AC 2011-926: IDEALS: A MODEL FOR INTEGRATING ENGINEERING DESIGN PROFESSIONAL SKILLS ASSESSMENT AND LEARNING

Denny C. Davis, Washington State University

Denny Davis is Professor of Bioengineering and Director of the Engineering Education Research Center at Washington State University. He has led multi-institution collaborations developing and testing assessments and curricular materials for engineering design and professional skills. He has been a Fellow of the American Society for Engineering Education since 2002.

Michael S. Trevisan, Washington State University

Dr. Michael S. Trevisan is Professor of Educational Psychology and Associate Dean for Research and External Funding in the College of Education at Washington State University. Dr. Trevisan’s expertise is in educational measurement and evaluation and he is published widely in these areas. For the last several years he has collaborated with Dr. Denny Davis to develop engineering education design assessments.

Howard P Davis, Washington State University

Dr. Davis received degrees from The Evergreen State College (BA 1976), WSU (BS 1981, MS 1988) and the University of Oregon (Ph.D. 1993). He is currently a Clinical Assistant Professor in the Gene and Linda Voiland School of Chemical Engineering and Bioengineering. He has been the president and CEO of IPM, a medical device company and Total Dynamics LLC a software company. He is also on the board of directors of Developing World Technologies, a company started by former students of the capstone class that he teaches. His interests include engineering and entrepreneurship pedagogy and assessment, technology development and clinical applications of biomedical instrumentation.

Steven W. Beyerlein, University of Idaho, Moscow

Dr. Beyerlein serves as the coordinator for an inter-disciplinary capstone design course in the College of Engineering at the University of Idaho. In this endeavor, he collaborates with five other colleagues from the departments of Mechanical Engineering, Electrical Engineering, Computer Engineering, Biological Engineering, and Computer Science. He is engaged in multiple research projects associated with engine testing, alternative vehicle development, design pedagogy, and program assessment.

Susannah Howe, Smith College

Susannah Howe is the Design Clinic Director in the Picker Engineering Program at Smith College, where she coordinates and teaches the capstone engineering design course. Her current research focuses on innovations in engineering design education, particularly at the capstone level. She is also involved with efforts to foster design learning in middle school students and to support entrepreneurship at primarily undergraduate institutions. Her background is in civil engineering with a focus on structural materials; she holds a B.S.E. degree from Princeton, and M.Eng. and Ph.D. degrees from Cornell.

Phillip L Thompson, Seattle University

Jay McCormack, University of Idaho

Jay McCormack is an assistant professor in the mechanical engineering department at the University of Idaho where he is an instructor for the college’s interdisciplinary capstone design course. Dr. McCormack received his PhD in mechanical engineering from Carnegie Mellon University in 2003.

Patricia Brackin, Rose-Hulman Institute of Technology

M. Javed Khan, Tuskegee University

M. Javed Khan is Professor of Aerospace Science Engineering at Tuskegee University. He received his Ph.D. in Aerospace Engineering from Texas A&M University, MS in Aeronautical Engineering from the US Air Force Institute of Technology and BE in Aerospace Engineering from Karachi University. His research interests include engineering education and vortex dominated flows and aircraft design. Address: 100 Luther Foster Drive, Chappie James Center, Room 325, Tuskegee University, Tuskegee, AL 36088; mjkhan@tuskegee.edu

©American Society for Engineering Education, 2011
Abstract

Engineering degree programs are being asked to prepare graduates with professional skills and abilities to innovate and succeed in complex problem-solving contexts. This paper proposes a six-step integrated assessment and learning model, which when employed in the context of a capstone design course, develops and documents high levels of professional skills in students. The Integrated Design Engineering Assessment and Learning System (IDEALS) model integrates project-based challenges with formative assessments and instruction before conducting summative assessment of students’ professional skills achievements. Individual steps of the IDEALS model are grounded in theories of learning and principles of sound assessment. Elements of the model are illustrated by applications to teamwork, professional development (self-directed learning), and professional responsibility. When this model is employed in authentic engineering contexts, it enhances student performances of professional skills and yields documentation of individual student achievement important to assignment of grades and to program accreditation.

Introduction

Engineering grand challenges confronting the global community call for engineers to work across cultures, adapt to change, innovate, and develop solutions that are sensitive to a broad set of technical, business, and social constraints. This requires a comprehensive set of professional skills in addition to technical engineering competence. Among the professional skills needed by engineers of the twenty-first century are abilities to: work with diverse teams, demonstrate professional and ethical responsibility, and engage in self-directed learning that enables adaptability and leads change. Although important to society and the engineering profession, the teaching of professional skills is not often within the expertise of engineering faculty and is frequently shortchanged in the curriculum.

In a 2005 study of capstone design courses in the United States, professional skills being taught in these courses varied widely. Commonly included were communication, ethics, project management, decision making, teamwork, engineering economics, safety, and leadership. Two notable omissions among the top twenty skills being taught are entrepreneurship and self-directed (lifelong) learning, both of which are vital to successful technological development.

