Mid-Program Assessment and Classroom Improvement of Engineering Students in Engineering Design

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Abstract: *Through the TIDEE (Transferable Integrated Design Engineering Education) project, assessment tools and performance criteria have been developed to quantify student achievement in the engineering design process, teamwork skills, and design communication skills. A seven-point scale describes performance levels spanning from entering engineering students to professional design engineers.*

Mid-program assessment tools were used to assess student achievement of engineering design capabilities during introductory classes in engineering design. Assessment results describe the level of a typical entering student's knowledge and performance in engineering design. These results also indicate that students can reach engineering design achievement targets set for the mid-point of an engineering degree program when the preparatory learning environment is a well-structured outcomes-based design curriculum.

During the past few years engineering faculty have created many new introductory and intermediate engineering design courses. How can we assess the effectiveness of these new approaches? Do courses develop the skills needed by the engineering profession and employers in the twenty-first century? Can these courses help programs satisfy ABET Engineering Criteria 2000?

Participants in the Transferable Integrated Design Engineering Education (TIDEE) project have developed assessment materials that can be used to measure student skills, knowledge, and attitudes in engineering design. Classroom experiences and faculty workshops have contributed to the development and refinement of assessment tools suitable for use in early parts of engineering degree programs. These provide the basis for curriculum refinement to enhance student learning of design.

I. Background of TIDEE

The TIDEE project, with support from the National Science Foundation and leadership from the University of Washington, Washington State University, Tacoma Community College, and the Washington Council for Engineering and Related Technical Education (WCERTE), has been a four-year effort to improve design education in the State of Washington. [1] TIDEE project participants have produced introductory engineering design curriculum that develops understanding of the engineering design process, teamwork, and design communication skills. [2,3,4,5]

TIDEE project leaders have used and modeled the engineering design process and/or assessments in more than thirty-five workshops. Thus, TIDEE curriculum and assessment materials have experienced a form of peer review. [8,9]

II. An Introduction to Design Class

A three-credit Introduction to Engineering Design class at Tacoma Community College (TCC) has been developed using the TIDEE model for engineering design education. This class, offered during the fall and winter quarters, is used to achieve students' engineering design competencies and to assess their achievement of design competencies relative to those desired at the end of the first two years of engineering program curricula. The class typically is comprised of about thirty students between fourteen and forty years of age.

Students in the class participate on two different teams, one team in each half of the quarter. Teams have four to six members each. The class meets an hour and a half twice each week using highly-structured activities that focus on developing students' design process skills more than on creating design products.

The two halves of the class term are similar. After teams are formed, a team identity is created, activities are introduced to improve interpersonal communication skills, a short design project is completed, and a longer more complex team design project follows. During the second half of the quarter, emphasis is placed on developing project management skills and on understanding manufacturing processes. [7]

III. Assessment Methods

The TIDEE project has developed assessment methods to determine students' design capabilities prior to or at the mid-point in an engineering degree program. [11] Four different assessment methods have been used:

- Short-answer exam
- Team design assignment
- Reflective paper
- Self-assessment

The short-answer exam, measures students' basic knowledge about the design process, teamwork, and design communication. The team design assignment and reflective paper, linked in their administration, provide information about students' abilities to apply and critique their capabilities in design. The student self-assessment provides a second measure of students' performance and reveals their awareness of learning they have achieved. This paper presents results from use of the team design assignment, reflective paper, and self-assessment methods to determine students' learning of targeted engineering design capabilities.

Team Design and Reflective Paper

Team design assignments and reflective papers have been used at both the beginning and end of the term. This provides a measure of students' initial knowledge and their final knowledge, the difference indicating their learning of design in the introductory design course.

For the team design assignment, student teams are asked to create a testing procedure to determine how well an instructor-selected hand tool meets the most important requirements of prospective customers. Students are told to use the engineering design process, teamwork, and design communication in this assignment and to document their processes.

Three- or four-person teams are assigned for the 45-minute design assignment. Each person receives a set of handouts that defines their assignment, describes tasks, and specifies deliverables. This material includes "a design journal" with spaces to record steps taken in the team's design process and to record and describe team members' roles and responsibilities for this assignment. One design journal is submitted per team.

Each team receives a hand tool with its packaging material, for which a testing procedure is to be defined. Typical tools selected are garden pruning shears, a multi-pattern water sprinkler, a glasscutter, and pet nail trimmer with extra blades and antiseptic.

