A Model for Transferable Integrated Design Engineering Education

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Abstract

Historically, the teaching of engineering design has varied widely, depending heavily on the design instructor. In many cases, educational outcomes cited for engineering design have focused on quality of design products and neglected the professional skills necessary for design. Recent pressures from employers of engineering graduates and accrediting agencies for engineering programs are directing increased attention to design and professional skill development. As a result, engineering educators are seeking to understand engineering design and to implement improved practices for teaching, learning, and assessing of engineering design.

The Transferable Integrated Design Engineering Education (TIDEE) project, with funding from the National Science Foundation (NSF EEC9973034), has collaborated with engineers and educators across the Pacific Northwest and the United States to make design education more effective and transferable across disciplines and institutions. This paper presents results of this work and subsequent impacts on engineering education, including:

1. Collaboration among an interdisciplinary community of engineering design educators committed to achieving measurable improvements in the readiness of graduates for team-based design in the modern workplace
2. Definitions of student learning outcomes for engineering design, based on broad constituency input, that guide engineering design curriculum development across an entire degree program
3. A framework for organizing and implementing engineering design instruction that develops students' capabilities in the use of the engineering design process, teamwork, communication, and higher-level professional skills required in engineering practice
4. An assessment and evaluation system that supports classroom assessments for improved student learning and evaluations of student achievement for program assessment and accreditation.

Background and Need

Prior to the 1990s, engineering education remained essentially unchanged for decades, with emphasis on the science of engineering (as opposed to design) and classrooms featuring teacher-centered (as opposed to student-centered) instruction. Engineering education reform in the 90s gave increased attention to making freshmen engineering courses more attractive to traditionally underrepresented students in engineering[1]. New and revised courses emphasized student teams, active learning exercises, and increased student involvement in engineering design. At the same time, employers of engineers voiced concerns about graduates' preparation in professional skills such as teamwork, communication, social awareness, ethics, and business[2]. This encouraged the Accreditation Board for Engineering and Technology (ABET) to adopt outcomes-based Engineering Criteria[3] that became mandatory in 2001. These criteria require engineering programs to give evidence that graduates are able to design to meet a need, work in teams, communicate, and consider several broad constraints in design projects.

Outcomes-based accreditation has presented great challenges and opportunities for engineering design faculty. First, faculty traditionally have held widely varied definitions of design and differing expectations about products of students' design activities in their classes, resulting in a lack of models or standards to follow. Also, for engineering program accreditation, faculty need not only to define design but also to teach students how to design, and to assess students' design capabilities. Additionally, for programs attempting to integrate design across the curriculum, and especially in places where a large fraction of juniors transfer from community colleges, articulating engineering design outcomes across institutions became a critical issue. As indicated by a recent survey of 300 capstone design instructors across the US, faculty see a need for help in assessing engineering design learning outcomes[4].

Collaboration Model

Challenges of design education and assessment led to formation of the Transferable Integrated Design Engineering Education (TIDEE) consortium in the mid 1990s. The TIDEE consortium first drew from faculty expertise in the state of Washington to address these issues. TIDEE began by collaborating with members of the Washington Council for Engineering and Related Technical Education (WCERTE), a statewide body of colleges and universities who offer instructional programs in engineering and engineering technology. At semiannual meetings of WCERTE, TIDEE leaders facilitated faculty workshops producing common understandings and definitions for design education. In October 1996, WCERTE members adopted a statement endorsing the need for foundational learning of engineering design processes in students' freshman and sophomore years, which launched substantive collaborative efforts in design education[5].

In subsequent years, additional institutions throughout Pacific Northwest states collaborated in expanding definitions of engineering design educational outcomes and in the development and dissemination of assessments for student achievement in design. Most recently, the TIDEE consortium has articulated a vision that captures the essence of issues affecting continuous improvement in engineering design education:

TIDEE Vision

An interdisciplinary community of engineering design educators committed to developing, implementing, and refining processes which lead to measurable improvements in the readiness of our graduates for team-based design in the modern workplace.