For accreditation, engineering programs in the United States must demonstrate that their graduates have achieved eleven or more specific learning outcomes. Included in engineering accreditation requirements are the following professional skills outcomes:

- an ability to function on multidisciplinary teams,
- an understanding of professional and ethical responsibility, and
- a recognition of the need for, and an ability to engage in life-long learning.
Most programs attempt to develop these student abilities and assess them in a capstone engineering design course. Most capstone design instructors also express a lack of confidence in their abilities to assess these outcomes.

National leaders agree that our educational system needs reform. As stated by James Pellegrino, “Very little of what we know about competence and development of expertise has been used to shape curricular goals, instructional processes, or modes of assessment.” He explains that a society aspiring to address tomorrow’s global challenges must prepare its people to transfer understanding to new problems, demonstrate creativity and innovation, and practice adaptive expertise. He states further that assessments need to focus on deep learning and understanding, not simply rote facts. Importantly, reform is needed in both instruction and assessment.

Assessment supports student learning and documents student achievement. Formative assessment, used during the learning process, assists learning by providing students and teachers information about student strengths and difficulties with learning. This helps teachers modify instruction to meet students' needs, and it helps students determine skills and knowledge to learn and make necessary adjustments in thinking. In many different classroom environments, formative assessment has been demonstrated to help students learn more. Students also benefit from receiving training in self-assessment. In addition, summative assessment, evaluation of individual achievement after a phase of education, can guide teachers to make changes in instruction or to modify the curriculum. Formative assessments and summative assessments must be aligned to support instructional learning goals.

An assessment is a tool designed to obtain data on student achievement and behavior, and can be used to draw reasonable inferences about what students know, feel, and can do. High quality assessment will have a clear purpose, appropriate learning targets, proper methods, appropriate sample, and no bias or distortion. The following three major components of assessments must be aligned:

1. Cognition – beliefs about how learners represent knowledge and develop expertise of interest to the assessor,
2. Observation – tasks students complete to provide evidence of their learning, and
3. Interpretation – methods and tools used to reason about learning from fallible observations.

All components of an assessment instrument must be rooted in an understanding of the ways in which the targeted learning is achieved and made observable. To be most valuable to the graduate and to society, important learning goals and outcomes must be achieved and assessed in an authentic context representing practices of the engineering professional community.

**Goal**

The goal of this paper is to present and illustrate the use of the Integrated Design Engineering Assessment and Learning System (IDEALS). The IDEALS model integrates learning and
assessment to develop targeted professional skills and effectively document this achievement. This model, described briefly in Figure 1, provides a basis for the authentic learning of professional skills and the assessment of professional skills achievement, giving assurance that skills learned will be transferable to the professional workplace.

<table>
<thead>
<tr>
<th>Initiate</th>
<th>Define</th>
<th>Execute</th>
<th>Assess</th>
<th>Learn</th>
<th>Show</th>
</tr>
</thead>
</table>

The IDEALS learning and assessment model develops and documents learning through a (two-stage) six step sequence: Initiate, Define, Execute, Assess, Learn, and Show. The first stage is triggered by a context-specific challenge (Initiate), produces conjectures about appropriate actions to take (Define), and leads to actions taken based on tentative understanding (Execute). The second stage begins by formative assessment of the tentative understanding (Assess), which prompts refined learning through practice (Learn), and later is evaluated in a purposeful demonstration of knowledge (Show). The result is professional skills knowledge that has been tested in a semi-authentic professional community.

Figure 1. IDEALS Integrated Learning and Assessment Model.

**Learning and Assessment Model**

The following sections present a theoretical basis for the IDEALS learning and assessment model, illustrate its application for three types of professional skills, and discuss the types of results expected when implementing the model in a capstone engineering design course setting.

**Targeted Professional Skills**

In this paper, three professional skills are targeted to address ABET accreditation requirements, Washington Accord engineering competencies, engineer of 2020 attributes, and the profile of the engineer: teamwork, professional responsibility, and professional development. These skills are vital to engineering practice and are often associated with the engineering community of practice. These three professional skills are discussed in the following paragraphs.

