

# Efficient and Effective Strategies for Collecting Assessment Data

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## Abstract

The accreditation process for engineering programs was substantially changed ten years ago when the ABET EC2000 criteria were implemented. (The moniker EC2000 is no longer in use; they are now simply the ABET criteria.) Programs must define specific goals and objectives, collect sufficient data to make an objective determination of whether graduates are or are not meeting these objectives, and demonstrate evidence of using the data to effect continuous programmatic improvement. These accreditation criteria present programs with significant challenges. Departments must determine what data are needed and collect it regularly. To be sustainable, assessment plans must make efficient use of faculty time. This paper will present strategies for integrating the collection of assessment data with the process of grading individual student assignments.

The Rowan Chemical Engineering programs' identified objectives are all summative in nature: e.g., "Graduates will have the ability to do..." Consequently, programmatic assessment strategies are based upon two courses that offer a *culminating* experience with respect to these desired outcomes; namely, the capstone design course and the Junior/Senior Engineering Clinic. In both courses, the major deliverables are final design reports and final presentations. Detailed grading rubrics have been crafted for these assignments in both courses. The rubrics are used both as a tool for evaluating the students' work and as a mechanism for communicating expectations to the students. The specific criteria for individual assignments are each mapped to one or more of the programmatic outcomes. This paper presents the grading rubrics themselves, illustrates the mapping of assignment criteria to program outcomes, and demonstrates how the same raw data can be used both for grading individual students and for program assessment.

## Background

### *Programmatic Assessment for Engineering*

Since 2000, ABET<sup>1</sup> has required that in order to be accredited, engineering programs must demonstrate that they are practicing continuous assessment and continuous improvement. Components of a good assessment strategy include:

- 1) Establish specific goals and educational objectives for the degree program. These must encompass 11 outcomes<sup>2</sup> (designated "A-K") identified by ABET as essential for *all* engineering programs.
- 2) Measure the degree to which graduates of the program are attaining the goals and outcomes
- 3) Use the data collected in step 2 to identify opportunities for improvement, and modify the program accordingly
- 4) "Close the loop" by assessing whether the changes led to improved attainment of desired outcomes<sup>1</sup>

According to Dr. Gloria Rogers<sup>3</sup> the most difficult part of the process, and one which most engineering programs do not do well, is "identification of a limited number of

performance indicators for each outcome.” An outcome is a broad statement such as “The Chemical Engineering Program at Rowan University will produce graduates who demonstrate an ability to apply knowledge of mathematics, science, and engineering,” which mirrors ABET outcome A<sup>1</sup>. Dr. Rogers notes that programs “...tend to go from broad outcomes to data collection without articulating specifically what students need to demonstrate...”<sup>3</sup>

The importance of “articulating specifically what students need to demonstrate” has long been understood at the level of individual courses. Felder, for example, has long advocated for writing clear, carefully thought out instructional objectives for courses<sup>4</sup> and communicating them to students at the start of the course. Felder subsequently outlined strategies for writing instructional objectives for courses and pedagogical strategies for delivering courses that were consistent with meeting the ABET A-K criteria.<sup>5</sup> This paper presents an example of a programmatic assessment strategy that integrates the course and program levels as follows:

- 1) Identify courses that offer a *culminating experience* in the curriculum
- 2) Identify essential elements for each of these courses
- 3) Prepare grading rubrics that evaluate student achievement with respect to each element
- 4) Map the elements of the courses to the programmatic objectives; verify that each programmatic objective is well represented
- 5) Evaluate student design reports and final presentations using the grading rubrics
- 6) Use the data obtained from the evaluation both for individual student grading and for programmatic assessment

A previous paper<sup>6</sup> described how this process evolved over the past ten years. This paper focuses on the assessment process as it is currently implemented. One section is devoted to each of the six tasks summarized above.

### **1) Identify Courses that Offer a Culminating Experience in the Curriculum**

The program’s current assessment plan is built around two courses: Chemical Plant Design, the capstone design experience, and Junior/Senior Engineering Clinic, an interdisciplinary project-based course.