After completing the design assignment, students are asked to write (individually) a reflective paper about their design effort. Information provided them identifies five elements in the design process they should address. They are to describe specific actions their team employed that fell within each element of the design process and to tell how their team achieved quality results. They are to identify responsibilities of each team member, describe how they performed and how the members contributed to the performance of the team. Finally they are to describe how information was managed and communicated, and how this enhanced team understanding and performance. The full assessment instrument is found in reference [12].

Students are told they will be graded on how well they write their paper. This provides an incentive for them to take the task seriously. Results of the assessment are shared with students so they understand their strengths, areas needing improvement, and what they need to do to reach targeted performance levels for the mid-point in their engineering program.

Prior to scoring, students' reflective papers are randomly ordered, mixing papers from different time periods to minimize scoring bias. Then trained TIDEE team members work in pairs or larger groups to score each paper. Each evaluator independently determines a score for the student's performance in the design process, teamwork, and design communication. Scores are then discussed and a consensus reached for each score. Results are recorded as integer values. At times, when it is impossible for evaluators to score papers at the same location, each evaluates the paper independently, and scores are averaged.

Self Assessment

Students' perceptions of their design capabilities are an important part of design education and design assessment. Beginning in the fall quarter of 1995, all students at TCC in the introductory design class have been given a self-assessment to measure their perceived growth in design capabilities. The self-assessment is based upon TIDEE competencies for engineering design that were developed in 1995. [1] The categories used in the self-assessment include:

- Information Gathering
- Problem Definition
- Idea Generation
- Evaluation and Decision Making
- Implementation
- Teamwork
- Communication

Each of these categories contains multiple definable competencies. For example, competencies within the teamwork category are described in Figure 1.

__ Individuals understand their own and other members' styles of thinking and how they affect teamwork.
__ Individuals understand the different roles included in effective teamwork and responsibilities of each role.
__ Individuals use effective group communication skills: listening, speaking, visual communication.
__ Individuals cooperate to support effective teamwork.

Figure 1: TIDEE Teamwork Competencies in 1995

In the self-assessment, students are asked to assess change in their performance during a specified period of time by deciding whether they:

(a) Made significant progress
(b) Worked on the competency without much change
(c) Didn't work on the competency during the specified time period

Over the past several years, the design self-assessment has been administered to eight different classes taught by two different instructors at TCC. Students are asked to assess their learning for the first half of the term and again for the second half of the term.

IV. Performance Categories and Scale

Subsequent to 1995, design educational outcomes have been refined to further clarify design competencies and desired student achievement levels. Based on input from workshop participants, advisory panel members, and other contacts, TIDEE project leaders have defined three design categories: design process, teamwork and design communication. Multiple subcategories defined under each design category are defined in the following sections.

Design Process Category

INFORMATION GATHERING: Information identified and obtained to support design process and design decisions
PROBLEM DEFINITION: Development of design goals and specific requirements that will ensure a successful design
IDEA GENERATION: Gathering and creating new ideas and concepts for consideration in development of a design
EVALUATION: Using appropriate methods and tools to determine how well concepts meet requirements
DECISION MAKING: Making design decisions based on proper consideration of evidence and issues
IMPLEMENTATION: Advancing design decisions toward delivery of design products desired by clients
PROCESS DEVELOPMENT: Management of design activities to support effectiveness and improvement

Teamwork Category

PURPOSE AND GOALS: Defining and maintaining clear focus for team's efforts
ROLES AND RESPONSIBILITIES: Establishing and performing responsibilities assigned to team members
TEAM ATTITUDE: Creating and maintaining a supportive team climate
PLANNING: Allocating and utilizing time for tasks and for overall team effort
RESOURCE MANAGEMENT: Accessing, allocating, and utilizing team resources to achieve goals
OPERATING PROCEDURES: Establishing and utilizing processes to ensure effective team interactions and productivity
REWARDS: Defining and implementing incentives and rewards for team and individual achievement

Design Communication Category

ORGANIZATION AND STRUCTURE: Organizing information for understanding and clarity
ACCURACY AND RELIABILITY: Ensuring and documenting completeness and accuracy of information
STYLE AND LANGUAGE: Presenting information in language and style understandable by target audience
LISTENING: Receiving and processing information actively to ensure understanding
VALUE: Communicating information elements that add value to recipients
AVAILABILITY: Ensuring proper balance between information availability and security

