Measuring Learning Outcomes for Engineering Design Education

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Abstract

Foundational to the assessment of engineering degree programs is the definition of learning outcomes for engineering design. This paper presents a framework within which engineering design learning outcomes can be defined and assessed. Learning outcomes related to the engineering design process, teamwork, and design communication are established over a range of performance levels. Tables of performance descriptions define engineering design performance along a continuum of proficiencies from the beginner to the practicing professional. Along this continuum, learning outcomes are proposed for graduating engineers and for engineering students mid-way through their programs of study. Assessment instruments and scoring scales are developed around these learning outcomes. These scoring definitions and assessments provide bases for benchmarking student performance, for developing and scoring assessments of design and for communicating graduates' capabilities to employers and other educators.

Introduction

The adoption of Engineering Criteria 2000 for use in accreditation decisions by the Accreditation Board for Engineering and Technology (ABET) has heightened engineering educators' interest in assessment of student learning outcomes. A cursory review of the eleven required capabilities of graduates listed in Criterion 3 of these criteria[1] reveals that design is an important component of engineering degree programs. Students must be able to perform design and many related aspects of open-ended team-based problem solving, and educators must assess and document students' achievement[2]. Once student achievement of design has been assessed, this information is useful for feedback to both students and faculty to improve student learning of design. Over time, assessment information also can be used to benchmark achievement and to establish targeted performance levels for students in related degree programs.

Concepts of Engineering Design

Definitions of engineering design vary considerably, depending upon the author of the definition. However, design typically encompasses activities between the identification of a technical need and the delivery of a technological artifact to meet that need. In some cases, design includes testing, manufacturing and life-cycle considerations. In many cases, the complexity of design projects requires the formation of teams to produce effective design solutions. Lumsdaine et al. have identified twelve steps as part of the engineering design process[3]. Davis et al. have identified six elements or types of activities that comprise the engineering design process[4]. In all cases, engineering design is described as a process that engages people in creative effort toward producing a design product (item, process, or system) that meets stated requirements. Design is iterative— repeating steps or actions as needed to improve design products.

Assessment requires clear definition of students' capabilities desired at specific points in a curriculum. Rogers and Sando point out that assessment requires an overall goal, objectives or statements defining circumstances that indicate achievement of the goal, and performance indicators stating what students are able to do[5]. ABET requires definition of educational objectives and outcomes for an engineering degree program. For a given degree program, engineering design assessment may appear in a number of different forms, but engineering design outcomes must be defined and their achievement by graduates assessed. In this paper, we define engineering design as a multi-faceted achievement domain, and we use multiple performance indicators to evidence achievement of three different engineering design outcomes.

The goal of engineering design education is to produce graduates prepared to understand and practice engineering design in entry-level engineering positions in successful companies or organizations. Graduates must have knowledge of the processes used in team-based engineering design, and they must be able to perform these (as teams) well enough to produce design deliverables expected by clients. In engineering programs intending to prepare graduates with these capabilities, engineering educators must be able to define, teach, and assess student achievement in the processes used in design.

The Transferable Integrated Design Engineering Education (TIDEE) project has developed design definitions and assessments for the first half of engineering programs, based on input from 2- and 4-year institutions across the nation. These have been used to support design education coordination and assessment within the state of Washington[6, 7]. The project defined three dimensions of the design learning domain that are fundamental to team-based engineering design: (a) design process, (b) teamwork, and (c) design communication. Students must master these three to be successful, so these are the dimensions of engineering design learning outcomes:

> DESIGN PROCESS— Defining, performing, and managing steps to create and deliver a technological product that meets or exceeds needs of clients.
>
> TEAMWORK— Organizing and managing the activities and resources of multiple people to achieve results beyond what can be done individually.
>
> DESIGN COMMUNICATION— Exchanging and managing information needed to support effective design.

