introducing an assessment plan into a k–12/university engineering partnership

Daniel W. Knight and Jacquelyn F. Sullivan

BACKGROUND

The goal of the Integrated Teaching and Learning (ITL) Program in the College of Engineering and Applied Science at the University of Colorado at Boulder was to provide a multidisciplinary learning environment that integrated engineering theory with practice and promoted creative, team-oriented problem-solving skills. Housed in the ITL Laboratory, a 34,400 square foot, technology-rich, hands-on learning facility, the program is equipped with design labs, measurement and analysis tools, team workrooms, manufacturing and electronics centers, and interactive learning exhibits (Carlson and Sullivan 2004). The ITL’s K–12 Engineering Outreach Initiative extends the hands-on, inquiry-based learning vision into the K–12 community, using project-based engineering as a vehicle for the integration of math and science. It supports the belief that hands-on, active learning engages students in the excitement and satisfaction of gaining competency in science, technology, engineering, and math (STEM) (deGrazia et al. 2001; Schaefer, Sullivan, and Yowell 2003). Comprehensive assessment is also an important component of the initiative.

The outreach initiative targets three areas in its strategy to encourage young people to consider careers in engineering:

* The recruitment and preparation of university students serving as engineering “ambassadors” in Denver K–12 classrooms and after-school programs.
* The offering of summer engineering classes, workshops, and camps for K–12 students and teachers to enjoy the challenges of engineering.
The development of standards-based K–12 engineering education curricula for use in K–12 classrooms across the country.

Supported by the National Science Foundation and the U.S. Department of Education, seven engineering graduate students serve yearlong fellowships as in-depth science and math content resources and engineer role models in K–12 classrooms. In collaboration with the K–12 teachers, the fellows introduce hands-on engineering activities to students as a real-world approach to theoretical science and math concepts (deGrazia et al. 2001).

During the summer, K–12 students and teachers participate in active-learning engineering classes and workshops that focus on specific STEM subject areas. For example, Creative Engineering was a weeklong electromechanical design-and-build class for students entering ninth grade. Mechanics Mania was a two-day, standards-based professional development workshop, in which upper-elementary-level teachers explored the importance of mechanics in solving everyday problems. In these workshops, engineering instructors and fellows from the University of Colorado at Boulder taught STEM fundamentals within an engineering context in fun and engaging ways (Poole, deGrazia, and Sullivan 2001; Schaefer et al. 2004).

Since the inception of the ITL K–12 Engineering Outreach Initiative in 1997, a robust collection of comprehensive engineering curricular units has been created for use in K–12 science and math classrooms. Topics include the laws of motion, airplanes, electricity, environment (air and water), energy of motion, and mechanics. Each lesson features affordable, hands-on activities designed especially for specific age ranges to strengthen youngsters’ theoretical concepts and support their learning.

**Outreach Assessment Plan and Results**

**Program Development**

As the program was developed by ITL members, a detailed assessment plan provided structure for the curriculum. During this developmental phase, an assessment matrix was created to specify program goals, objectives, performance criteria, and assessment methods (Rogers and Sando 1996).

An assessment matrix specifying two of the seven goals that the fellows had for the teachers and students, as well as a portion of the objectives and criteria for each goal, is shown in Table 1. One goal is to improve teachers’ skill and comfort with STEM content knowledge and pedagogy. This broad goal was translated into two more-specific learning objectives: (1) broaden an appreciation for inquiry-based, hands-on learning among teachers, and (2) avoid creating more work for the teachers. Criteria were developed to specify the precise level of performance required to meet each objective. Success was achieved if 90% of teachers indicated a willingness to participate in the program and if 90% of teachers reported that the program did not increase their workload.