Performance criteria are defined for engineering design categories and subcategories using a seven-point scale. This scale is defined for scores of 1, 3, 5 and 7 to represent performance expected of entering freshmen, entering juniors, new engineering graduates, and professional design engineers, respectively. Performance scales for the design process, teamwork, and communication categories are presented in the appendix. Performance criteria for the subcategories (too long to include in this paper) can be viewed at the TIDEE web site. [11]

V. Reflective Paper Assessment Results

Students' reflective paper assessment scores are discussed separately for the first administration (pre) in a term at TCC and for the second administration (post) in the same term. The first administration occurred at the beginning of the winter quarter 1999, and the second at the end of the eighth week. Students' reflective papers received scores for each design category and subcategory. Class averages of these scores are presented in Table 1.

Pre-Assessment Results

Students' pre-assessment scores were at the "one" or "two" level in most subcategories for the engineering design process. The typical class average for any subcategory was about 1.5. Occasionally a student achieved a "three" for a single subcategory.

In the information gathering subcategory, students as a group exhibited strong skills; here they averaged about one point higher than for most other subcategories. Several students received a score of "four," which suggests that high schools do a reasonable job of developing information gathering skills. However, results show that students were less prepared to evaluate or rank the importance of information they obtained (evaluation) or to make decisions based on this information (decision making).

Even though many students had past team experiences, their scores in the teamwork category were not as high as their performance in the design process. Excitement students exhibited during the design activity contributed to a relatively high score in team attitude.

Table 1: Assessment Results for Reflective Papers

Category	Pre	Post	Delta
Overall Design Process	1.4	2.5	1.1
Information Gathering	2.4	3.7	1.3
Problem Definition	1.5	2.8	1.3
Idea Generation	1.7	2.7	1.0
Evaluation	1.7	2.4	0.7
Decision Making	1.3	2.0	0.7
Implementation	1.5	2.3	0.8
Process Development	1.4	2.5	1.1
Overall Teamwork	1.5	2.4	0.9
Purpose and Goals	1.5	2.1	0.6
Roles and Responsibilities	1.2	2.8	1.6
Team Attitude	3.0	3.5	0.5
Planning	1.2	1.5	0.3
Resource Management	1.8	2.3	0.5
Operating Procedures	1.4	2.0	0.6
Rewards	1.2	1.3	0.1
Overall Communication	2.3	2.9	0.6
Organization and Structure	2.8	2.7	-0.1
Accuracy and Reliability	2.2	2.8	0.6
Style and Language	2.3	2.9	0.6
Listening	2.5	2.6	0.1
Value	1.7	3.0	1.3
Availability	2.4	3.0	0.6

In the communication subcategories, scores averaged in the low to mid "twos." The students demonstrated reasonable written skills. This reflected writing skills that students had gained elsewhere in school or work.

Post-Assessment Results

Students achieved higher performance scores in their second assessment (post-assessment). This increase was observed in the design process, teamwork, and communication categories.

During the quarter, students typically increased their scores one unit in the design process category. Even information gathering skills showed this amount of improvement.

In the teamwork category, students' largest gains were in the roles and responsibilities subcategory, an increase of 1.6 units. This probably related to the fact that, during prior team experiences (inside and outside of class), students typically were unassisted in developing their team skills. By contrast, the class spent much time developing functional roles and teaming skills.

Students showed least improvement in subcategories related to team management, such as purpose and goals, planning, operating procedures, and resource management. They improved their performance in these subcategories, but only slightly more than half a unit. The subcategory of rewards showed little improvement and remained quite low. To more effectively assess students' performance in these subcategories, a longer-duration design assignment is needed.

Students' written communication skills gained about a half point during the quarter, particularly in the accuracy and reliability and the style and language subcategories. By the end of the quarter, students also understood more clearly the importance of making design information readily available to all team members for effective design. They showed large improvements in the value subcategory, indicating their ability to contribute useful information to the design process or the topic being communicated.

The pre and post assessment results imply that students remain at the same design performance level until they are taught principles and processes important to design. Older students gain some design skills through their "working-world experiences," but not enough to reach the mid-program target score of 3. This indicates the importance of quality design education in engineering degree programs from the beginning to the end of the curriculum.

VI. Student Self-Assessment Results

Results from student self-assessments are discussed in terms of the numbers of students selecting each of the three descriptors for their learning during the specified period.