This vision highlights the need for collaboration among engineering design educators across numerous disciplines and institutions to produce educational materials and methods that significantly improve preparation of engineering graduates for engineering practice and design. Broad collaboration is required for development of versatile educational materials and assessments and for adoption of these resources.

Successful collaboration in TIDEE efforts has produced:

- Increased discussion of educational topics among participants and colleagues
- Rich educational processes and materials reflecting diverse perspectives and expertise
- Consensus definitions and expectations that guide curriculum development and articulation
- A model for instructing students through collaborative learning techniques

Responsive Outcomes

Educational outcomes establish important targets for instructional programs and student learning. Specifically, educational outcomes for engineering design are a subset of the learning outcomes for entire engineering degree programs. Importantly, for engineering programs accredited by ABET, program educational outcomes must encompass ABET Engineering Criteria 3a-k outcomes, as listed below[3]:

Programs must demonstrate that graduates have:

a) *an ability to apply knowledge of mathematics, science, and engineering appropriate to the discipline*
b) *an ability to design and conduct experiments, analyze and interpret data*
c) *an ability to design a system, component, or process to meet desired needs*
d) *an ability to function on multi-disciplinary teams*
e) *an ability to identify, formulate, and solve engineering problems*
f) *an understanding of professional and ethical responsibility*
g) *an ability to communicate effectively*
h) *the broad education necessary to understand the impact of engineering solutions in a global/societal context*
i) *a recognition of the need for, and an ability to engage in, life-long learning*
j) *a knowledge of contemporary issues*
k) *an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice*

TIDEE outcomes have been defined by considering the ABET outcomes above, while also looking forward to performance expected from engineering graduates in the workplace. Figure 1 shows a process by which design education outcomes are derived from longer-range capabilities of engineers (e.g., the profile of an engineer after graduation). The profile leads to definitions of engineering program outcomes, a subset of which is design outcomes. In the TIDEE project, design learning outcomes have been defined at both the end-of-program and mid-program points.

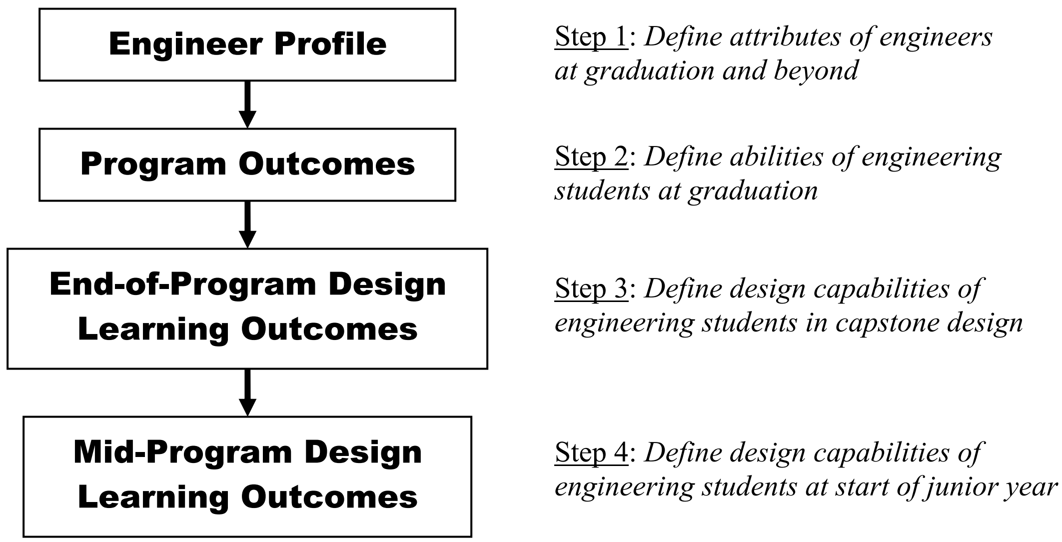

Figure 1. Process for Defining Engineering Design Learning Outcomes.