#### *Chemical Plant Design*

Note that programmatic objectives require that graduates will possess certain skills and aptitudes. Demonstrating, for example, that students are capable of designing heat exchangers while they are enrolled in heat transfer is not a realistic measure of the capabilities of *graduates*. The capstone design course is the most straightforward venue for evaluating the abilities of graduates, since it is taken in their final semester and requires them to synthesize information learned throughout the four-year curriculum.

The capstone course in the Chemical Engineering program is called Chemical Plant Design. Student teams are tasked with designing a complete chemical process, (e.g., design a process to manufacture 50 million pounds of methyl methacrylate per year)

including economic analysis and assessment of safety and environmental impact. Plant design problems can be framed such that they draw from every required chemical engineering course in the curriculum. Further, the course at Rowan has always been team-taught by a tenure track faculty member and an adjunct faculty member with an industry background, in order to ensure that problems are genuinely reflective of engineering practice. Despite these facts, the capstone design course cannot realistically be the *sole* vehicle for assessing achievement of programmatic objectives. The two most prominent reasons are:

- One program objective is that graduates will have the ability to function effectively on multidisciplinary teams. While students work in teams of 4-5 in Chemical Plant Design, neither the teams nor the design problems can be well described as “multidisciplinary.”
- Some program objectives are related to ability to perform hands-on experimental and laboratory work. Chemical Plant Design makes extensive use of simulation but has never been taught with a wet lab component (at least, not at Rowan).

The next section describes a project-based course that complements Chemical Plant Design.

### *Junior/Senior Engineering Clinic*

Rowan University has an eight-semester Engineering Clinic program intended to provide Engineering students with experience solving practical, open-ended engineering problems. The sequence culminates in the Rowan Junior/Senior Engineering Clinic, in which students work on real engineering research and design projects. Project teams work with close faculty supervision and usually consist of 3-4 students; sometimes drawn from a single discipline but generally representing more than one, depending on the needs of the particular project. Most projects are externally sponsored, either by local industry or government agencies. Consequently, the Junior/Senior Clinic provides the most genuine reflection of engineering practice in the curriculum: the projects are real problems with real clients.

Every Junior/Senior Clinic project is unique. While all Engineering Clinic project teams need to identify and apply relevant engineering principles synthesized from a variety of courses, there is no stipulation that any *specific* chemical engineering subject matter (e.g., heat transfer, diffusion, chemical reaction kinetics) be a substantial aspect of every project. Consequently, the Junior/Senior Clinic provides an ideal setting for assessment of engineering skills in general (functioning on multi-disciplinary teams, etc.), the capstone design course provides an ideal setting for assessment of discipline-specific skills, and many program outcomes (e.g., communication skills, understanding solutions in societal/global settings) are well represented in both courses.

## **2) Identify Essential Elements for Each Course**

While the specific design problem in Chemical Plant Design is different every year, one can identify elements such as an economic analysis, an environmental impact assessment,

etc., that are integral components of *any* chemical process design. A list of the identified essential elements for plant design is given below. Similarly, every Junior/Senior Clinic project is unique, but there are general expectations that are common to all clinic projects, such as defining objectives, executing a plan to attain them, interpreting data to form valid conclusions, etc. The desired outcomes for these project-based courses are listed below.

*Essential Elements for Chemical Plant Design projects:*

- Overall Process Conceptualization
- Physical Properties of Chemicals
- Reaction Stoichiometry and Kinetics
- Separation Techniques
- Sizing & Design of Unit Operations
- Use of Modern Engineering Tools
- Estimation of Capital Costs
- Estimation of Revenues and Operating Costs
- Overall Economic Analysis
- Tier 1 Environmental Analysis
- Tier 2 Environmental Analysis
- Analysis of Process Hazards
- Conclusions and Recommendations
- Effective Written Communication
- Effective Oral Communication

*Essential Elements for Junior/Senior Engineering Clinic projects:*

- Meeting Deadlines
- Defining Project Goals
- Working in Teams
- Project Organization
- Record Keeping
- Safety
- Professional Conduct
- Professional Attire
- Execution of Project Plan
- Awareness of Existing Relevant Technical Literature
- Understanding and Application of Underlying Principles
- Apparatus or System Design
- Laboratory Functions
- Use of Modern Engineering Tools
- Societal/Global Perspectives
- Interpretation of Results
- Formulating Conclusions
- Making Recommendations

