An Assessment Matrix for Evaluating Engineering Programs

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ABSTRACT

In this paper we describe the use of an assessment matrix to help faculty develop an assessment plan for their engineering program. Use of the matrix assures that each of the key steps in an effective assessment plan is addressed: setting goals and objectives; selecting performance criteria; planning an implementation strategy; choosing appropriate measures; setting a timeline; and providing timely feedback. The matrix has been used successfully to provide an assessment framework for engineering curricula, individual courses, and educational research projects.

I. INTRODUCTION

In response to a variety of internal incentives, such as the desire to improve our teaching and our students' learning and in response to external pressures from accreditation agencies, legislatures, and industry, most engineering programs are currently developing assessment plans to document student learning outcomes and improve the quality of their programs. In this paper we discuss a matrix which we believe provides faculty with the structure they need to develop an effective assessment plan but with the flexibility to be adapted for a variety of settings and purposes. The matrix has been used successfully at our own institution and in assessment workshops at other institutions; it can also easily be used for educational project evaluation[1] or individual course assessment. Our goal in developing the matrix was to help demystify assessment for engineering faculty and assuage some of their fears about assessment.

In the paper we first present a brief overview on developing an assessment plan and then introduce details of our matrix. To help illustrate the utility of the matrix in program assessment, we provide two extensive examples of matrices designed to meet specific ABET criteria. Finally, we include a glossary of common assessment terms used in this paper to help novice assessors better understand the matrix and its use.

II. DEVELOPING AN ASSESSMENT PLAN

Although most engineering faculty are not experienced at formally assessing and evaluating educational programs, they are experienced at other forms of assessment. For example, assessment is an important element of supervising a graduate student towards completion of a thesis project, developing research proposals and publications, conducting technical or educational research, or completing an engineering design project. Thus, engineering faculty possess extensive implicit knowledge of assessment processes.

We have found that direct reference to an engineering design process can be a helpful way to guide development of a program assessment plan. As shown in Figure 1, engineering design is an iterative, non-linear process beginning with identification of stakeholder (particularly client) needs, followed by detailed development of project goals and objectives, generation of design alternatives, selection of the "best" design that meets project objectives while addressing anticipated constraints, and communication of results to stakeholders, who in turn provide feedback which is used to refine and improve the final design.[2]

Although collecting assessment data and analyzing the results may be more complex and less objective in education than in technical research, the goal is clear—to determine as reliably as possible if the stated program goals and objectives have been met and, if not, to decide what steps should be implemented to improve each student's educational experience.

Using the design process shown in Figure 1 as a guide, we recommend completing the following steps to develop a program assessment plan:

- Identify program goals consistent with institutional goals and the needs of internal and external stakeholders including accrediting agencies such as ABET.
- Develop program objectives and performance criteria for each program goal.
- Decide what program curricular and co-curricular activities will address each objective.
- Determine the best methods for assessing and evaluating each objective and when assessment data will be collected.
- Report results to stakeholders and use feedback to improve the program and the assessment process itself.

Each of these steps will be discussed more fully in the next section.

III. THE ASSESSMENT MATRIX

We have found that the easiest way to begin developing a program evaluation plan is to use an assessment matrix, summarized in Table 1, which we adapted and expanded from a similar matrix included in the National Science Foundation's *User Friendly Handbook for Project Evaluation*.[3] We are also indebted to the outcomes assessment guidelines developed by Gloria Rogers and Jean Sando and published in *Stepping Ahead: An Assessment Plan Development Guide*.[4]

The program assessment matrix provides faculty members (especially ones with little assessment experience) with a structure for developing their assessment plan using a series of questions—as they answer the questions, they essentially articulate the plan. Thus, the matrix provides a "hands-on," concrete tool for guiding development of the assessment plan—it is not an abstract document that simply lists what needs to be done. As shown in Table 1, questions are posed in the matrix to help develop the following aspects of the plan: program goals and objectives; performance criteria; implementation strategy; evaluation methods; timeline; and feedback. Each of these components of the plan should be treated as iterative and fluid as the program's curriculum is taught, assessed, and revised. Additional details to help faculty members work through the planning process are discussed below.