**Teamwork**. Teamwork traditionally has meant work done by a number of associates, each doing a part, but subordinating individual prominence for the betterment of the whole. Thus, teamwork competence requires that individuals be able to work with people of diverse disciplines, backgrounds, and capacities—in either leadership or member roles—to enable the team to efficiently and effectively achieve team goals. Building supportive team relationships, allocation of work, doing work together, and documentation and communication of project information are important components of being an effective team. The teamwork learning outcome to be demonstrated in a capstone or similar team project environment is defined in Table 1.
Table 1. Professional Skills and Learning Outcomes for Capstone Design

<table>
<thead>
<tr>
<th>Skill Area</th>
<th>Capstone Course Learning Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teamwork</td>
<td>In the context of team project work, team member behaviors and team processes contribute to constructive relationships, joint achievements, individual contributions, and information management that synergistically yield high team performance and productivity.</td>
</tr>
<tr>
<td>Professional Responsibility</td>
<td>While engaged in a team project to meet stakeholder needs, individuals recognize important professional and ethical responsibilities and demonstrate abilities to reason and fulfill these responsibilities in concert with applicable codes and norms of practice.</td>
</tr>
<tr>
<td>Professional Development</td>
<td>While engaged in engineering project work, individuals recognize needs for development of technical, interpersonal, and individual attributes, plan and achieve progress, and articulate tangible current and future value from professional development.</td>
</tr>
</tbody>
</table>

*Professional Responsibility.* Professional responsibility addresses moral, legal, and ethical accountabilities for which one must answer. For engineers, this means that one is informed about and reasons through obligations to society, clients, and the profession, then appropriately applies ethical principles to responsible fulfillment of obligations. These obligations are defined by moral and professional codes, norms of engineering practice, and the public’s expectations regarding societal, health, safety, legal, natural resource, and cultural impacts of engineering work. The professional responsibility outcome to be demonstrated in a representative professional work environment is stated in Table 1.

*Professional Development.* Professional development, as used in this paper, includes lifelong learning, anticipating and responding to needs for change, and self-directed learning that produces documented achievements. Professional development is the act, process, and result of taking purposeful action to advance by degrees the visible manifestation of knowledge, skills, or attitudes desired. For meaningful professional development, the engineer must recognize the need to advance certain abilities, take responsibility for personal development, engage purposefully to achieve desired development, and reflectively assess and validate the effectiveness of these achievements for meeting present and long-term needs.

**Learning Context and Theories**

Learning professional skills in the context of capstone design courses or similar team-based project experiences can be described by a mix of cognitive, constructivist, and motivational models. In the semi-authentic professional communities of project teams with real stakeholders, social interactions will shape student learning. Interdependence and accountability to teammates also produce learning through negotiation and by modeling of behaviors. Motivation for learning will depend upon alignment of individual goals with team, course, and stakeholder goals, and this motivation will affect the durability of learning. Students’ self-efficacies also influence their motivation, so feedback from peers and instructors...
will affect student confidence and motivation to learn. Table 2 summarizes conditions in which the team-based design experience occurs.

Table 2. Summary of Team-Based Project Learning Context

<table>
<thead>
<tr>
<th>Learning Environment</th>
<th>Team Culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Each student is a member of a team developing a design solution under time and resource constraints.</td>
<td>o Each student brings unique experiences, abilities, habits, and personal goals.</td>
</tr>
<tr>
<td>o The results of student work will be judged by diverse stakeholders.</td>
<td>o Project completion requires contributions and cooperation from all members.</td>
</tr>
<tr>
<td>o Students have professional and ethical responsibilities associated with the project.</td>
<td>o Team operating conditions must be defined (negotiated), implemented, and managed by the team.</td>
</tr>
<tr>
<td>o Students must individually identify and learn missing skills needed to complete the project.</td>
<td>o Teammates must give and receive feedback to support ongoing improvement.</td>
</tr>
<tr>
<td>o Students are part of a community of practice (teammates, classmates, project advisors, and others) in which learning occurs.</td>
<td>o Team members must recognize that teamwork produces work greater than the sum of individual contributions.</td>
</tr>
</tbody>
</table>

Learning and motivation theories explain the ways that students will learn professional skills, and they suggest effective instruction and assessment practices. The following paragraphs draw from a summary by Svinicki to identify theories and practices that are relevant to professional skills development and assessment in capstone design classes. Table 3 identifies instructional practices suggested by each of the theories.

A. Cognitive Learning Theories. Cognitive learning theories state that learning experiences are inputs to the student’s cognitive learning processes. Learning begins when senses take in information and it is processed in short-term memory. Here information is compared with previous knowledge, checked for inconsistencies, organized, and fit into existing or refined structures of knowledge in long-term memory. Interconnections of the new knowledge to other knowledge make it more meaningful and more easily retrieved. Frequent referral to stored knowledge results in longer-lasting memory. Based on cognitive theories, instructional practices should: bring attention to important information, sequence instruction to develop connections, help students organize their knowledge, connect with previous knowledge, give multiple and varied applications, and let students monitor their own learning processes.
Table 3. Suggested Instructional Practices Based on Learning and Motivation Theories