The next step was to choose an assessment method to assess each criterion.
A survey was administered to all of the participating teachers at mid-year. Across each of the four years, teachers were asked if they wanted to continue with the program (yes or no) and to explain their answer. The results showed that 96% of teachers (109) wanted to continue with the program. One teacher stated, “I greatly appreciate giving my students exposure to ‘real-life’ application of science by working with fellows. Eighth graders benefit greatly by being able to ask questions and by having a connection with people pursuing science/engineering who aren’t too much older than themselves.” Information from this assessment tool indicated that program objectives were met.

**PROGRAM IMPLEMENTATION**
A comprehensive assessment plan is also important during the implementation phase to provide real-time formative feedback to program developers and instruc-

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**TABLE 1.**
Excerpt of Assessment Matrix for Integrated Teaching and Learning (ITL) Program’s K–12 Engineering Outreach Initiative

<table>
<thead>
<tr>
<th>Goals</th>
<th>Objectives</th>
<th>Performance Criteria</th>
<th>Assessment Methods</th>
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<tbody>
<tr>
<td>1. Improve teachers’ skill and comfort with STEM content knowledge and pedagogy.</td>
<td>1a. Broaden an appreciation for inquiry-based, hands-on learning among teachers.</td>
<td>1a. 90% of teachers indicate a willingness to participate again in the fellows-in-the-classroom program.</td>
<td>1a. Teacher semester survey.</td>
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<td></td>
<td>1b. Do not create more work for K–12 teachers.</td>
<td>1b. 90% of teachers report that the program did not increase their workload.</td>
<td>1b. Teacher semester survey.</td>
</tr>
<tr>
<td>2. Enrich STEM learning by K–12 students.</td>
<td>2a. Student learning is enhanced through experiencing relevant, hands-on, inquiry-based engineering curricula.</td>
<td>2a. Compared to control groups, treatment students demonstrate a significant increase in STEM content knowledge.</td>
<td>2a. Student content test.</td>
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<td>2b. Students gain knowledge of engineering as a career, an understanding of the pervasiveness of engineering in their world, and an appreciation of engineering as creating things for the benefit of society.</td>
<td>2b. At the end of the year, students demonstrate a greater understanding of engineering as a career.</td>
<td>2b. Student attitude survey, student focus group.</td>
</tr>
</tbody>
</table>
tors. A variety of formative assessment methods have been incorporated into the design of curricula for use in the K–12 classrooms, all targeted at answering the important question, “How do you know your students get it?” For example, one hands-on activity incorporated into a middle school environmental science lesson has students collect water and test for water quality. The activity is followed by a formative assessment activity in which students work in pairs to brainstorm other methods of testing water quality. The students then create a flowchart demonstrating their methods for collecting and treating drinking water. By examining the flowcharts, teachers gain insights into students’ understanding of the concepts. Similar formative assessment activities can be found in Kagan (1994).

Formative assessment tools are used to provide K–12 students with feedback. A rubric of a formative assessment tool used by undergraduate mentors provided feedback to high school girls involved in a six-week summer internship called Girls Embrace Technology (Figure 1). The rubric is made up of measurement scales representative of the course objectives (Caso and Kenimer 2002). Rubrics typically have weighted anchors on each scale that provide an example of exceptional, fair, and poor performance (Davis et al. 1998). For example, the scale entitled “Participation” is anchored on the upper end by the following statement: “Participates actively and enthusiastically in the team project” and on the lower end by “Low level of participation; somewhat going-through-the-motions.” The rubric, with its weighted anchors, is a useful rating tool for undergraduate team mentors who are generally inexperienced in giving performance ratings.

PROGRAM SUSTAINABILITY
Assessment also plays an important role in program sustainability, providing summative results for accountability. Summative assessment plans make use of qualitative and quantitative methods to assess four different targets: content knowledge, skills, affect, and opinions (Cunningham 1998; Payne 1994). Summative data are gathered and used at the end of outreach offerings to evaluate attainment of the goals and objectives.