- Effective Written Communication
- Effective Oral Communication

### **3) Prepare grading rubrics that evaluate student achievement of instructional objectives**

The elements identified in the previous section are relatively broad s. With no further guidance, gauging the performance of a specific student or team with respect to one of these (on, for example, a 1-10 scale) is quite subjective. Consequently, consistent with the strategy outlined by Felder,<sup>5</sup> detailed rubrics that benchmark the meaning of specific levels of performance have been crafted for each of the elements listed in the previous section. Example rubrics are provided in Table 1. The entire Rowan Chemical Engineering department participated in a previous study<sup>7</sup> that demonstrated excellent repeatability between ratings assigned by different faculty members using the rubrics. In the years since then, more rubrics have been added and details have evolved with time, but subsequent studies have continued to demonstrate inter-rater reliability when using the rubrics<sup>8</sup>.

By College policy, all Junior/Senior Clinic projects include a mid-semester review presentation, a final written report and a final presentation. Individual faculty set deadlines and expectations for additional deliverables (e.g., progress reports, memos, etc.) to meet the needs of their specific projects, but the department's assessment plan only uses data obtained for these common assignments. Similarly, in Chemical Plant Design, there is always a final report and final presentation that are heavily weighted in the course grading, and the rubrics described in the previous section are specifically designed for these final deliverables. Other assignments such as progress reports and homework are assigned at the discretion of the instructor but do not figure into programmatic assessment.

### **4) Map the course outcomes to the programmatic objectives; verify that each programmatic objective is well represented**

The chemical engineering program has four goals:

Goal 1 - Develop students who understand and apply the core scientific, mathematical, and engineering principles that form the basis of chemical engineering.

Goal 2 - Develop students who work individually and in diverse teams and effectively utilize advanced technology to solve complex problems.

Goal 3 - Develop students who gain a perspective on the role of engineering in a global society including the importance of ethics, professional responsibility, diversity and culture, lifelong learning, safety, sustainability and the environment.

Goal 4 - Develop students who communicate their ideas effectively in various formats to both technical and non-technical audiences.

There are 15 instructional objectives related to these goals (three of which are further sub-divided into distinct outcomes) as summarized in Appendix A. Final reports and presentations in Junior/Senior Clinic and Chemical Plant Design clearly contain evidence regarding whether or not students have met these goals and objectives. This evidence is gleaned through a systematic mapping of the expectations for individual assignments to the programmatic objectives which they reflect. An example portion of the mapping is illustrated in Table 2.

### **5) Evaluate student design reports and final presentations using the grading rubrics**

The complete grading rubrics are distributed to students in both Chemical Plant Design and Junior/Senior Engineering Clinic during the first week of class. The purpose of using a 1-10 scale and benchmarking the meanings of 10, 7 and 5 is to communicate expectations to students in familiar terms. The specific weighting of each individual outcome in the grading of assignments varies from project to project and is at the discretion of the course instructor, but students recognize that the 10/10 column summarizes what they need to do to earn an A, the 7/10 column summarizes what they need to do to earn a C, etc. As previously reported,<sup>6</sup> average performance in Junior/Senior Engineering Clinic improved when the practice of distributing the rubrics in the first week of class was implemented, though the improvement was not dramatic enough to be statistically significant with the relatively small sample size available (~12 teams per semester).

Each assignment (report or presentation) is then evaluated by the course instructor or project manager and scored on a scale from 1-10 with respect to each element, using the rubrics as a guide. Logistically, this is done using Microsoft Excel spreadsheets. The rubrics are summarized on the sheet and ratings for each element are entered into specific cells. A screen capture of a portion of the Chemical Plant Design spreadsheet is shown in Figure @, and the complete spreadsheets are available from the author on request ([dahm@rowan.edu](mailto:dahm@rowan.edu)).