A. Goals and Objectives

Developing clear goals and objectives is the key to the success of an assessment plan. Faculty often fail to spend the time necessary to articulate clear goals and objectives before they rush to develop, measure, and evaluate a program's curriculum. They need to begin by defining broad programmatic goals and then answering such questions as "What are the program objectives?" and "What should students know and be able to do when they complete the program?" Here we are defining "goal" as a broad statement of desired program outcomes[4] such as "students who complete the program should be able to communicate effectively." An objective is a "detailed statement which describes under what circumstances the goal will be achieved."[4] For the communication goal outlined above, the first objective might be that "students should be able to communicate effectively in writing to a variety of audiences for a variety of purposes." Subsequent objectives under the same goal could address oral and graphic communication skills. Objectives should be clear, precise, and measurable. For example, the objective "Students will know more about design after completing our design sequence" is too general because "know more" is a vague term with different meanings for each faculty member and student.

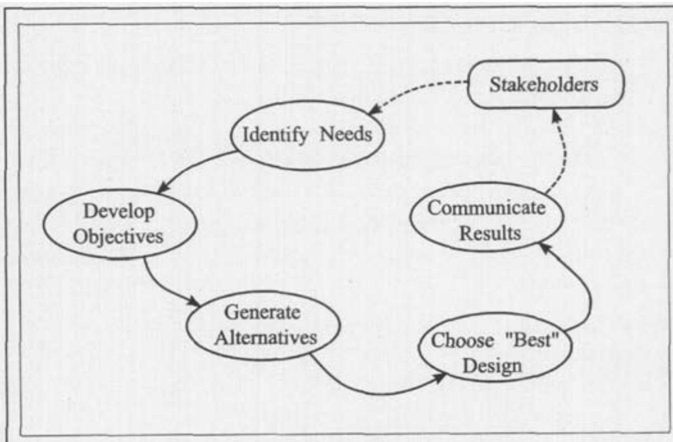

Figure 1. Schematic diagram of an engineering design process.

The objective becomes more focused when rephrased as "After completing our design sequence, students will be able to articulate the design process and use it to satisfactorily complete a project." Both of the components of this objective—"articulate the design process" and "use it to complete a project"—lend themselves to measurable performance criteria. As a second example, consider the program objective stated as "retain more students to the completion of their degree." Issues surrounding such an objective include quantifying "more" and setting reasonable timelines on "completion of their degree." These issues would have to be addressed in order for the objective to become measurable and useful.

Articulating clear goals and objectives will help faculty achieve consensus on the educational mission of their program. Not everyone would agree with our rephrasing of the examples, but a faculty group working to clarify these objectives would be forced to agree on definitions of terms such as "know more" and "completion of degree."

B. Performance Criteria

Faculty should also articulate performance criteria for each objective to be evaluated. A performance criterion "defines the level of performance required to meet the objective"[4] and indicates the types of data that will be collected to provide supportive evidence. Once again, faculty must discuss and agree upon what performance levels they expect their students to achieve; this discussion will help make explicit faculty ideas and beliefs about satisfactory levels of student performance. The questions to be answered here are "How will you know the objectives have been met?" and "What level of performance meets each objective?" For example, the performance criterion that "75 percent of the students who take our Introduction to Engineering course will remain in engineering two semesters after they complete the course" represents a measurable level of performance for a program objective to improve student retention. As a second example, consider a program objective to ensure that all students are able to work in multidisciplinary teams by the time they graduate. An effective performance criterion for this objective might be "Students will rate their teammates as satisfactory or higher on six characteristics of effective team performance." This example illustrates the use of student-reported formative data to help students work better in teams and also to monitor overall development of each student's teaming skills.

