses in all engineering disciplines[27]. The biggest differences in capstone design courses stem from the types of projects undertaken rather than the disciplines involved[16]. A majority of projects are client sponsored and feature manufacturing methods, test fixtures, or proof-of-concept devices. The remaining projects revolve around competitions sponsored by professional societies, creation of new consumer products, or service to the local community. All project types require students to apply technical skills, (b) use team-based processes, and (c) engage in reflective thinking in addition to creating a high quality product. Assessment activities in capstone design courses, therefore, need to consider both the processes used by designers[3] and the products they deliver to clients[8].

Learner Profile – After selecting the terminal behaviors desired in a course, it is critical to analyze student preparation in prior coursework, decomposing targeted behaviors into subordinate skills and planning needed interventions to systematically cultivate these skills[28]. Hierarchies of cognitive domain[29], social domain[30], and affective domain[31] learning skills found in the *Faculty Guidebook* are a valuable reference in doing this subordinate skill analysis. Any number of learning style inventories can be used to understand differences in student populations within a particular class[32]. Not paying attention to the learner profile can lead to bias and distortion in the use of assessment instruments, potentially alienating a subset of students from the intended benefits of the course.

Performance Criteria - Design performance involves two different types of outcomes: learner development and solution development[17]. Learner and solution development progresses from fragmented understanding and design ideas to a more mature state of integrated understanding and design solutions. It includes: (a) personal capacity, (b) team processes, (c) solution requirements, and (d) solution assets. The first two areas relate to learner development while the latter two relate to solution development. All four areas are defined in Table 2 and performance criteria for each area are defined further in a companion paper[17]. Performance criteria should consider expectations of all stakeholders associated with assessment activities.

Table 2. Performance Areas for Engineering Design

Engineering design draws from nurtured personal abilities and team processes to create valuable solutions that exhibit progressively refined understanding of stakeholder needs and constraints.

Performance Areas:

- **Personal Capacity**: Individuals performing and improving individual skills essential to engineering design
- **Team Processes**: Teams developing and implementing collective processes that support team productivity in design
- **Solution Requirements**: Definition of goal state for design activities and features expected to satisfy stakeholder needs and constraints
- **Solution Assets**: Results from a design project that meet needs and deliver satisfaction as well as value to key project stakeholders

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Observation: Measuring Performance

Measures – High quality assessment or evaluation of any performance depends on accurate and reliable measurements of key performance factors. One can detect low-level understanding by using simple, quantitative tools, such as multiple-choice tests, true-false quizzes, and vocabulary definitions. However, more sophisticated measurement schemes are needed to assess or evaluate systems thinking, procedural knowledge, and attitude formation[33]. This is further complicated in a capstone design course environment where student teams work on different projects for different clients. Rubrics are tools that can help capstone instructors come to legitimate conclusions about the construction of higher-level conceptual knowledge, performance skills, and attitudes. Attributes of a quality rubric include: (a) clear criteria, (b) rich, descriptive language, (c) positive attainment, (d) differentiation of performance, product, and effort, and (e) universal validity and reliability[34]. Taking time to establish a holistic rubric that emphasizes and integrates desired elements specified in the performance criteria is helpful in selecting from among alternative performance tasks. Holistic rubrics that span novice to expert are also helpful in conveying course expectations to students and achieving consensus among project stakeholders on the quality of course outcomes produced.

Tasks – A variety of venues exist for observing student performance in capstone courses—journals, reports, team meeting agendas/minutes, design review presentations, project plans, web pages, proposals, final reports, and reflective essays. However, selecting performance tasks before considering performance criteria can compromise assessment validity as well as waste precious student and faculty time. A goal of the current TIDEE project is to match performance tasks to performance criteria that follow from a conceptualization of engineering design that is appealing to many faculty members across a broad spectrum of disciplines[17].

Sampling – Once performance tasks are selected, decisions need to be made about what factors should be featured (knowledge and skills), who should produce these (individuals versus teams), and when these are optimally deployed. Sampling considerations should be embedded in performance task design and training for these who will administer assessment instruments. Student-centered language should be selected in task instructions. Faculty-centered language should be used in guidelines for administration. Explicit instructions should be given about student preparation, orientation of students, and time allocated for completing tasks. Each of these actions increases the likelihood that assessment results will not be biased against particular learning styles or cultural backgrounds.

Interpretation: Connecting with Stakeholders

Scoring – Scoring rubrics and decision rules should be prepared to assist faculty in analyzing student work. These should align with the intended performance criteria and provide insights how to assign accurate performance ratings against previously determined performance measures. Pilot testing in different class settings and institutions is needed to definitively demonstrate validity and reliability. To the extent that assessment instruments deliver results that stray from their intended target (performance criteria and measures), it is the performance tasks and scoring instructions that should be revised, not the other way around.

Expectations – Many stakeholders are involved in capstone design courses and each stakeholder has different needs. (See Table 3.) For those directly involved in the course, these needs should be inventoried and acknowledged at the start of each course implementation. For those not directly involved, these needs should be reviewed and discussed in a departmental advisory board meeting at least once between ABET accreditation visits. These needs revolve around different types of learning outcomes—competencies, movement/growth, accomplishment, experience, and integrated performance[35].