The engineer profile was defined through a process involving people from numerous educational institutions and disciplines and from leading employers of engineering graduates[6]. First, an initial set of attributes was drafted by TIDEE project leaders using a variety of publications and web sites as resources[7-12]. This set of attributes was structured as a survey to obtain ratings of importance and universality for 12 attributes and 30 supporting key actions. Responses were received from 30 capstone design course instructors of various disciplines and 10 engineers in business and industry. These ratings and suggestions provided by respondents enabled TIDEE personnel to generate a revised draft of the profile, defining 12 attributes and 45 key actions that evidence characteristics of high performing engineers.

The profile of an engineer, presented in Table 1, characterizes the engineer who is productive after graduation and advancing rapidly in responsibility as a professional. These attributes span all of the ABET EC 3a-k abilities plus additional abilities and attitudes important to the engineer's working environment. Therefore, these attributes encompass the range of actions or attitudes desired in engineers at the time they graduate and others for which a bias toward learning is present at graduation. Many of these attributes are possible outcomes of capstone design projects that engineering students experience, so most are relevant to engineering design education.

Table 1. Attributes and Key Actions Defining the Profile of an Engineer.

Attribute	Key Actions
Technically Competent Competent in knowledge and tools of engineering	Demonstrates knowledge of mathematics, physical and life sciences in engineering problem solving
	Demonstrates knowledge of statistics, experimental methods, and data analysis in engineering problem solving
	Demonstrates knowledge of engineering sciences, engineering economics, and information technology in engineering problem solving
	Demonstrates ability to use contemporary engineering tools to analyze, solve, and document engineering problems
Business Aligned Conducts engineering in a business environment	Able to articulate business goals and objectives for a project
	Able to manage costs, schedule, and performance to achieve stakeholder requirements
	Able to estimate costs and benefits associated with a business plan
	Sensitive to international and multicultural issues in a global economy
	Able to visualize and articulate business opportunities in technological development
Customer/Quality Focused Pursues quality targets expressed by customers	Establishes successful relationships with internal and external customers to understand their needs and expectations
	Characterizes, improves, and controls processes that ensure high quality and customer satisfaction
	Contributes to an environment that supports continuous quality improvement
Idea Generator Finds and creates useful ideas	Thinks creatively (independently and cooperatively) to identify and formulate innovative alternatives
	Searches broadly and deeply to obtain relevant information, technologies, and ideas
	Contributes to a working environment that enhances innovation
Decision Maker Makes sound decisions	Recognizes key issues, problems, and opportunities that merit attention
	Formulates clear decision and evaluation criteria that incorporate all relevant factors and risks
	Evaluates alternatives and results relative to requirements and established criteria
Solution Integrator Produces engineering products, processes, plans, and/or systems	Develops engineering solutions that meet needs of society in the context of global, social, political, and environmental constraints
	Designs technological solutions that are implementable and sustainable
	Applies systems engineering principles to problem solving
	Incorporates appropriate state-of-the-art technologies and products into solutions
Teamworker Builds and maintains effective collaboration	Shows sensitivity and respect for perspectives and contributions of people from different cultures and backgrounds
	Builds and maintains trusting, productive, enjoyable working relationships and resolves conflicts, as necessary, in a timely fashion
	Develops shared goals and strategies to guide team effort
	Serves as an effective team player contributing to individual and team successes
Leader Initiates and facilitates achievement	Plans, monitors, and manages tasks for timely project completion
	Formulates and articulates a vision that motivates others
	Helps others respond to challenges and grow professionally
	Recognizes and rewards individual and team accomplishments
Communicator Exchanges information to meet needs of stakeholders	Listens and observes attentively and effectively to assess audience information needs
	Documents information, results, and reflections for future use
	Organizes and presents a message to achieve desired understanding and impact
	Uses understanding of constraints and personal and organizational behaviors to gain support
	Keeps stakeholders informed about matters that affect their work while protecting necessary confidentiality
Results Oriented Proactively completes assignments	Accepts responsibility and accountability for an assignment
	Establishes priorities and maintains focus to complete important tasks on time amidst multiple demands
	Takes necessary initiative and appropriate risks to overcome obstacles and achieve objectives in a timely fashion
Change Manager Pursues strategic personal development	Seeks input and remains flexible to respond to challenges and feedback
	Anticipates and embraces challenges based on knowledge of contemporary issues
	Invests in self-assessment, planning, and learning for ongoing professional growth
Principle Centered Acts from professional and ethical principles	Displays integrity, consistency, ethical, and professional demeanor in engineering practice and working relationships
	Participates in professional and service organizations for the benefit of society
	Complies with appropriate professional codes, standards, and regulations