C. Implementation Strategy

It is important to make sure that program objectives, performance criteria, and implementation strategies mesh. For example, important questions such as "How will the objectives be met?" and "Which program activities help to meet each objective?" should be answered as the implementation strategy is developed. We have seen assessment plans with numerous lofty goals for student achievement between entry and graduation. However, the faculty developing these goals sometimes fail to allow sufficient opportunities in the curriculum for students to meet the goals. For example, if students are to learn the design process, or how to communicate effectively, or to gain an understanding of contemporary issues, they must have an opportunity within the curriculum and/or co-curriculum to learn, practice, and improve these skills and abilities. Just as a researcher carefully plans an experiment, so too the faculty must carefully plan the program to help students

Goals	What are the overall goals of the program? How do they complement institutional and accreditation expectations?
Program Objectives	What are the program objectives? What should your students know and be able to do?
Performance Criteria	How will the objectives be met? What program activities (curricular and co-curricular) help you to meet each objective?
Evaluation Methods	What assessment methods will you use to collect data? How will you interpret and evaluate the data?
Timeline	When will you measure?
Feedback	Who needs to know the results? How can you convince them the objectives were met? How can you improve your program and your assessment process?

Table 1. Program assessment matrix.

meet specific goals and objectives. Often faculty members lack the "big picture" view of the curriculum, thinking only of their individual specialties and courses. One benefit of developing an assessment plan is that the process itself allows the faculty to examine the entire curriculum and to see how each faculty member's courses fit into the program's overall goals and objectives.

D. Assessment Methods

Once program objectives and an implementation strategy have been developed, general assessment methods and evaluation strategies should be selected. We are defining assessment as "collecting and analyzing data on student academic performance," and evaluation as "interpreting assessment data to draw conclusions about how well program goals and objectives are being met."[4] Good assessment allows faculty to draw sound conclusions about the program. The basic questions here are "What assessment methods will you use to collect data?" and "How will you interpret and evaluate the data?" The methods selected will depend on many factors including time and money available, but several rules of thumb apply:

- Explore a range of possible methods, qualitative and quantitative, formative and summative, depending on the program objectives.
- Whenever possible, use more than one method — triangulate.
- Realize that for some program objectives it may be difficult or impossible to obtain purely objective assessment results. However, methods exist to assess complex objectives with a high degree of precision and reliability.

Many assessment techniques are available to interested faculty members including quantitative instruments such as standardized examinations and questionnaires, and qualitative instruments such as focus groups, ethnographic studies, and protocol analysis. Descriptions of these and other assessment techniques are widely available (see reference 5 for a concise overview of 13 commonly-used methods); many innovative methods are discussed in this special issue of the *Journal of Engineering Education.*

Once the methods are selected, appropriate data should be collected and analyzed and results compared with the performance criteria established earlier. If, for example, a department has decided that it should retain 75 percent of its students two semesters following an Introduction to Engineering Course, its measures will be relatively straightforward: compare the students who registered for the class two semesters ago to those remaining in the program. If the percentage is around 75 percent, fine. If not, the results can be used to begin a discussion about the reasons for a lower or higher than expected retention rate. Note that the evaluation of such data and decisions about how to use the results for program improvement are often complex; that is, the root cause of poor retention may be hard to identify. However, a high quality assessment process helps programs make decisions based on data, not hunches or anecdotal evidence.

E. Timeline

The important question here is "When will you measure?" Some objectives require formative (mid-course) measurements; others are summative and can reasonably be put off until students reach the end of the curriculum. A combination of formative and summative assessment usually works best. For example, students' ability to work well in multidisciplinary teams is a skill that takes time to develop. Most programs would wish to measure teamwork ability at more than one key point in their students' education, perhaps at the end of each academic year. The same could be said for other developmental skills such as oral and written communication and critical thinking. Such formative assessment provides valuable feedback to both students and programs and encourages corrective action before it is too late. On the other hand, technical knowledge acquired in specific classes may be best assessed once at an appropriate place in the students' program. Although there are no clear-cut rules about when to collect data, most successful assessment programs prefer to maintain longitudinal data on their students so that progress toward meeting program objectives can be steadily monitored. In addition, the collection of longitudinal data allows programs to demonstrate "value added" by the curriculum, to show how students gain in knowledge and skills from one point, e.g., sophomore year, to another point, e.g., graduation. A single, summative, evaluation makes it difficult to measure any *change* in student outcomes