### **6) Use the data obtained from the evaluation both for individual student grading and for programmatic assessment**

Some faculty ask their student teams to provide a self-evaluation of their own work using the rubrics and site specific evidence to defend their ratings. Other faculty simply use their own evaluation of reports and presentations to inform the assignment of grades. Faculty have the discretion to determine that specific elements are not applicable to a particular project (though this is rare) and to weight the importance of each element in grading. Prior to introduction of grading rubrics for Junior/Senior Engineering Clinic, most faculty assigned grades by a holistic evaluation of the team's work throughout the project. Since the grading rubrics were devised, faculty have reported feeling more confident that the grades they assign are legitimately fair reflections of student performance.<sup>9</sup>

The department's assessment coordinator collects the evaluations of each team in Chemical Plant Design and Junior/Senior Engineering Clinic. The mapping of elements of individual projects to program instructional objectives, which was summarized in Table 2, is programmed into the spreadsheets. Consequently, once the data is compiled into a central spreadsheet, the overall student performance with respect to each of the program's educational outcomes is automatically summarized, as illustrated in Figure 2.

## **Summary**

This paper provides a brief introduction to strategies for assessment at the program level and the course level. It also demonstrates that if assessment instruments are carefully designed, collection of data for program assessment need not be cumbersome: the same raw data collected during the routine activity of grading student assignments can also be applied to programmatic assessment. The strategy is summarized in a six-step method that is applicable to any engineering program, though the specific objectives to be assessed and courses in which to implement the strategy will be different for every program.

**Table 1: Grading rubrics for assessment of Junior/Senior Clinic projects.**

Project Element	An "A" team (10)	A "C" team (7)	A "B" team (5)
Project Goals	Actively involved in defining ambitious and achievable objectives that thoroughly addressed fundamental project needs	Assisted in defining objectives, but required significant faculty guidance even once the project was running	Took little initiative in defining the project and waited to be told what to do
Underlying Principles	Applied relevant chemical, physical and/or mathematical principles in an accurate and, as possible, quantitative manner. Provided an insightful and reasonable theoretical interpretation or model of experimental results	Demonstrated some knowledge of relevant chemical, physical and/or math principles. Provided a valid but cursory theoretical interpretation of experimental results	Application of underlying principles is fundamentally flawed or absent entirely
Apparatus or System Design	Designs apparatus or system that is safe, economical and meets project requirements	Design meets requirements of project but may not be fully optimized, and/or some retro-fitting required to overcome initial design errors or oversights	Design does not meet requirements of project
Modern Engineering Tools	Team used modern engineering tools (e.g. simulation, spreadsheets, word processors and graphics software) as appropriate for project. Team <i>fully utilized</i> capabilities of available engineering tools to work efficiently and accurately	Team used modern engineering tools for obvious applications. Capabilities of software not fully utilized, leading to inefficient use of time and/or diminished quality of final product.	Modern engineering tools would have benefitted project but were either substantially mis-used or not used.
Interpretation of Results	Obtained and adequately interpreted meaningful results, critically analyzed results using appropriate mathematical models	Produced significant results but provided limited meaningful interpretation, error analysis is largely qualitative or incomplete	Generated more excuses than results, analysis is lacking or wrong
Societal/Global Perspectives	Team demonstrated thorough awareness of significance and impact of project in societal/global context, explicitly and insightfully addressing issues such as energy, environment, economics, government regulation, etc.	Team demonstrated some awareness of global/societal issues, team made accurate but broad observations regarding energy, environment, etc.	Team paid superficial or no attention to societal/global issues.



**Table 2: Mapping of aspects of Junior/Senior Clinic projects to five programmatic outcomes (the Chemical Engineering Program at Rowan has 18 total outcomes).**

	Ability to apply knowledge of mathematics, science, and engineering.	Acquisition and interpretation of experimental results	Design and conduct appropriate experiments	Working knowledge of chemistry principles	Working knowledge of chemical engineering principles
Deadlines					
Project Goals					
Teaming					
Project Organization			<b>X</b>		
Record Keeping		<b>X</b>			
Professional Conduct					
Professional Attire					
Safety		<b>X</b>			
Execution of Project Plan			<b>X</b>		
Technical Awareness	<b>X</b>			<b>X</b>	<b>X</b>
Underlying Principles	<b>X</b>			<b>X</b>	<b>X</b>
System or Apparatus Design	<b>X</b>				
Laboratory Functions		<b>X</b>			
Modern Engineering Tools					
Interpretation of Results	<b>X</b>	<b>X</b>			