The first summative assessment approach involves content testing. Changes in content knowledge are determined through the use of objective tests that ask students to choose from several answers (Cunningham 1998). Care was taken to ensure that course content was appropriately sampled. Up, Up and Away, a professional development workshop for teachers, explored the fundamentals of aerodynamics in a hands-on way. Twenty teachers anonymously completed a 10-item, multiple-choice test before and after the workshop. One sample item read as follows:

*For a powered airplane in steady, level flight, drag:*

*Is the sum of friction and pressure forces plus a part created from lift.*

*Must balance the thrust.*

*Must have the same magnitude as the lift.*
**FIGURE 1.**
Formative Performance Feedback Rubric Used in a Summer High School Internship (Girls Embrace Technology)

<table>
<thead>
<tr>
<th>Participation: Enthusiasm, involvement, and commitment</th>
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<tr>
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<tr>
<td>Participates actively and enthusiastically in the team project.</td>
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<tr>
<th>Information Technology Knowledge: Willingness and ability to learn new software</th>
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<td>Eager to learn new information technology knowledge; eager to take risks and stretch oneself to apply knowledge.</td>
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<th>Project Management Skills: Organization, Goal Setting, and Attainment</th>
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<td>Highly organized and efficient, pushes project toward goals; aware of time and deadlines.</td>
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The average pretest score was 44% across all items; a 75% posttest average demonstrated a 30% knowledge gain. T-test statistical procedures indicated a difference that was significant at the $p < .05$ level.

A second example of content testing was conducted with the fellows in the classroom program. The fellows, in cooperation with the K–12 teachers, developed content tests for 13 curricular units (i.e., Electricity and Magnetism, the Human Body, and Sound and Light). Fellows collected 1,139 matched pre- and posttests from eight schools (an experimental group in grades 3–12 and a matched control group that received a traditional curriculum) (see Figure 2). Analysis of variance statistical procedures revealed a significant interaction effect ($p < .01$), indicating that the experimental and control groups demonstrated different learning gains. While both test and control students began at the same place and both demon-
strated significant gains, the ITL outreach group scored significantly higher than the control group on the posttest. In our opinion, summative data indicate that the ITL outreach curriculum and instruction more strongly affected student learning than did the traditional classroom curriculum and instruction.

We believe that this type of summative assessment had several advantages: Scoring could be accomplished with a high degree of accuracy (only one correct answer); the efficient format allows assessment to be inserted into a full curriculum; and external parties (such as granting and accreditation agencies) trust the results from objective tests. A strong criticism of this testing method is that it does not gauge the actual application of the knowledge (Cunningham 1998). Conceptual understanding is difficult to determine with a limited number of test questions.

Skills self-confidence is the second summative assessment tool used in ITL outreach initiatives. Students rate their confidence on a variety of skills associated with curriculum goals and objectives. Skills self-confidence is associated with motivation to pursue careers in engineering (Ponton et al. 2001). The 35 high school students attending Success Institute (a weeklong design-and-build camp targeting students typically underrepresented in engineering) reported their largest skills confidence gain as “giving technical presentations” (oral presentation experiences required in the curricula). Student confidence in oral presentation skills is developed through training in the use of PowerPoint software and rehearsing performances and conducting presentations to an audience of their family members, instructors, and peers. Student pre and post responses are a relatively efficient method of gaining insights without burdening instructors or training external judges.

A third summative assessment approach is the measurement of affective characteristics, such as interest in engineering and science, and comfort working in teams. Interest assessment predicts future behavior above and beyond the assessment of ability (Holland 1997). Similarly, comfort working in teams is an important predictor of success in engineering (Newport and Elms 1997). Student interest in majoring in engineering is measured at the beginning and end of the American Indian Upward Bound program (a six-week summer design-and-build initiative conducted at the University of Colorado at Boulder for recruiting Native American youth into the engineering field). Student interest in majoring in engineering jumped 33% in this program for the eight students, where students reported that they were “somewhat interested” at the beginning of the program and “highly interested” by the end of the program.