F. Feedback

Here the key questions are "Who needs to know the results?", "How can you convince them the objectives were met?", and "How can you improve your program and your assessment process?" The stakeholders for a program or curriculum (e.g. faculty, students, other programs, accrediting agencies) should be identified and their needs analyzed. Different audiences clearly have different agendas and will need information presented in different ways to be informed that a program meets its goals and objectives. Evaluation reports should be customized to meet the needs of various audiences and delivered in time to be useful. For example, students' ability to apply mathematical concepts would be important not only to the mathematics department, but also to engineering departments who expect their students to be mathematically competent. In addition, programs interested in ABET accreditation could also use these data as part of the evidence that students have satisfactorily acquired the competencies specified in Criterion 3a ("Graduates will have an ability to apply knowledge of mathematics, science, and engineering"). Each of these stakeholders has an interest in the same assessment data—but for different reasons and purposes.

IV. Examples of Program Assessment

Two examples of assessment serve to illustrate the points that we have made. Both of the examples were designed to demonstrate achievement of ABET Criteria 2000 goals: the ability to solve engineering problems (Criterion 3e) and the ability to communicate effectively (Criterion 3g) respectively. First, we discuss an example from the assessment plan of a chemical engineering department and then we provide an example dealing with written communication. These examples are meant to be illustrative only; many alternative approaches to the objectives outlined here could be taken. The matrix is designed to allow for flexibility to mirror the uniqueness of each program.

A. Assessment Within a Chemical Engineering Program

Table 2 summarizes a completed assessment matrix for one goal from a chemical engineering department evaluation plan focusing on assessing students' ability to apply knowledge of engineering fundamentals when formulating and solving chemical process problems. This goal was written to address ABET criterion 3e which states that "graduates will have an ability to identify, formulate, and solve engineering problems."[6] Chemical engineering faculty decided that the best way to measure students' competence in problem-solving was to use performance assessment methods in two courses where an ability to solve engineering problems is essential—unit operations laboratory (a junior-level course) and process design (a senior-level course). These courses are designed to help students apply their knowledge of engineering and problem solving in a context which closely resembles professional engineering practice.

As shown in Table 2, students' ability to solve equilibrium and rate process problems in their final design project is assessed using a faculty-developed scoring rubric. The rubric contains specific problem-solving attributes to be assessed (e.g. problem formulation, identification of key assumptions, computational accuracy, etc.) and characteristics which specify each level of performance on a 1 (inadequate) to 5 (excellent) Likert scale. Student ability to solve unit operations problems is assessed in the unit operations laboratory course using a second faculty-developed rubric. By working together to develop each rubric, faculty were able to identify and articulate the attributes of good problem-solving skills for chemical engineering students. Developing a department assessment plan required faculty to make explicit their views and reconcile differences among their implicitly-held beliefs.

After further discussions, the faculty decided that approximately 80% of design students should be rated at least "adequate" on problem-solving skills in their final project and that approximately 80% of unit operations students should be rated at least "adequate" on problem-solving skills in their laboratory work. Each performance criterion was purposely established at a very high achievement level because problem-solving was deemed a crucial attribute of successful chemical engineering professionals.

Once the performance criteria and evaluation methods were

Goals: What are the overall goals of the program? How do they complement institutional and accreditation expectations?

Chemical Engineering graduates will be able to identify, formulate, and solve chemical process problems (ref. ABET criterion 3e)