Approach to Design Assessment

Assessment begins with the establishment of learning outcomes for these dimensions. Then assessment instruments are developed to fit the established learning outcomes, they are administered and scored, and results are interpreted. We begin with the establishment of learning outcomes for engineering design.

Achievement in engineering design falls along a continuum that stretches from performance of the beginner (e.g., entering freshman without engineering experience) to that of the practicing professional with refined design skills. Such a continuum is presented in Figure 1. Assessment of students' design capabilities is proposed at two locations on this continuum— mid-program and end-of-program points.

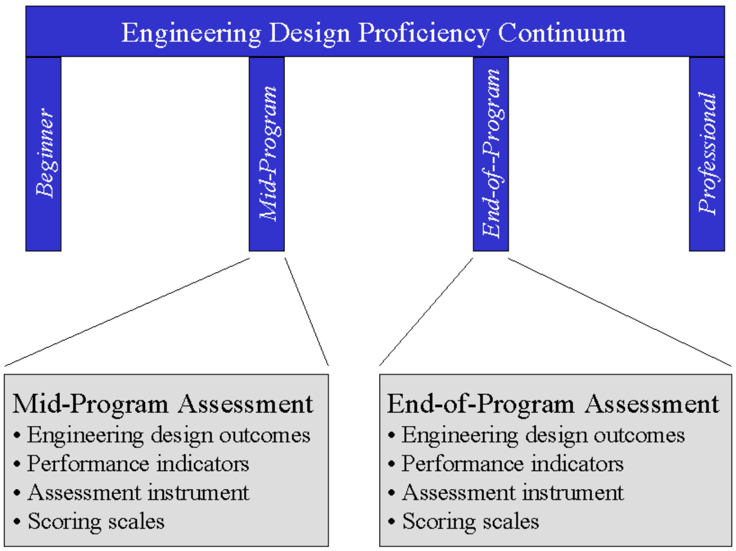

Figure 1. Engineering Design Learning Continuum with Assessment Points Identified

Different proficiencies are found along this continuum. Table 1 presents definitions for design process, teamwork, and design communication proficiencies at the beginner, mid-program, end-of-program, and professional levels. Additional continuum detail for elements under design process, teamwork, and design communication are available from the TIDEE web page[8].

Table 1. Summary Proficiency Continuum for Learning Dimensions in Engineering Design

	Beginner	***Mid-Program***	***BS Graduate***	***Practiced Professional***
DESIGN PROCESS	The design process is not evident or evident only in part. There is no effort to develop or manage a process for design.	The design process is evident. Depth of understanding is seen in parts. The need for iteration is recognized. There is some evidence of time and resource management.	The entire design process is evident and used effectively. Some steps are repeated to improve results. Depth of understanding is seen in several parts of the process. The overall process is managed.	The entire design process is used skillfully, parts repeatedly. The process is planned, recorded, and reviewed regularly. Both processes and products are improved. All design criteria are met or exceeded. Creativity, thorough analysis, and customer understanding are seen.

TEAMWORK	The group does not show coordination or organization to support collective effort. Roles are not assigned. There is no team identity.	Individuals work toward a collective goal. Members understand and perform assigned roles. Member commitment and cooperation are evident. Members seek consensus.	The team organizes and allocates time and resources. Defined procedures and climate support team success. Members accept roles and perform them well, cooperate, and work for consensus and team success.	The team has a clear focus and is structured for responsibility, empowerment and accountability. Members perform roles well, show strong team commitment, interact effectively. Team identity, climate, rewards, and structured activities enhance team and member performance.
DESIGN COMMUNICATION	Information generally is not available, reliable, understandable or useful.	Information is of value but not as complete and useful as desired. It lacks some technical accuracy, refinement, reliability and availability.	Information is valuable, understandable, technically correct and available to users. Its reliability is stated. Grammar is correct. It is kept from unauthorized users.	Information is recorded and transmitted accurately and conveniently to/from users. Uncertainties are documented. Presentation is professional, without technical or language errors. Information is secure and supports design excellence.