Team	Team 5	Team 6	Average	Overall Process Design	A	C
4	7	7	8.333333	Overall Process Conceptualization	Process meets stated objectives & is thoroughly optimized.	Process meets stated objectives but is not well optimized. Opportunities for recycle, heat integration etc. not explored.
5	10	10	10	Physical Properties of Chemicals	Physical properties and safety hazards of all species known, clearly presented, and used to inform design	Physical properties and MSDS sheets for chemicals are present, but some design decisions display lack of understanding of significance of the information
6	10	10	10	Reaction Stoichiometry and Kinetics	Reactor models are accurate and realistic based upon available information, and reactor is thoroughly optimized. Any assumptions are clearly stated and reasonable.	Reactor models are self-consistent but may include assumptions that are unnecessary, dubious or not explicitly acknowledged. Optimization attempted but not fully achieved.
7	8	8	9.333333	Separation Train	Individual separation operations are carefully chosen, sequenced for maximum efficiency, and thoroughly optimized. Models are realistic. Assumptions are explicitly stated and reasonable.	Workable separation operations are chosen but some reasonable alternatives not explored. Desired objectives achieved but not with maximum efficiency. Some assumptions unnecessary, dubious or not explicitly acknowledged.
8	8	7	8.333333	Sizing & Design of Unit Operations	Sizing calculations for all equipment is accurate and based upon sound engineering principles. Assumptions clearly stated and reasonable. Materials of construction chosen for clear and valid reasons.	All needed equipment is accounted for, but some sizing calculations are sub-optimal or overly simplistic. Materials of construction acceptable for application but may be unnecessarily expensive.

**Figure 1: Screen capture of spreadsheet used for Chemical Plant Design. Faculty enter the evaluations on the “Raw Data” tab shown here.**

34	Goal 1, Objective 4: The Chemical Engineering Program at Rowan University will produce graduates who possess a working knowledge of chemical engineering principles including balances, fluid mechanics, transport phenomena, separations, reaction engineering, unit operations, thermodynamics, and process design (AIChE Professional Component).			
37	Overall Process Conceptualization	8.333333		
38	Physical Properties of Chemicals	10		
39	Reaction Stoichiometry and Kinetics	10		
40	Separation Train	9.333333		
41	Sizing & Design of Unit Operations	8.333333		
42	Tier 1 Analysis	9.5		
43	Tier 2 Analysis	9.166667		
44	Analysis of Process Hazards	8.833333		
46	Goal 2, Objective 1, Outcome A: The Chemical Engineering Program at Rowan University will produce graduates who demonstrate an ability to design a system, component, or process to meet desired needs (ABET - C). Students will select a component based on chemical engineering principles that is of an appropriate size and type to meet desired needs.			
48	Reaction Stoichiometry and Kinetics	10		
49	Separation Train	9.333333		
50	Sizing & Design of Unit Operations	8.333333		
51	Goal 2, Objective 1, Outcome B: The Chemical Engineering Program at Rowan University will			

**Figure 2: Screen capture of the spreadsheet used for Chemical Plant Design. On the “Outcomes” tab, student achievement with respect to each outcome is summarized.**

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## Bibliographical Information

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<sup>2</sup> ABET, Inc., "Criteria for Accrediting Engineering Programs," available at <http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2010-11%20EAC%20Criteria%2011-03-09.pdf>

<sup>3</sup> G. Rogers, "How are we Doing? Assessment Tips with Gloria Rogers," available at <http://www.abet.org/Linked%20Documents-UPDATE/Assessment/Assessment%20Tips8.pdf>

<sup>4</sup> R. Felder and R. Brentd, "Objectively Speaking," *Chemical Engineering Education*, 31, 3 (1997).

<sup>5</sup> R. Felder and R. Brentd, "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *Journal of Engineering Education*, 92, 1, (2003).

<sup>6</sup> K. Dahm, "Practical, Efficient Strategies for Assessment of Engineering Projects and Engineering Programs," *Proceedings of the 2010 ASEE Annual Conference and Exposition*, Louisville, KY, June 2010.

<sup>7</sup> J. A. Newell, H. Newell, and K. D. Dahm, "Rubric Development and Inter-Rater Reliability Issues in Assessing Learning Outcomes," *Chemical Engineering Education*, 36, 3 (2002).