<table>
<thead>
<tr>
<th>Theory</th>
<th>Suggested Instructional Practices</th>
</tr>
</thead>
</table>
| (A) Cognitive Theories        | 1. Bring important information to the learner’s attention and spend time on it  
                                   2. Present related information in close proximity for developing connections  
                                   3. Assist memory by presenting organizational structures, examples, and asking students to create structures and examples  
                                   4. Connect new knowledge to previous knowledge and ask students to do so as well  
                                   5. Give students varied opportunities to apply knowledge to strengthen connections  
                                   6. Teach students to take control of their learning through metacognitive processes such as, setting goals, monitoring progress, and taking corrective action. |
| (B) Social Cognitive Theories | 1. Show (demonstrate) processes to be learned, using models closely aligned with the processes that students should employ  
                                   2. Let students see positive consequences from behaviors they are to demonstrate  
                                   3. Make steps of the modeled processes observable, even the thinking processes behind the performance of the process  
                                   4. As appropriate, help learners create mental models of processes, increase their motivation for learning processes, and gain confidence they can do what is asked. |
| (C) Constructivist Theories    | 1. Let the students experience the environment directly to gain realistic perspectives  
                                   2. Structure the classroom around real problems with environments that simulate authentic problem contexts  
                                   3. Assess in ways that allow students to demonstrate knowledge in authentic contexts and of the type appropriate for the problem  
                                   4. Teachers should appear as co-learners, and students should be in the process of becoming experts in the problems they are addressing. |
| (D) Expectancy Value Theory    | 1. Make learning tasks more valuable to the learner, more under control of the learner  
                                   2. Scaffold learning so the student has early successes, receives needed help, recalls earlier successes, and can focus on short-term successes before long-term ones. |
| (E) Attribution Theory         | 1. Use student reflection to help students connect outcomes to their choices  
                                   2. Give accurate attributions for outcomes; model “giving attributions” for students  
                                   3. Give accurate feedback to students, helping them develop good evaluation skills. |
| (F) Achievement Goal Orientation Theory | 1. Encourage student mastery by emphasizing progress rather than by making comparisons with other students  
                                   2. Give feedback individually and privately and clearly show how one can improve  
                                   3. Demonstrate through your own attitude that mistakes are an opportunity to learn  
                                   4. Give students some choice and control over their learning |
| (G) Self-Determination Theory  | 1. Give learners opportunities to choose among alternative ways of learning material  
                                   2. Give learners some control over their work (e.g., timing, how presented)  
                                   3. Model desired values about learning (e.g., adopting others’ goals) and provide feedback with respect to the desired values. |
B. Social Cognitive Theories. Social cognitive theories state that the social component of learning experiences adds sources of knowledge and provides ongoing challenges that require recall, revision, and reconnecting of knowledge in the long-term memory. Social cognitive (or sociocognitive) learning theory posits that learners learn from watching and engaging with others. Learners observe role-models (instructors, peers, advisors) engaging in a behavior and watch the consequences of these behaviors to judge whether they should be adopted. The learner creates a mental model of the behavior from which to reproduce the behavior. Based on sociocognitive theories, instruction should: model processes students should employ, help students see benefits from behaviors being taught, articulate thinking behind processes, and provide assistance in student learning and motivation.

C. Constructivist Theories. Constructivist theories posit that the learner constructs a personal mental model (understanding) of the information based on previous knowledge and how the information is received. The learner is in direct control of his/her learning, so new information must be presented to answer the learner’s questions and must be driven by the learner’s interests. Social constructivism adds an emphasis on the construction of understanding through the learner’s interaction with other learners. Learners negotiate meaning and refine understanding by contrasting their perspectives with other learners and the instructor. Learners learn as they change their views based on input from others and their environment. Instructional practices suggested by this theory include: realistic professional environments for learning, authentic problems, assessment in authentic environments, and teachers showing self-growth in addressing problems they give to students.

D. Expectancy Value Theory. The expectancy value theory states that the learner’s motivation to learn is based on the value of what is being learned and the learner’s expectancy of success in learning it. Value to the learner may be judged by the novelty, usefulness, complexity, degree of learner control, or alignment of the new knowledge with the learner’s goals. The learner’s expectancy of success is influenced by past successes and failures, beliefs about the difficulty of the learning, self-confidence, what others say, and the causes of success and failure. This theory suggests the following instructional practices: giving students more value and more control over learning and supporting them to be successful repeatedly as they learn.

E. Attribution Theory. Attribution theory posits that learners are motivated more when successes are attributed to themselves and they maintain an image of competence. If the learner is in a position to influence success, he or she is more motivated to try than if external influences predominate. Students accept responsibility when they believe they are in control, but do not if results are outside of their control. Instructional strategies suggested by this theory include: having students reflect and acknowledge the results of their choices, giving accurate attributions for results, giving accurate feedback, and helping students accurately self-assess.

F. Achievement Goal Orientation Theory. The achievement goal orientation theory states that students may, possibly at different times, approach learning with a mastery goal or a performance goal orientation. With a mastery goal orientation, learners pursue an outcome of mastery of the skill and have a focus on learning, even in the face of challenges and risks.
With a performance goal orientation, learners focus on achieving the appearance of competence for the sake of some reward, so they avoid risk-taking in learning that could jeopardize their reputation or rewards. This theory suggests that instruction should: encourage student mastery for long-term benefits, give clear (and private) feedback for improvement, model how mistakes are opportunities to learn, and allow students to learn at a pace that makes them successful.