Program Objectives	Performance Criteria	Implementation Strategy	Assessment Methods	Timeline	Feedback
What are the program objectives? What should your students know and be able to do?	How will you know the objectives have been met? What level of performance meets each objective?	How will the objectives be met? What program activities (curricular and co-curricular) help you meet each objective?	What assessment methods will you use to collect data? How will you interpret and evaluate the data?	When will you measure?	Who needs to know the results? How can you convince them the objectives were met? How can you improve your program and your assessment process?
Graduates will be able to identify, formulate, and solve the following types of chemical process problems:					
equilibrium and rate processes	80% of students in process design will be rated at 3 (adequate), 4 (good) or 5 (excellent) on engineering problem-solving ability in their final design project.	Students complete process analysis, thermodynamics, fluid mechanics, heat transfer, mass transfer, and reaction kinetics courses.	Each student's final project from process design will be assessed by design instructors using a rubric developed by department faculty.	Projects will be assessed at the end of the semester.	Results will be used by department faculty to improve instruction in rate and equilibrium processes courses, to provide individual students with feedback on their progress towards graduation, and to assess how well graduates meet ABET requirements.
unit operations	80% of the students in unit operations laboratory will be rated at 3 (adequate), 4 (good) or 5 (excellent) in engineering problem-solving ability in each open-ended lab experiment.	Students complete fluid mechanics, heat transfer, and mass transfer courses.	Each student's performance on each lab experiment will be assessed by lab instructors using a rubric developed by department faculty.	Experimental work will be assessed during the unit operations laboratory course.	

Table 2. Assessment matrix for a chemical engineering program goal.

established, determining the appropriate timeline for collecting assessment data was straightforward. Assessment of final design projects has to occur after completed projects are submitted at the end of each semester, while assessment of performance on laboratory experiments can occur throughout the laboratory course. This strategy allows collection and analysis of both formative and summative data about students' problem-solving abilities. Also note that the design and laboratory reports can potentially be used to assess goals related to two other ABET criteria–3c ("Graduates will have an ability to design a system, component, or process to meet desired needs") and 3b ("Graduates will have an ability to design and conduct experiments, as well as to analyze and interpret data"), suggesting that carefully-selected measures can be used to assess multiple goals and objectives.

Finally, Table 2 summarizes the department's plans for providing timely and pertinent assessment results to three stakeholder groups-faculty members who teach equilibrium processes, rate processes, and unit operations courses; students who have completed these courses; and ABET. Faculty will use assessment data to improve teaching and learning while students will receive feedback on development of their problem-solving skills as they progress towards graduation. The data will also be used as a measure of how well chemical engineering graduates meet ABET requirements. Thus, the same assessment data can be used to meet different evaluation needs for multiple stakeholders. Since each group will use the results for different purposes, data will need to be selected and presented differently. For example, students will be most interested in their individual assessment results, faculty will be concerned about aggregate results for specific courses being assessed, and ABET will view the results as part of the comprehensive chemical engineering program assessment plan.

B. A Writing-Across-the-Curriculum Program

ABET Criterion 3g states that programs must be able to demonstrate that their graduates have the "ability to communicate effectively." The matrix (Table 3) focuses on one of several possible objectives under this goal for an engineering program—the ability to communicate effectively in writing. In response to the question "What should your students know and be able to do?" the faculty developed the following objective: "Students should be able to communicate effectively in writing to a variety of audiences using a variety of writing strategies. They should produce letters, memos, abstracts, reports, laboratory reports, proposals, and research papers." Clearly the program's focus is on multiple audiences, purposes, and genres within the technical communication realm.

The faculty in the engineering program have also agreed upon performance criteria: in their case, *all* students must demonstrate competency in written communication in order to graduate. This kind of "pass/fail" requirement may have serious consequences for students and should be considered very carefully before being adopted. However, it also sends a very strong message about the value the institution places upon written communication skills.

As shown in Table 3 the faculty have also indicated specific courses in each year where students can receive instruction and practice their writing skills. The faculty have decided to use a portfolio

Goals: What are the overall goals of the program? How do they complement institutional and accreditation expectations?