The two assessment points shown in Figure 1 were selected because of their importance to program assessment and improvement. The one at baccalaureate degree completion (graduation) is selected because it is crucial to engineering program assessment (as for ABET accreditation). The one at the mid-program point (e.g., completion of first two years of an engineering program) is important to support effective transfer of students from two-year and pre-engineering programs into baccalaureate degree programs.

At these assessment points, assessments are developed to obtain performance information, and scoring scales are developed to match the assessments. The following sections describe assessments and scoring scales for these two points.

Mid-Program Assessment

A “Mid-Program Assessment for Team-Based Engineering Design,” used on a pilot basis since 1998, has provided a three-component assessment instrument and five-point scoring scale for design assessment[9]. Version 2 of this assessment uses revised assessment questions and revised scoring scales. Version 2 scoring has a five-point scale stretching from outcomes of the beginner to those at the mid-program point, thereby indicating that students "have reached the goal" (score of 5) or providing a quantitative indicator of their deficiencies (scores from 1 to 4). This scale definition provides resolution useful for directing educational improvement, yet it does not have so many scale divisions that scorer agreement cannot be obtained.

The version 2 mid-program assessment includes a short-answer quiz that addresses students' foundational knowledge about the design process, teamwork and design communication. Additionally, a group activity engages students in a team design activity and produces worksheets that report team roles, the design process used, design requirements, and the design product. A reflective essay provides more information on the team's design process and communication performance and on member understanding of teamwork and communication processes.

Table 2 presents an example to illustrate the framework for the mid-program assessment. (Additional detail is found on the TIDEE web page). Note the relationships among performance indicators, assessment questions, and scoring. There are five performance indicators for the design communication outcome: organization, reliability, relevance, listening, and availability. The assessment questions elicit information about how design communication should occur and how it did occur in a team exercise. Scoring definitions distinguish among different extents to which the performance indicators are evident in the students' quiz and essay responses.

Table 2. Assessing Mid-Program Design Communication

Performance Indicators	At the mid-program level, students participating in the mid-program assessment are able to communicate effectively with team members and with those who read their assessment materials. Performance indicators include: a. *Organization*— Students organize information in their worksheets and essays to make it understandable. b. *Reliability*— Students provide responses to questions that fully address the question or instructions given them. c. *Relevance*— Students present answers and write their essays using language, grammar and format acceptable to the reader. d. *Listening*— Students listen to team members and respond in ways that enhance their communication. e. *Availability*— Students share ideas, knowledge and recorded information with team members.
Assessment Evidence	Quiz Question: In team-based design, documentation and exchange of design information are important. List features that constitute effective **communication** in a team design effort. Essay Question: For team **communication**, describe the ways your team managed information and communicated among team members. Describe any communication qualities that enhanced member understanding and team performance.
Scoring Scale	1: Students provide information that as a whole is not correct, not understandable, or not useful to assess their design understanding. Their usage of design terminology and grammar is poor. Their answers to questions are inadequate. They don't listen to team members. 3: Students provide information that is generally understandable, but it is of limited value in assessing their understanding of design. Their usage of design terminology and grammar is fair. Their organization of information is satisfactory. Their responses to questions are moderately adequate. They listen somewhat passively. 5: Students provide information that is clear and understandable and it contains detail needed to show their understanding of design. They use design terminology and grammar relatively well. They organize information to be understandable. They provide sufficient answers to questions. They listen carefully.

A similar approach is used to establish learning outcomes and to define scoring scales for student achievement of learning outcomes for design process and teamwork. (If more focused feedback is desired, scorers may assign a separate score for each of the performance indicators under design process, teamwork, and design communication). In this manner, student achievement of engineering design learning outcomes is measured, providing a basis for program improvements prior to the mid-program point in engineering programs.