Engineering program educational outcomes can be derived from the attributes of an engineer. An examination of attributes in Table 1 shows that four major groupings are present, as shown in Table 2: (1) engineering fundamentals, (2) multidisciplinary problem solution and design, (3) interpersonal skills, and (4) personal characteristics. These four subjects identify major categories of engineers' capabilities that need to be addressed in all engineering degree programs. Thus, these four can easily become areas around which program educational objective statements can be written as high-level, far-reaching targets to be achieved by the engineering degree program.

Table 2. Attribute Grouping and Relevance at Mid- and End-of-Program.

Attribute	Grouping	2-Yr Outcome	4-Yr Outcome
Technically Competent	*Engineering Fundamentals*	*Basics*	*Competent*
Business Aligned	Multidisciplinary Problem Solution and Design		*Introductory (Multidisciplinary Design and Solution Processes)*
Customer/Quality Focused			
Idea Generator		*Introductory (Design Processes and Projects)*	
Decision Maker			
Solution Integrator			
Teamworker	*Interpersonal Skills*	*Intro Teamwork*	*Competent*
Leader			
Communicator		*Introductory*	*Competent*
Results Oriented	*Personal Characteristics*		*Competent*
Change Manager			
Principle Centered		*Basics*	*Competent*

The end-of-program design education outcomes are derived from a program-relevant set of the key actions in the engineer profile. Based on the 4-year outcome column of Table 2, end-of-program outcomes should include high levels of engineering fundamentals, teamwork, communication, results orientation, and principle centeredness in addition to elementary levels in multidisciplinary design. Because the capstone design course typically embodies the highest level design experience in a degree program, these program level design education outcomes may be the same or very similar to the capstone design course learning outcomes. The capstone design course outcomes need also to provide rich definitions of desired capabilities while also being a reasonable set of outcomes to assess.

A set of 10 TIDEE capstone design course learning outcomes is presented in Table 3. These include achievements related to the quality of design solutions related to client and societal needs, interpersonal skill development, and individual personal characteristic development. Clearly, these 10 outcomes define engineering graduate capabilities that reach beyond traditional capstone design course outcomes, which were: quality design products and all team members contributed to the project. Thus, this profile-based set of outcomes promises to prepare graduates better for the challenges of the engineering profession.

Table 3. Capstone Design Course Learning Outcomes and Definitions

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

Mid-program outcomes are important for integrated program curricula. By establishing intermediate educational targets, they also support effective transfer of engineering students between programs at the entering-junior level. The need for established mid-program design education outcomes was highlighted by the following statement endorsed by the WCERTE organization in October 1996:

"The foundations for design education must be incorporated into the first two years of engineering and engineering technology curricula. This includes development of competence in communication, teamwork, and the creative problem solving or engineering design process."

In response to this endorsement, focus group discussions were facilitated in WCERTE meetings to develop consensus definitions of mid-program design learning outcomes. Outcomes for the engineering design process, teamwork, and design communication were defined[13], as presented in Table 4.

Table 4. Mid-Program Design Learning Outcomes.