A fourth type of summative assessment is the use of the “opinionnaire,” an open-ended assessment that ascertains student opinions about specific course components and program outcomes using broad, free-response questions (Payne 1994). Three open-ended questions are asked of participants at the conclusion of outreach classes and workshops: (1) What did you like best about the curriculum? (2) What did you find least satisfying about the curriculum? and (3) How could the curriculum be improved? One school principal associated with the fellows pro-
gram answered the opinionnaire question “What do you like best about the program?” by writing, “The quality of the fellows—they come in very knowledgeable and very eager to work with our students.” Open-ended questions are a useful complement to quantitative data because the questions do not pre-forecast experiences by providing structured response categories and allow program participants to report information that may not have been considered by program planners.

LESSONS LEARNED
Two major lessons were learned during the implementation of the ITL Program’s K–12 Engineering Outreach Assessment Plan.

Note: Data were collected from eight schools, grades 3–12. The experimental group received the ITL curriculum and the control group received a traditional curriculum.
Lesson 1: All parties must be aware of and committed to the assessment plan prior to program initiation. The development of an assessment matrix, securing informed consent, the administration of surveys, and looping assessment results into the program design are demanding and time-consuming. The rewards for these efforts are plentiful, but resistance to this cumbersome process can be expected unless expectations are agreed upon in advance.

Lesson 2: It is important to set up a debriefing shortly after the completion of each class, workshop, or camp. A debriefing session gathers all parties involved in the K–12/university components to review outcomes, share and discuss specific assessment results, and incorporate the lessons learned into the design of future plans and offerings. Without this timely concluding step, substantial time and resources spent on assessment may be wasted. Scheduling a debriefing places the analysis of assessment data on a shorter timeline and offers results for interpretation to a multidisciplinary audience with the goal of integration and informed changes (Poole, deGrazia, and Sullivan 2001).

Summary
A comprehensive assessment plan is a key component of the ITL Program’s K–12 Engineering Outreach Initiative. The plan provides an analytical structure for guiding workshop development, shaping implementation, measuring success at conclusion, and informing future planning. The design of our K–12 engineering outreach curricula typically begins with an assessment matrix that specifies course goals, objectives, performance criteria, and assessment methods. Curricular units incorporate an array of engaging formative assessment activities as well as the measurement of summative assessment targets. These include content-knowledge testing, assessment of skills self-confidence, affective characteristics, and open-ended questionnaires. The implementation results in valuable lessons learned. The importance of obtaining prior approval from the large number of parties involved in K–12 outreach and the importance of disseminating results in a timely fashion to assist future curricula design based on actual outcomes were significant findings.

Links to the National Science Education Standards
The work described in this chapter has links to two assessment standards of the National Science Education Standards (NRC 1996). The first is Assessment Standard A, assessments must be consistent with the decisions they are designed to inform. This standard suggests the need to deliberately design assessments in advance, which parallels the emphasis in this chapter on specifying an assessment matrix at the beginning of a programmatic effort. The second is Assessment Standard B, achievement and opportunity to learn science must be assessed. This standard is based on the need to assess the learning of content and the context in which the content is delivered. This process is discussed in this chapter in the section on summative assessment, as multiple assessment methods such as content testing and skills self-assessment are used for the purpose of determining program outcomes.
REFERENCES


RESOURCES


TeachEngineering.com This online collection gives K–12 teachers and engineering faculty access to a rich resource of STEM (science, technology, engineering, and math) lessons and activities. Available at [www.cea.wsu.edu/TIDEE/monograph.html](http://www.cea.wsu.edu/TIDEE/monograph.html).
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Jacquelyn F. Sullivan is founding co-director of the Integrated Teaching and Learning (ITL) Program and Laboratory. She co-teaches Innovation and Invention and a service-learning Engineering Outreach Corps elective. Sullivan initiated the ITL’s K–12 engineering outreach program. She has 14 years of engineering experience in industry and served for 9 years as the director of an interdisciplinary water resources decision support research center at the University of Colorado. She received her PhD in environmental health physics and toxicology from Purdue University.