End-of-Program Assessment

Assessment of student achievement of end-of-program engineering design learning outcomes requires similar definition of learning outcomes, assessment instruments, and scoring scales. The higher-level performance expectations for graduating seniors require an extensive design exercise from which to obtain evidence of their design capabilities. In accredited engineering degree programs, students' capstone design experience provides this exercise. Thus, the capstone design project becomes part of the assessment process for end-of-program design assessment. If it is a team-based design project, it fits the assessment framework described here.

We begin by defining design learning outcomes at the end of the baccalaureate degree program. Table 3 presents information for the design communication learning outcome, which has five performance indicators: organization, reliability, relevance, listening, and availability. Next, we define a list of design project evidence that relates to the design communication outcome. Then we construct a scoring scale for this evidence to distinguish levels of achievement reaching to the established end-of-program outcome. The scoring scale defines a score of 5 for the desired outcome and lower scores for lesser achievement, reaching downward to the minimum achievement anticipated.

Table 3. Assessing End-of-Program Design Communication

Performance Indicator	Students in a capstone engineering design project at the end of their engineering degree program are able to communicate effectively with team members and clients and manage information to support their design goals. Performance indicators include: a. *Organization*— Students organize their team records, progress reports, and final oral and written project reports so that the components and whole are understandable. b. *Reliability*— Students record and report project information that is complete and accurate, and sources and uncertainties are documented. c. *Relevance*— Students report project information using format, terminology and presentation quality expected by the intended audience. d. *Listening*— Students actively listen to clients and teammates and respond in ways that enhance communication. e. *Availability*— Students make project information available to those needing it and keep it from unauthorized users.
Assessment Evidence	<u>Project Records</u>: Project information filed or posted for use by the design team. <u>Progress Reports</u>: Weekly reporting of progress, plans, and target dates. <u>Oral Report</u>: Oral team project report to "sell" the design product. <u>Written Report</u>: Final design project report, including detail design and marketing issues.
Scoring Scale	1: Students provide information that has questionable reliability and some is not understandable; it is not complete enough to assess the quality of their design process or design products. Information is not readily available to those needing it. Students' usage of design terminology and technical terms has substantive errors. Their grammar or organization or presentation format detracts from the message. Students are unskilled at speaking to an audience and in answering questions. Students don't adequately follow instructions. They listen inattentively to clients or to team members. 3: Students provide information that is generally understandable and it includes detail necessary to understand their design process and design products. They make information available to others upon request. Students use design terminology and technical terms with few errors. Their grammar, use of the language, and presentation format are acceptable. They organize information well enough to communicate structure of the information. They speak plainly to audiences and respond reasonably to questions. They give attention to what is said by clients and team members. 5: Students provide information that is clear and very understandable; it includes detail needed to understand their design process and design products. They make information available to authorized users on a systematic, ongoing basis. They document uncertainties and sources of information. They use design terminology and technical terms correctly. Their grammar, use of language, and presentation format enhance their communication. Their organization of information supports understanding of the whole and its parts, and it aids in finding needed information. Students present their project articulately to an audience and answer questions effectively. They listen carefully to understand clients and team members.

Comparable performance indicators, lists of evidence, and scoring scales are defined for end-of-program teamwork and the design process outcomes. Together the design process, teamwork, and design communication outcomes establish a basis for assessing students' achievement of engineering design learning outcomes relative to end-of-program expectations for them.

Summary

We have presented a framework and tools to assess student achievement of team-based engineering design learning outcomes at two points in engineering curricula—mid-program and end-of-program. These are based on the establishment of learning outcomes at these two points, then defining performance indicators, lists of evidence, and scoring scales. Additional information on TIDEE engineering design assessments and scoring is found on the TIDEE web page at: www.cea.wsu.edu/TIDEE/.

These definitions and assessment instruments provide a means for measuring achievement under consistent conditions and with established definitions for scoring. By adopting this framework and these assessment tools, engineering educators will be able to obtain reliable assessment results, establish benchmarks for performance, and systematically improve engineering design education.

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