Outcome Name	Key Actions
Design Process. Students are able to follow a systematic process to develop a creative solution for a stated need.	a. Appropriate information is accessed and used to inform the design process. b. Project requirements are defined to include relevant technical and non-technical criteria. c. Creative ideas are generated to address needs throughout the design process. d. Analysis of ideas and design decisions are based on appropriate methods and criteria. e. Design products stem from design decisions and meet client expectations. f. Activities in the design process are managed to enhance productivity and product quality.
Teamwork. Students are able to work together to achieve a collective goal more effectively than if they had worked separately.	a. Team purpose and goals are clearly defined and have member commitment. b. Members understand their roles and responsibilities and perform them to support team success. c. Team members exhibit respect for one another and are motivated by team pride. d. Team plans include schedules and milestones that ensure progress toward goals. e. Team member empowerment is evidenced by effective use of member skills and other resources. f. Members understand and follow procedures that support team success. g. Rewards and recognition are used to encourage team success as well as member success.
Design Communication. Students record and transmit information accurately and routinely to achieve understanding needed for effective design.	a. Information is organized to make it understandable in its parts and whole. b. Information content is relevant to audience needs and interests. c. Completeness, accuracy, and supporting materials give message credibility. d. Mechanics, word choice, and format of presentation make message clear and easy to understand. e. Students record/exchange information frequently enough to support design activities. f. Information shared does not violate confidences. g. Recipients listen/read attentively to understand.

Design Pedagogy

Teaching engineering design requires educational methods that enable diverse students to learn both design concepts and processes. Reaching students with varied learning styles requires teaching methods that give students opportunities to see processes in action, have processes explained, practice these processes, and discover process details themselves[14-16]. Students also benefit from substantive feedback during the learning process[17]. These principles are embodied in the TIDEE design curriculum model.

The TIDEE curriculum model supports flexible use in a variety of classroom and institution settings. Key features of the model are[18]:

1. Structured collaborative learning activities
2. Balanced attention given to design processes and design products
3. Assessment components embedded in nearly all activities

TIDEE design activities use cooperative learning to accelerate development of cognitive, interpersonal, and affective skills. In most cases an inductive approach (beginning from concrete experience and proceeding to theoretical conclusions) is favored over a deductive approach (beginning from theoretical principles and applying them to physical situations). This instructional strategy is consistent with developmental models for young adults[19]. Numerous activities include instruments such as the Hermann Brain Dominance Model, Myer Briggs personality indicator, or the Kolb learning style inventory to generate awareness of students' strengths and how these can be coupled with talents of others to enhance design team performance.

A variety of curriculum materials have been generated to support the development of working expertise in the field of design[20]. They begin with a wide variety of structured design experiences for introductory engineering design classes. Students engage in multiple design cycles that progressively increase in complexity. TIDEE curricula build student capabilities in several areas crucial to effective team-based design. Supporting themes for learning activities include:

- Shaping realistic goals
- Creating focused problem definitions
- Developing detailed plans
- Establishing effective timelines
- Assigning operational roles and responsibilities
- Developing professional capabilities
- Using reflection to assess value added through performance reviews
- Developing and engaging in effective client interviews

TIDEE curricula are sequenced in a three-step development cycle that can add value at any point in an engineering program[18]. The steps include: (1) building teams and teaming skills, (2) expanding design competencies in short, structured activities, and (3) challenging student teams to apply their skills in more complex multi-week projects. The first step establishes a culture for cooperation and effective team function. The second develops an operational definition of quality performance and provides strategies and tools for skill improvement. The third step prepares students to practice engineering in a minimally-structured environment with expectations of high-level performance.

Structured learning activities articulated by activity sheets form the core of TIDEE curricula. Activity sheets have descriptive titles, define learning objectives, enumerate deliverables and criteria for success, outline tasks, and identify resources that support each learning activity. Their recommended placement within design courses and specific class sessions is shown in course syllabi, unit schedules and daily agendas made available to both students and faculty. Instructor guides contain alternative ideas on setting up and bringing closure to these activities. Each activity has set time limits to help keep teams focused on the process and move forward. TIDEE curricular materials and supporting resources are found on the TIDEE web site: www.tidee.cea.wsu.edu.