<sup>8</sup> K. Dahm, W. Riddell, E. Constans, R. Harvey, J. Courtney, and P. von Lockette "Implementing and Assessing the Converging-Diverging Model of Design in a Sequence of Sophomore Projects," *Advances in Engineering Education*, 1, 3 (2009).

<sup>9</sup> J. A. Newell, H. L. Newell, K. D. Dahm, "Rubric Development for Assessment of Undergraduate Research: Evaluating Multidisciplinary Team Projects," *Chemical Engineering Education*, 37, 3 (2003).

## **Appendix A: Chemical Engineering Program Goals and Objectives**

**Goal 1 - Develop students who understand and apply the core scientific, mathematical, and engineering principles that form the basis of chemical engineering.**

The four program educational objectives related to Goal 1 are:

- 1) The Chemical Engineering Program at Rowan University will produce graduates who demonstrate an ability to apply knowledge of mathematics, science, and engineering (ABET - A).
- 2) The Chemical Engineering Program at Rowan University will produce graduates who demonstrate an ability to design and conduct chemical engineering experiments as well as to analyze and interpret data (ABET - B).

This objective is sub-divided into two outcomes: “Students will approach tasks involving the acquisition and interpretation of experimental results in a logical and systematic fashion” and “Students will design and conduct appropriate experiments that effectively use limited resources to obtain the necessary information.”

- 3) The Chemical Engineering Program at Rowan University will produce graduates who possess a working knowledge of organic, inorganic, materials, and physical chemistry and a background in other advanced chemistry topics as selected by the individual student (AIChE Professional Component).
- 4) The Chemical Engineering Program at Rowan University will produce graduates who possess a working knowledge of chemical engineering principles including balances, fluid mechanics, transport phenomena, separations, kinetics and reaction engineering, unit operations, thermodynamics, and process design (AIChE Professional Component).

**Goal 2 - Develop students who work individually and in diverse teams and effectively utilize advanced technology to solve complex problems.**

The seven program educational objectives related to Goal 2 are:

- 1) The Chemical Engineering Program at Rowan University will produce graduates who demonstrate an ability to design a chemical engineering system, component, or process to meet desired needs within realistic constraints (e.g. economic, environmental, social, political, health, safety, manufacturability, sustainability) (ABET - C).

This objective is sub-divided into two outcomes: “Students will select a component based on chemical engineering principles that is of an appropriate size and type to meet desired needs” and “Students will design a process or system, consisting of components, into operations that convert raw materials into desired products.”

2) The Chemical Engineering Program at Rowan University will produce graduates who have an ability to function on multidisciplinary and/or diverse teams (ABET - D).

3) The Chemical Engineering Program at Rowan University will produce graduates who demonstrate the ability to identify, formulate and solve engineering problems (ABET - E).

4) The Chemical Engineering Program at Rowan University will produce graduates who understand contemporary issues relevant to the field of chemical engineering (ABET - J).

5) The Chemical Engineering Program at Rowan University will produce graduates who have the ability to use techniques, skills, and modern engineering tools necessary for chemical engineering practice (ABET - K).

6) The Chemical Engineering Program at Rowan University will produce graduates who have experience in undergraduate research and engineering in practice.

7) The Chemical Engineering Program at Rowan University will produce graduates who possess skills and experience in working with both bench and pilot scale hands-on chemical engineering equipment.

**Goal 3 - Develop students who gain a perspective on the role of engineering in society including the importance of ethics, professional responsibility, lifelong learning, safety, sustainability and the environment.**

The three program educational objectives related to Goal 3 are:

1) The Chemical Engineering Program at Rowan University will produce graduates who have an understanding of professional and ethical responsibilities (ABET - F).

2) The Chemical Engineering Program at Rowan University will produce graduates who have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context (ABET - H).

3) The Chemical Engineering Program at Rowan University will produce graduates who recognize the need for and the ability to engage in lifelong learning (ABET - I).

**Goal 4 - Develop students who communicate their ideas effectively in various formats to both technical and non-technical audiences.**

A single objective exists for Goal 4. The Chemical Engineering Program at Rowan University will produce graduates who demonstrate effective oral and written communication skills (ABET - G).

For assessment purposes, “effective oral communication skills” and “effective written communication skills” are assessed as two distinct outcomes that fall within this objective.