Students should be able to communicate effectively in writing (ref. ABET criterion 3g)

Program Objectives What are the program objectives? What should your students know and be able to do?	Performance Criteria How will you know the objectives have been met? What level of performance meets each objective?	Implementation Strategy How will the objectives be met? What program activities (curricular and co-curricular) help you meet each objective?	Assessment Methods What assessment methods will you use to collect data? How will you interpret and evaluate the data?	Timeline When will you measure?	Feedback Who needs to know the results? How can you convince them the objectives were met? How can you improve your program and your assessment process?
Students should be able to communicate effectively in writing to a variety of audiences using a variety of writing strategies. They should produce letters, memos, abstracts, reports, laboratory reports, proposals, and research papers.	A student graduating from the program should receive an overall score of "exceeds standards" or "meets standards" on the portfolio he/she submits to the writing assessment committee, based on the rubric developed by the WAC committee and augmented by the major program.	Freshman year—Writing-intensive H&SS course; Introduction to Engineering Practices I course Sophomore year—Introduction to Engineering Practices II course Junior and Senior years—2 courses each year that are approved as "writing intensive" by the school-wide WAC committee.	Students will keep portfolios of selected written work over their CSM careers. Faculty advisors will evaluate the portfolios yearly in writing. Students will assess their progress in communication skills yearly in writing. Portfolios will be evaluated before graduation by a faculty/industry committee using a rubric developed by the school-wide WAC committee.	Formative assessment and self-evaluation will be done yearly. A final, summative assessment will be completed in the student's final semester.	The results will tell us whether our WAC program is effective. The writing program, departments, students, accrediting agencies, and prospective employers need to know the results. Aggregate feedback can be used to pinpoint areas in the curriculum in need of improvement/change. Individual students will receive both formative and summative feedback.

Table 3. Assessment matrix for a program communication goal.

system for measuring student development in writing. Portfolios are commonly used in writing assessment and there is a rich assessment literature pertaining to them.[7, 8] In the example, each student maintains a portfolio which is evaluated yearly by advisors as well as by the student himself or herself (formative assessment). In addition, the portfolios are evaluated summatively as a graduation requirement by a faculty/industry committee using a rubric developed by the institution-wide writing-across-the-curriculum committee. In such a system, students are informed from the beginning of their program what the criteria are for successful completion of the writing requirement; they thus become active participants in the assessment of their own progress towards meeting program goals.

Feedback from the process goes to students, the program, employers, and accrediting agencies. The student receives both formative and summative feedback; the formative feedback helps him/her to know areas of strength and weakness which can then be built upon or remediated. The engineering program faculty learn whether the writing-across-the-curriculum program is successful in preparing students to meet the program goal of "communicating effectively in writing." Careful tracking of assessment results helps identify specific areas in the curriculum in need of revision. Prospective employers have confidence that students can meet high standards articulated in part by industry, and ABET is given assurance that program graduates are effective communicators.

CONCLUSIONS

We believe that engineering educators have the creativity and intellectual predilection to become good program assessors. Our assessment matrix was designed to provide some structure as they begin the process of exploring the many possibilities for effective assessment. The matrix was designed to allow maximum flexibility in the choice of objectives, implementation strategies, measures, and feedback while at the same time assuring that each of these essential components of the assessment process is considered. Our hope is that faculty will use it as a valuable tool in developing assessment plans.

VI. GLOSSARY OF TERMS

Assessment—collecting and analyzing data on student academic performance[4]

Evaluation—interpreting assessment data to draw conclusions about how well program goals and objectives are being met[4]

Feedback—providing stakeholders and other interested parties with the results of the assessment and evaluation process

Formative assessment—assessment designed to monitor progress and provide direction for midcourse corrections

Goal—broad statement of desired program outcomes[4]

Method—process or instrument used to collect assessment data

Objective—detailed statement which describes under what circumstances it will be known that the goal has been achieved[4]

Performance assessment—assessment based on completion of tasks which demonstrate one's knowledge and/or skill in a specific activity

Performance criteria—statements which define the level of performance required to meet an objective[4]

Qualitative assessment—assessment which relies upon non-numerical data that are descriptive and interpretive[3]

Quantitative assessment—assessment which relies upon numerical measurements[3]

Rubric—a scoring guide which provides descriptions of student work of varying quality

Stakeholders—individuals or groups who have an interest in the quality of an educational program

Summative assessment—assessment designed to demonstrate how closely goals and objectives have been met and provide direction for program improvement

Triangulate—the use of more than one method to assess a program goal

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