Design Assessment

Assessment and evaluation are important for improvement of student learning and for documentation of student achievement. The quality of assessment and evaluation systems depends upon their alignment with five principles articulated by Stiggins[12]:

1. Defining clear and appropriate learning targets
2. Identifying users and uses of assessment information
3. Selecting assessment methods appropriate for the targets and uses
4. Sampling to achieve representative results
5. Preventing distortion and bias

Because assessment and evaluation can be used for different purposes, it is important to make the following distinctions in terminology and purpose:

Assessment is providing "friendly" feedback:

- Measurement of student achievement for purposes of guiding improvement
- Producing identified strengths and suggestions for improvement without a "grade"

Evaluation is providing "judgmental" feedback:

- Measurement of student achievement to judge students' success or failure
- Producing a definitive score reflecting achievement on a performance scale

From these two definitions, it is clear that assessment plays a significant role in classroom activities focused on developing and refining student abilities. Assessment is imbedded in instruction and used frequently to demonstrate its value and to encourage students to take risks that enhance learning. This approach is consistent with the TIDEE instructional model described earlier, integrating assessment into instruction.

The principal TIDEE assessment tool for design education outcomes in early years of the curriculum (e.g., freshman, sophomore, junior) is the TIDEE Design Team Readiness Assessment (DTRA)[22]. The DTRA is comprised of three component parts, as illustrated in Table 5. From this assessment, student performance is examined in terms of underlying understanding of team-based design and students' abilities to put into practice the processes of team-based design. The DTRA instrument has been evaluated for inter-rater reliability[23] and for validity in measuring design capabilities of students[24]. The full assessment instrument, including scoring rubrics and scoring decision rules, is available at www.tidee.cea.wsu.edu. Recommendations for implementing the DTRA are consistent with Stiggin's principles for quality assessments[25].

Table 5. Components of the TIDEE Design Team Readiness Assessment (DTRA).

Component	Description
Design Team Knowledge Assessment	• Short, constructed response questions • Answers written individually in 15 minutes • Define understanding of engineering design process • Define key elements of effective teamwork • Define characteristics of effective design communication

Design Team Performance Assessment	• Team performance assessment • Design activity completed in 45 minutes • Demonstrate use of effective teamwork • Utilize the engineering design process • Document activities and achievements
Design Team Reflection Assessment	• Individual 2-page, take-home essay assessment • Reflecting on recent Design Team Performance Assessment • Describe, explain, analyze use of engineering design process • Describe, explain, analyze use of teamwork • Describe, explain, analyze use of communication

The DTRA is used primarily for formative assessment purposes, to give students feedback on their preparedness for team-based design before beginning major design projects. It can be administered profitably to students ranging from entering freshman to entering seniors at several educational institutions. Its administration typically produces the following benefits:

To Students

- Clarification of design team concepts and processes
- Clarification of instructor expectations related to design skills
- Recognition of personal strengths and areas for improvement
- Increased knowledge about and relationships with classmates

To Faculty/Programs

- Indication of student preparedness for team design
- Identification of design topics requiring additional instruction and practice
- Evidence that assessment steps have been taken to improve learning (for ABET)

Students' design experiences and outcomes in their senior years require assessments for higher levels of learning and a broader set of professional skills than addressed in the DTRA. For yearlong capstone design courses seeking to develop the 10 course outcomes defined earlier, assessments must examine quality of design products, interpersonal skills, and personal characteristics required in engineering practice. Consequently, TIDEE capstone design course assessments utilize multiple instruments to address this broad set of outcomes.

TIDEE capstone design assessment is achieved through the use of performance tasks integrated into the projects courses. Different performance tasks are used as assessments (to provide friendly feedback) or as evaluations (to produce points toward course grades). Table 6 shows a sample set of performance tasks for capstone design courses and their mappings to course learning outcomes.

Table 6. Assessment Performance Tasks for Capstone Design Course Outcomes.