G. **Self-Determination Theory.** Self-Determination Theory states that students are most highly motivated when they feel that they are in control and operating autonomously. Intrinsic motivation occurs when the student has a basic human need (being in control) met. For instruction to capitalize on this form of motivation, it should: give learners choices in ways to learn, control over how success is shown, and model desired valuing of learning.

This summary illustrates the importance of authentic professional experiences, accurate self-assessment and feedback, negotiated understanding, multiple opportunities to apply learning, instructors modeling desired skills, and student-shaped learning experiences. These form the basis for the integrated learning and assessment model described below.

**IDEALS Learning and Assessment Model**

Student learning can be modeled by a series of steps that describes how students are prepared, experience situations, process information, and are coached to gain desired knowledge, skills, and abilities. The Kolb cycle models learning as a concrete experience, followed by observation and reflection, producing a conceptualization and generalization, and finishing with testing of the concept in new situations\(^{28}\). Challenge-based instruction teaches problem solving around “challenge” problems proposed by the instructor, solved by small groups, shared with the larger class, and learning moderated by the instructor\(^{29}\). Using a reflective practice model, the learner begins by “naming” or identifying a challenge faced, “framing” a possible approach, “moving” to experiment with a proposed solution, and “reflecting” on the activity to learn from the experiment\(^{30}\). These models vary by the learning environment, the forms of instructor intervention, and the ways in which reflection and feedback occur.

The proposed IDEALS integrated learning and assessment model was constructed to fit the semi-authentic professional practice design project context. This model integrates formative and summative assessment with project-based learning experiences to form the two-stage, six-step process presented earlier in Figure 1 and defined (by step) in Table 4. The Initiate, Define, and Execute steps produce first-stage performances of learning usually based upon limited knowledge available when encountering the challenge. The Assess, Learn, and Show steps produce a more advanced performance based on assessment of earlier performances and additional practice in the context of the challenge. Thus, the IDEALS learning and assessment cycle enables learners to experiment, receive feedback, reflect-in-action, and deepen their understanding in professional settings before performing for high-stakes evaluation. Note also
that three steps (Initiate, Execute, and Learn) are facilitated learning and three steps (Define, Assess, and Show) are assessment—alternating these two types of opportunities to learn.

Table 4. IDEALS Integrated Learning and Assessment Model Steps Illustrated

<table>
<thead>
<tr>
<th>Step</th>
<th>Example of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>INITIATE</td>
<td>A professional (e.g., teamwork, self-directed learning, ethical) challenge arises in the context of a team-based design project; this delays progress or limits performance.</td>
</tr>
<tr>
<td>DEFINE</td>
<td>Through <em>formative assessment</em> (problem analysis and planning), students assess the situation, define important needs, set goals, and create a plan for achieving strong performance.</td>
</tr>
<tr>
<td>EXECUTE</td>
<td>Students take action, in concert with team and project goals, to implement their plan toward achievement of strong processes and high quality work products.</td>
</tr>
<tr>
<td>ASSESS</td>
<td>Through <em>formative assessment</em>, students self-assess, peer-assess, or jointly assess progress toward goals and revise plans as needed to enhance achievements.</td>
</tr>
<tr>
<td>LEARN</td>
<td>As students thoughtfully practice their knowledge in the problem context, they advance their knowledge to become more characteristic of professionals.</td>
</tr>
<tr>
<td>SHOW</td>
<td>Through <em>summative assessment</em>, students document (show, explain, extend) their achievements in work products, skill development, and learning.</td>
</tr>
</tbody>
</table>

The following discussion of steps of the IDEALS model references (by letter and number) the practices suggested by learning and motivation theories summarized in Table 3. As suggested by social constructivism theories (C2), learning begins *(Initiate)* with a challenge that arises from the context of the team-based project. This step also fits the “naming” stage of the reflective practitioner. Next the students state *(Define)* the desired outcome for this challenge. They clarify the problem and define their understanding of the actions that will resolve the problem. This fits the “framing” stage of the reflective practitioner and aligns with giving students control over their learning (G1, G2) and developing negotiated understandings of the situation as defined by social constructivist theories (C). In the third step, students act on *(Execute)* their plan to address the issue, which corresponds to the “move” step of the reflective practitioner. It also gives students contextualized learning experiences that are aligned with constructivist theories (C1, C2) and opportunities to control their own learning experience (G1, G2). Thus, this first stage of the model gives students an opportunity to scope the problem and attempt its solution, creating an opportunity to learn at a higher level.