A competency is a collection of knowledge, skills, and attitudes needed to perform a specific task effectively and efficiently at a defined level. A common question about a competency outcome is: 'what can the learner do at what level in a specific situation?' Movement is documented growth in a transferable process or learning skill. A common question about a movement outcomes is: 'what does increased performance look like?' Accomplishments are significant work products or performances that are externally valued or affirmed by an outside expert. A common question about an accomplishment outcome is: 'how well does student work compare with work products of practitioners in the field?' Experiences are interactions, emotions, responsibilities, and shared memories that clarify one's position in relation to oneself, a community, or discipline. A common question about an experience outcome is: 'how has this experience changed the learner?' Integrated performance is the synthesis of prior knowledge, skills, processes, and attitudes with current learning needs to address a difficult challenge within a strict time frame and set of performance expectations. A common question about integrated performance is: 'how prepared are students to respond to a real-world challenge?' Taken together, the performance areas shown in Table 2 and the performance criteria formulated in the companion paper[17] can answer questions relevant to all five types of outcomes in a capstone course.

Table 3. Capstone Course Stakeholders and Their Needs

Stakeholders Directly Involved	**Needs**
Students	Want deep learning and professional development embedded in an immersive experience; accountability to deliver a result to a client; opportunity to strengthen performance in design; an accomplishment to market to future employers
Course Instructors	Want to mentor in a challenging and complex environment; stay current with industrial practices, technology, and design tools; collaborate with peers; be treated fairly and rewarded for performance
Technical Staff	Want to advance professional skills by consulting on real-world engineering problems; generate resources for expanding design/laboratory infrastructure
Project Advisors	Want effective course infrastructure and support, including well-defined roles, scope of involvement, credit on job evaluation; opportunity to coach students on project management and engineering fundamentals; professional growth for themselves
Clients	Want novel approaches to problems; results with favorable return on investment; visibility among students for recruitment; to contribute to professional growth of students and faculty; to stay involved with their alma mater or another regional institution
Stakeholders Indirectly Involved	**Needs**
Other Instructors	Want first-rate graduates; a program to be proud of; students applying engineering principles; responsible use of resources; ABET data collection point
Administrators	Want inter-disciplinary interaction across departments and colleges; support for recruiting efforts; leadership in ABET process; hub for coordinating student competitions; strengthen industry contacts
Advisory Boards ABET Evaluators	Want engineers who are self-directed; who can solve open-ended problems; who can collaborate effectively; who meet needs of future employers

Reporting – Educators use two distinct assessment processes (formative and summative). Formative assessment provides feedback on knowledge, skills, attitudes, and work products for the purpose of elevating future performances and learning outcomes. Summative assessment determines the level of quality of a performance or outcome and enables decision-making based on the level of quality demonstrated. Formative and summative activities both have their purposes, and when used correctly, both can add significant value to teaching/learning. However, there can be detrimental effects when people involved have not agreed whether the reporting process is formative or summative[36]. Table 4 highlights these differences and underscores the importance of keeping the purpose of an assessment activity in mind when reporting back to stakeholders.

Table 4. Differences between Formative and Summative Assessments

Issue	**Formative Assessments**	**Summative Assessments**
What is the purpose?	To improve quality of future performances	To determine quality of present performance
Who requests it?	Assessee	Client
Who performs?	Assessee	Evaluatee
Who observes the performance?	Assessor	Evaluator
Who sets criteria?	Assessee and Assessor	Client (with possible consultation with evaluator)
Who uses the information?	Assessee (in future performances)	Client (to make decisions)
When can feedback occur?	During or after a performance	During or after a performance
On what is feedback based?	Observations; strongest and weakest points	Level of quality based on a set standard
What is included in the report?	What made the quality of performance strong; how one might improve future performances	The quality of the performance, often compared to set standards
Who receives the report?	Assessee	Client
For what is the report used?	To improve performance	To make judgments

Conclusions

Three user perspectives have been brought together in a framework that supports assessment for learning as well as assessment of learning in capstone design courses. These perspectives include the researcher interested in advancing the understanding of design content and design pedagogy knowledge, the practitioner interested in bolstering skills important to the profession, and the student seeking design learning and professional growth. The framework cements together guiding principles that facilitate defining appropriate assessment targets, collecting sound and relevant performance data, and providing relevant feedback to different capstone course stakeholders.

TIDEE is currently applying the assessment framework presented here to create three instruments that can improve learning, grading, and program evaluation associated with capstone design courses in all engineering disciplines. These include: (a) an instrument for examining growth in personal capacity (knowledge/skills applied in problem solving as well as orientation toward professional development), (b) an instrument for examining design team processes (team dynamics and productivity); and (c) an instrument for examining solution requirements (consideration of stakeholder needs and formalization of specifications). A companion paper provides a case study of progress to date in crafting these instruments[17]. The methodology being used to develop the instruments is outlined in Table 5. Note how different aspects of the capstone course assessment framework add value to different steps in the instrument development methodology. It is interesting to note that while the methodology is linear, the manner in which framework components are invoked is non-linear. To date, our experience has been that an assessment framework and an assessment instrument development methodology are quite complementary, with the framework serving as a quality assurance tool in the execution of each step in the methodology.

Table 5. Relation between TIDEE Methodology and Subcomponents of Framework

Step in Methodology	**Relevant Subcomponents from Framework**
1. Define Area of Performance	Professional Profile, Expectations
2. Understand Performance Expectations	Professional Profile, Learner Profile
3. Extract Performance Factors	Professional Profile, Course Context
4. Articulate Performance Criteria	Performance Criteria, Expectations
5. Distinguish Performance Levels	Performance Criteria, Measures
6. Select Performance Tasks	Performance Criteria, Measures, Tasks
7. Develop Assessment Instrument	Performance Criteria, Tasks, Scoring
8. Plan Administration	Sampling, Scoring, Reporting
9. Analyze Measured Performance	Scoring, Performance Criteria, Measures
10. Report Results	Reporting, Expectations

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