	Assessment Performance Tasks					
Course Outcomes	Project Manage-ment Plan	Product Evaluation Plan	Project Progress Reports	Written Design Report	Oral Design Report	Reflective Growth Paper
1. Perform Professionally	X		X			X
2. Produce Quality Design Solutions				X	X	
3. Establish and Develop Relationships	X		X			X
4. Manage Schedules and Resources	X		X			
5. Generate Creative Solution Ideas		X		X	X	
6. Make Decisions Based on Broad Criteria	X			X	X	
7. Use Contemporary Tools Effectively				X	X	
8. Defend Performance of Solution		X		X	X	
9. Communications Effectively	X	X	X	X	X	X
10. Assess and Pursue Professional Growth	X		X			X

Note that each performance task identified in Table 7 spans multiple course learning outcomes. This minimizes effort spent on assessment and allows instructors to craft performance tasks to fit related multiple course outcomes. Figure 2 shows an abbreviated form of the Project Progress Report performance task. Note how this performance task gives evidence for performing professionally, developing relationships, managing schedules, communication, and professional growth.

Name:		**Project:**
Date:	**Reporting Period:**	**Hours on Project this Period:**
PROGRESS FOR REPORTING PERIOD		
Your Goal(s) for this Period:		
Actions Taken to Achieve Your Goal(s):		
Specific Achievements:		
Assessment of Your Success:		
Insights Gained:		
PLANS FOR NEXT REPORTING PERIOD		
Your Goal(s) for Next Period:		
Plans to Achieve Your Project Goal(s):		
Planned Professional Development:		
SOUNDING AN ALERT ! !		
Conditions of Project Concern:		
Recommended Actions (what/by whom):		

Figure 2. Individual Progress Report Performance Task.

Scoring of assessments is based on scoring rubrics that include the outcomes addressed by that assessment. For example (as shown in Table 6), a rubric for written design reports includes scoring scales for quality solutions, creative ideas, decision making, use of tools, defending solutions, and communication. A sample scoring scale for decision making is given in Table 7.

Table 7. Scoring Scale for Decision Making

Score = 1	Score = 2	Score = 3	Score = 4
Decisions made without full participation of team; often passively or arbitrarily.	Requirements considered, not weighted when ranking options for decisions; team able to reach consensus.	Requirements weighted in making decisions; scoring methods used (e.g., decision matrix) at different points in decision making; team consensus in decision making.	Effective decision making tools and processes used at each design stage; technical and non-technical criteria prioritized and applied; decisions made with broad team input.

Capstone design course assessments used collectively can determine students' achievement related to all 10 of the capstone design course learning outcomes. This provides valuable tools for documenting program outcomes previously considered difficult to assess. In fact, through capstone design courses, most or all of the ABET EC 3a-k outcomes as well as other attributes of engineers can be achieved and assessed using this approach. Therefore, the bar has been raised for educating students for the engineering profession.

Summary

The TIDEE project has produced important tools for enhancing and documenting student capabilities related to engineering design. These developments draw from the profile of a high performance engineer after graduation to establish targeted design learning outcomes at the end-of-program and mid-program points. Instructional strategies for effective student learning of design knowledge and processes utilize structured, graduated collaborative learning activities, give attention to both design processes and products, and imbed assessment into instructional activities. Assessment tools have been developed to aid in monitoring student learning and in providing students feedback in an environment that encourages learning. TIDEE materials and methods empower engineering educators and students to achieve comprehensive capabilities for development of multidisciplinary design products along with strong interpersonal skills and personal characteristics required for success in a global engineering community.