The last three steps of the IDEALS model elevate student learning to that of the reflective practitioner. The *Assess* step enables students to gain feedback on their learning, self-assess their performance, and learn from their earlier experiment in learning, which corresponds to the “reflect” step of the reflective practitioner. This step provides feedback that is authentic (C3), that is improvement-focused (F1, F2), and teaches self-assessment skills (E3). The *Learn* step offers students an opportunity to extend learning to a knowing-in-action level, learning from reflective thinking occurring “in stride” while performing the work of a professional. This also aligns with the authentic learning environment (C1, C2) and allows learners to experience high achievements that motivate learning (D1). The final *Show* step focuses summative
evaluation on the students as they demonstrate high performance that resulted from earlier learning. This builds student confidence in their ability to learn (D1, D2) and provides evidence that they made choices that led to significant learning (E1, E2 above) in an authentic context (C1, C2). This step affords an opportunity for reflection-on-action that supports learning by reflecting upon completed learning experiences. These three steps heavily utilize various forms of reflection in an authentic context that builds expertise of the practicing professional who can continue learning and being productive in the face of many changes and challenges.

IDEALS Assessments

Based on the IDEALS model, both formative and summative assessments are needed to achieve high levels of professional skills development. Characteristic to this model, formative assessments are used to clarify student understanding of the challenges they encounter and to provide them feedback on progress being made toward their targeted skill development. Summative assessments are used to determine the performance levels achieved at the end of the project experience. Table 5 identifies nine IDEALS assessments created to correspond to the Define, Assess, and Show steps for teamwork, professional responsibility, and professional development. Two of the assessments are completed by the team as a whole to facilitate a negotiated understanding of the challenge, progress toward goals, and suitable action plans. The remaining assessments are completed by individual students to prompt their reflection and reveal their understanding.

Table 5. IDEALS Assessments by Step in the IDEALS Model and by Respondent

<table>
<thead>
<tr>
<th>Step</th>
<th>Teamwork</th>
<th>Professional Responsibility</th>
<th>Professional Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define</td>
<td>Team Contract [T]*</td>
<td></td>
<td>Professional Development Plan [I]**</td>
</tr>
<tr>
<td>Assess</td>
<td>Team Member Citizenship [I]</td>
<td>Professional Responsibility Formation [I]</td>
<td>Professional Development In-Progress [I]</td>
</tr>
<tr>
<td></td>
<td>Teamwork In-Progress [T]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Show</td>
<td>Teamwork Achieved [I]</td>
<td>Professional Responsibility Achieved [I]</td>
<td>Professional Development Achieved [I]</td>
</tr>
</tbody>
</table>

*[T] indicates completed by team; **[I] indicates completed by individual

Figure 2 shows a typical schedule for implementing IDEALS professional skills assessments as part of the IDEALS model implementation within a design project. Open triangles represent formative assessments; filled triangles are summative assessments. Each row constitutes an implementation of the IDEALS learning and assessment cycle for one family (e.g., teamwork) of assessments in the context of the design project. Note that the teamwork row includes three formative assessments, which are justified by the complexity of the teamwork challenges. The professional responsibility row includes only one formative assessment, although it can be repeated to provide additional feedback. Each row ends with a summative assessment.
Assessment Design

The quality of IDEALS assessments is evidenced by their compliance with the assessment triangle and fulfillment of a recognized set of quality criteria. According to the assessment triangle promulgated by the National Research Council, methods for gathering assessment data (observation) must be based on the ways that students learn and represent knowledge (cognition), and assessment results must be interpreted with this cognition in mind \(^{14}\). Earlier discussion of learning and motivation theories behind the IDEALS model gives evidence that the professional skill cognition and assessment are aligned. IDEALS assessments are constructed to gather data that reveals students’ perceived performances, attitudes toward professional skills development, negotiated understandings, abilities to self-assess, abilities to apply knowledge, and abilities to extend learning. These align with the ways students learn and demonstrate their learning of professional skills.

Stiggins identified five criteria for high quality assessment: clear purposes, clear and appropriate targets, proper methods, appropriate sample, and bias and distortion eliminated \(^{16}\). The following paragraphs explain how IDEALS assessments comply with these criteria.

**Clear Purposes.** Each IDEALS assessment fulfills either a formative or a summative purpose, not both. The Define and Assess step assessments are formative. The Show step assessment is summative.

**Clear and Appropriate Targets.** IDEALS learning targets are the learning outcomes defined in Table 1. For each outcome, performance factors are identified and scoring rubrics are defined at five levels: novice, beginner, intern, competent, and expert. For example, performance factors for the summative Teamwork Achieved assessment include: member contributions (peer ratings of contributions, contributions summaries written by peers, and contribution impacts on the team); an effective team process (description of the process, explanation of process value, and future
application of the process); and teamwork learning (description of learning achieved, description of the learning process, and future application of this process). These definitions, when shown to students, provide clear and appropriate learning targets for students.