Every student checked at least one box to indicate significant improvement in developing a design competency. As a group, students perceived that the area of greatest improvement was in teamwork. Sixty-nine percent of students responding said they had improved significantly in teamwork during the first half of the quarter. An unanticipated result was that this percentage increased to 75% for the second half of the quarter. This pattern repeated itself for all other categories. The lowest significant improvement percentage for any competency was about 60%.

At the end of the quarter, student teams were allowed to comment on their performance. At this time, team members explained how their learning differed between the two halves of the quarter. They indicated that during the first half they were learning how to function as a team and trying to understand the design process. In the second half they were learning to apply this knowledge. Both are valuable learning experiences that need to be scheduled into the class structure if students are to develop effective design skills.

Although self-assessment provides valuable information about students' progress, assessment by an experienced person is necessary to determine a measure of students' performance relative to specific targets. Students, especially at freshman and sophomore levels, have inadequate knowledge of design to make accurate judgments of design performance.

VII. Conclusions

Several important conclusions can be drawn.

1. The TIDEE reflective paper assessment can consistently reveal student progress in engineering design, identify strengths and areas where improvement is needed, and form a foundation from which strategies can be developed to meet end-of-program design outcomes.
2. A quarter-long class with a well-structured process for engineering design education can produce measurable gains in students' skills and knowledge in engineering design.
3. Students may need more than one introductory course in engineering design to achieve design capabilities targeted for the mid-program point in engineering degree programs.
4. Assessment data for entering engineering students provides information useful for developing effective introductory design education for these students.
5. Self-assessment data indicate that first-year engineering students can recognize their growth in design capabilities, but they are not able to accurately score their performance relative to specific targeted design capabilities.

TIDEE design performance criteria and scoring scales have proven useful for scoring student performance in engineering design. Agreement among scores of different evaluators indicates the validity of these scales for defining student achievement. Scale definitions referenced to mid-program (score = 3) and end-of-program points (score = 5) in engineering curricula provide a basis for establishing benchmarks and for comparing program effectiveness for design education over time. These serve as references from which institutions can define appropriate engineering design outcomes and document their program success to support accreditation under ABET Engineering Criteria 2000.

Assessing students' capabilities early in their engineering curricula can provide timely information so that curriculum may be adjusted before students graduate. Because the TIDEE mid-program assessments are not designed to measure performance at the top of the scoring scales, (scores greater than five), TIDEE personnel are developing a more extensive design assessment for end-of-program assessments that use the same scoring scales.

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Appendix

SCORE	DESIGN PROCESS	TEAMWORK	COMMUNICATION
7 **(Professional Design Engineers)**	All elements used skillfully, repeatedly, revised; depth of understanding in all parts; customer requirements fully met; process managed and improved. Most subcategory scores around 6; some at 7; none below 5.	Team structured for responsibility and performance; members empowered for team success; clear team focus; strong member commitment; member interactions highly refined; team and member successes rewarded. Score of 7 in many subcategories; none below 5.	Professional quality recording, transfer, presentation of information; information supports design excellence; reliability and security ensured. Scores 5 or above for all subcategories; several scores of 7; most around 6; none below 5.
5 **(End of Program)**	All elements demonstrate evidence of depth, some are repeated; process managed; quality design completed; requirements met. Most subcategory scores around 5; none below 3.	Team organized, allocates time and resources; procedures and climate support success; members committed, perform roles for team success. Score of 5 in many subcategories; none below 3.	Information of quality and usefulness; exhibits positive attributes in most subcategories, some score quite high. Most scores around 5; none at 1; some above 5.
3 **(Mid Program)**	Elements demonstrate evidence of depth; design completed; some management of effort. Scores of 3 in most subcategories.	Basic productive attributes seen in most subcategories; members understand, perform roles; commitment and cooperation evident. Score of 3 in most subcategories.	Information of value but not as complete and useful as desired; some subcategories need improvement. Most scores around 3; few scores of 1 or above 3.
1 **(Entering Student)**	Elements have little focus or understanding. Scores of 1 in most subcategories.	Many teamwork subcategories inadequately executed; roles ineffective or sporadically used. Score of 1 in most subcategories.	Information not reliable, not understandable, or not useful. Scores of 1 in most subcategories.

Table 2: Performance Criteria for the Overall Scores in the Design Process, Teamwork and Communication Skills