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References

1. National Science Foundation. (1996). *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*, NSF Report 96-139.
2. Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE). (1997). *ABET Criteria: Industry Expectations of New Engineers*.
3. ABET. (2003). Engineering Criteria, Accreditation Board for Engineering and Technology. www.abet.org.
4. McKenzie, L. J. (2002). End-of-Program Assessment: An Investigation of Senior Capstone Design Assessment Practices. Doctoral Dissertation, College of Education, Washington State University, Pullman, WA.
5. Trevisan, M.S., D.C. Davis, R.W. Crain, D.E. Calkins, and K.L. Gentili. 1998. "Developing and Assessing Statewide Competencies for Engineering Design," Journal of Engineering Education, vol. 87, no. 2, pp. 185-193.
6. Davis, D., S. Beyerlein, P. Thompson, K. Gentili, and L. McKenzie. 2003. "How Universal are Capstone Design Course Outcomes?" Proceedings of Annual Conference of American Society for Engineering Education.
7. NSPE. (2003). "Code of Ethics for Engineers." National Society of Professional Engineers, www.nspe.org.
8. NCEES. (2003). National Council of Examiners for Engineering and Surveying. "www.ncees.org.

9. IEEE. (2002). "Attributes of the 21st Century Engineer." www.-cseg.inaoep.mx/~jmc/21st.html.
10. Partis, A. (2002). "10 Attributes of a Professional Software Engineer." www.thundernet.com/alpartis/articles/engineer.shtml.
11. Boeing. (2003). "Boeing Attributes of an Engineer." www.boeing.com/companyoffices/pwu/attributes/attributes.html.
12. Hanneman, L., S. Mickelson, L. Pringnitz, and M. Lehman. (2002). "Constituent-Created, Competency-Based, ABET-Aligned Tools for the Engineering Experiential Education Workplace", ABET Conference on Assessment.
13. Davis, D., Gentili, K., Trevisan, M., and Calkins, D. (2002). Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability, *Journal of Engineering Education* 91(2): 211-219.
14. Lumsdaine, E., M. Lumsdaine, and Shelnutt. 1995. Creative Problem Solving: Thinking Skills for a Changing World, McGraw-Hill, Inc.
15. Johnson, D., R. Johnson, and K. Smith. 1991. Active Learning: Cooperation in the College Classroom, Interaction Book Company.
16. Bean, J. 1996. Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking and Active Learning in the Classroom, Jossey-Bass.
17. Angelo, T. and P. Cross. 1993. Classroom Assessment Techniques: A Handbook for College Teachers, Jossey-Bass Publishers.
18. Gentili, K., D. Davis, and S. Beyerlein. 2003. "Framework for Developing and Implementing Engineering Design Curricula. Proceedings of Annual Conference of the American Society for Engineering Education.
19. Duncan-Hewitt, W., D. Mount, S. Beyerlein, D. Elger, and J. Steciak. 2001. "Creating Design Experiences for Beginning Engineering Students According to Developmental Principles," Proceedings of 2001 Frontiers in Education Conference.
20. www.tidee.cea.wsu.edu. 2003. TIDEE Project web site.
21. Stiggins, R. 2001. *Student-Involved Classroom Assessment (3rd ed.)*. Upper Saddle River, NJ: Prentice Hall.
22. Davis, D., M. Trevisan, L. McKenzie, D. McLean, S. Beyerlein, C. Atman, R. Adams, K. Gentili, R. Christianson, J. McCauley, P. Daniels, T. Schuman, and P. Thompson. 2002. "Design Team Readiness Assessment: A Multi-Component Instrument for Measuring and Improving Prerequisite Knowledge, Skills, and Attitudes—Version 7," www.tidee.cea.wsu.edu.
23. McKenzie, L., D. Davis, M. Trevisan, and S. Beyerlein. 2001. "Enhancing Scoring Reliability in Mid-Program Assessment of Design," Proceedings of the 2001 ASEE Annual Conference.
24. Adams, R., Punnakanta, P., Atman, C., and Lewis, C. (2002). "Comparing Design Team Self-Reports with Actual Performance: Cross-Validating Assessment Instruments", Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
25. Davis, D., M. Trevisan, L. McKenzie, S. Beyerlein, P. Daniels, T. Rutar, P. Thompson, and K. Gentili. 2002. "Practices for Quality Implementation of the TIDEE Design Team Readiness Assessment," Proceedings of the 2002 ASEE Annual Conference and Exposition.