**Proper Methods.** IDEALS assessments prompt descriptions of behaviors and explanations by the students to reveal their understanding and attitudes \(^{16}\). Students are asked to identify the problem, define a plan of action, reflect on efforts to address the challenge, reflect on learning, and describe strong performances and their impacts—all of which reveal understanding. They also rate importance and perceived performance levels of a skill—revealing their attitudes toward these skills and abilities to self-assess these skills. Thus, the assessment methods align well with learning targets that include performance, understanding, and thinking processes.

**Appropriate Sample.** Steps in the IDEALS model guide the order of data sampling—first formative, then summative. Individual and team assignments ensure that all teams and all students provide data. Sampling of team process understanding occurs twice, which is useful for coaching improvement and documenting improvement. Multiple scores (multiple performance factors) for each assessment and written instructor feedback to each submitted assessment provide multiple pieces of information for coaching student performance and for assigning scores for performances. Sampling is adequate for guiding individual improvement, grading individual students, and documenting outcomes achieved by the class.

**Bias and Distortion Eliminated.** Assessment bias and distortion can arise when items or tasks differentially assess student competence or performance based on variables that have nothing to do with the task at hand. IDEALS assessments are comprised of items developed by a team of engineering design educators representing diverse students, engineering disciplines, and institution types. Assessment format and items have been tested and revised to reduce confusion and to clarify student expectations. Instructional modules (reading materials and in-class discussions) have been created to precede administration of formative assessments for two purposes: providing uniform preparation for students taking the assessments and creating familiar vocabulary and expectations prior to beginning the assessments. Assessments are typically assigned for out-of-class completion so that students have adequate time and an environment conducive for completing an assessment well. A possible form of bias is the student’s verbal skills, which could bias understanding of the assessment prompt and bias their articulation of their performance and understanding.

**Implementation of IDEALS Model**

**IDEALS Modules**

Instructional materials have been prepared to accompany selected IDEALS assessments to support student learning and to remove potential biases in assessment. Due to widely ranging backgrounds and vocabularies of students in (especially) multidisciplinary project courses, the formative assessments are structured as modules to prepare students for completing each assessment well. These modules contain pre-class readings and exercises, in-class team activities and discussions, and post-class assessments. The readings and classroom discussions clarify
student preconceptions, build common vocabulary, and provide organizational structure to help students connect their new understanding. The first formative assessment then focuses on understanding terminology and organizational structure, assessing one’s current stage of personal development, and identifying desired performances and/or plans. Subsequent formative assessments focus more on development of reflection and self-assessment (and some peer-assessment) skills. Subsequent assessments do not need the same kind of scaffolding since they assume that students have learned requisite material prior to completing the assessment.

Assessment Facilitation

Facilitation of professional skills development is vital to the success of student learning 33, 34. As noted earlier, instructor attitude toward, and modeling of, professional skills to be learned by students affects student motivation to learn and their ability to construct a mental model for the skills 25. Providing helpful feedback is also important to learning 25, 35. Helping students reflect on experiences is crucial to drawing the greatest learning from the experience 28, 36. Therefore, the manner in which professional skills learning is facilitated is important to using the IDEALS assessments effectively. The following practices have been found effective.

To aid motivation –

- In the context of the course, explain the rationale for developing professional skills and cite examples of leaders and employers who stress the importance of these skills.
- Explain how class project activities are intended to simulate professional work environments and require similar kinds of professional skills.
- Give illustrations of previous students and teams that have progressed very well as a result of strong (and improving) professional skills.
- Implement IDEALS modules at times when students recognize the need for help in related skills development.

To aid learning –

- Use IDEALS instructional materials, including in-class activities, to prepare students for IDEALS formative assessments.
- Use formative assessments before using the summative assessment in the same family of modules to orient students to terminology, thinking processes, and expectations.
- Discuss with students examples of excellent student work for an assessment prior to asking them to complete that assessment.
- Provide rapid and personalized written or oral feedback to students upon their completion of an IDEALS assessment.
- Facilitate in-class discussion of assessment results to point out benefits gained, strong performances, and steps to improve future responses.
Evidence of Module Impact

Recent use of IDEALS assessments has provided evidence of student learning, skill development, and positive attitudes toward professional skill development and assessment. Davis et al. reported from the use of the Team Member Citizenship assessment that students increased their teamwork skills, benefited from instructor feedback on assessments, and saw benefits from completing teamwork assessments. In a similar way, McCormack et al. documented student benefits from IDEALS assessment utilization and following the sequence of formative assessment followed by summative assessment. Students showed increased valuing of the professional skills as they progressed through their project and professional skills development experience.

When students identified professional skills that needed development in the context of their projects, they most often identified interpersonal skills such as communication, collaboration, and leadership. Thus, students themselves recognized the need for and the benefits from professional skills development. When students followed through to achieve and document their skill development, they provided solid evidence of achieving the ABET Engineering Criterion 3i (lifelong learning) outcome: demonstrating “a recognition of the need for, and an ability to engage in life-long learning.”

Teamwork Achieved Example

The following student response illustrates the thinking prompted by IDEALS assessments and learning that occurs in an individual student participating in these activities. Student A, who provides this response, has previously completed a Team Contract assessment and a Team Member Citizenship assessment. In the Teamwork Achieved assessment responses recorded below, Student A is discussing a team process that he/she considered to be effective.

Effective Process: “developing a supporting inclusive team climate”

Prompt: Describe what actions occurred when this "effective" team process was working well.

Student Response: Our team always took the time to remind each other how much of an impact each of us has on the success of the project. Although we were all busy at some point, the other members offered support and help when needed. I felt that I could trust my team members to do their part and deliver what they needed. We would communicate to each other both praise and constructive criticism honestly and productively.

Prompt: Explain how this "effective" team process contributed real value to your team and/or project.

Student Response: Due to the supportive climate, it was easier to work with the others and complete my contributions to the team. The open atmosphere encourages me to voice my opinion and ensure that I am investing as much as I can toward the success of the team.

Prompt: Explain how developing this "effective" process has equipped you for future team projects.

Student Response: This process has allowed me to see how important it is to keep the team morale high. This allowed for productivity and allowed for a sense of joy for achieving success.
together. In the future, I will definitely make sure that I participate in activities that ensure a supportive climate because it encourages all the team members to work harder.

Prompt: What new understanding of teamwork have you gained over the past year?

Student Response: I have learned that conflicts and differences in opinion will be inevitable in a team. Through this project, I’ve gained experience in handling this difference in perspective successfully. Instead of taking things personally, I learned to communicate my feelings as best as I can. I learned to listen effectively and evaluate others’ opinion against mine.

Prompt: Describe the (learning) process that led to this new understanding.

Student Response: I was able to learn this understanding through differences in opinion that I had regarding the final products we were to deliver and submit to the class. I argued that we should increase the quality of the final product but the others in my team argued that due to lack of time and resources, we had to settle with lesser quality. In the end, we were able to talk about the situation and come to a consensus. Due to lack of time and resources, we increased the quality as best as we can.

Prompt: How will this new understanding affect your approach to teamwork in the future?

Student Response: I believe that handling the situation in a civil and professional manner ensured that the team morale did not go down. At the same time, I was able to express my perspective and it was communicated to my other team mates. In the future, I will behave in a similar manner to ensure that I achieve the same results.

To understand these responses, let’s consider Student A’s previous responses to the Team Contract and Team Member Citizenship assessments. In the team’s contract, the team addressed team climate only briefly by the statement, “Meeting discussions will be conducted in a conversational format with special regard for a dialogue that is respectful and considerate of all members in attendance.” The Team Member Citizenship assessment revealed that Student A saw the other members “faithfully meeting expectations” with regard to “engaging members with respect,” but one member was perceived by teammates to “usually meet expectations, occasionally allow failure to occur” with regard to “demonstrating commitment.” This suggests that different members of the team had differing opinions about the value of completing the project well.

As Student A’s responses to the end-of-semester Teamwork Achieved assessment illustrate, Student A documented significant learning that resulted from the process of developing a supportive team climate. Student A acknowledged issues that caused potential problems, formulated an approach, took action, achieved better results, and learned principles valuable for the future. Thus, the series of teamwork assessments integrated with a team-based project enabled significant achievement of new learning and performance improvements as documented by the assessment steps in the IDEALS learning model.
Summary and Conclusions

The IDEALS model was presented as an integrated set of learning and assessment steps employed to develop and document high-level professional skills achievement in the semi-authentic professional context of a capstone engineering design project course. Learning and motivation theories were used to justify contextual, metacognitive features of this integrated learning and assessment model. A set of formative and summative assessments was presented for teamwork, professional responsibility and professional development, and these were sequenced to align with the IDEALS model. Early formative assessments were coupled with pre-class and in-class instructional materials to establish foundational shared knowledge and performance expectations that support effective student learning and the quality assessment of achievement. The IDEALS model’s integration of instruction and assessment was described as producing increased learning of professional skills and more valid measures of targeted performances that are valuable for grading and program outcomes documentation. An example from the IDEALS teamwork modules illustrated metacognitive development of the student as well as significant achievement in teamwork knowledge and performance.

The IDEALS model was formulated based on targeted professional skills and established learning theories. Evidence for its impacts on learning continues to be gathered and analyzed. Preliminary data show promising results related to student learning of professional skills, recognizing benefits from IDEALS learning materials and assessments, and positive attitudes about the importance of professional skills to their projects and careers.

Acknowledgements

The authors express their gratitude to the National Science Foundation, Division of Undergraduate Education, for support of this work under grant number DUE 0919248.
References Cited

17. International Engineering Alliance *Graduate Attributes and Professional Competencies*; 2009.