# Combining the Tasks of Grading Individual Assignments and Assessing Student Outcomes in Project-Based Courses

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## Abstract

ABET requires that engineering programs demonstrate continuous assessment and continuous improvement in order to be accredited. Central to the process is establishing and assessing measurable "student outcomes" that reflect whether the objectives of the program are being met. This paper examines effective strategies for measuring outcomes while using faculty time efficiently. One well-documented assessment strategy is constructing rubrics that measure achievement of desired outcomes and applying them to student work. The use of rubrics for grading of individual assignments and projects is also well documented. This paper demonstrates that a single rubric can be used for both tasks. In the Chemical Engineering program at Rowan University, assessment of student outcomes is primarily conducted through two project-based courses. Projects in these courses are evaluated by the instructor using the rubric, and the data is used both for grading students and for program assessment.

## Background

Since 2000, ABET has required that in order to be accredited, engineering programs must define program objectives and student outcomes, continuously assess how well these are attained, and use the assessment data to inform continuous improvement (Latucca, Terenzini, & Volkwein, 2006). In the early years of the new accreditation criteria, confusion sometimes occurred because different programs used terms like "goals," "objectives" and "outcomes" interchangeably or distinguished between them in different ways. More recently ABET has made efforts to "harmonize" the criteria and nomenclature (ABET, Inc., "A guide"). Using ABET's current definitions:

*Program Educational Objectives* are descriptions of "what graduates are expected to attain within a few years after graduation," (ABET, Inc., "A guide"). Each program defines its own educational objectives based upon its mission and the needs of its constituencies.

*Student Outcomes* describe "what students are expected to know and be able to do by the time they graduate," (ABET, Inc., "A guide"). These too are devised by each program individually but must include 11 outcomes (designated "A-K") identified by ABET as essential for all Bachelor's level engineering degree programs (ABET, Inc., "Criteria").

*Assessment* is the process of collecting data that "evaluate the attainment of student outcomes and program educational objectives," (ABET, Inc., "A guide"). Assessment processes can be qualitative or quantitative, and direct or indirect.

*Evaluation* is the process of interpreting the data, and "results in decisions and actions regarding program improvement," (ABET, Inc., "A guide").

There are currently nine accreditation criteria, with Criterion 2 covering Educational Objectives and Criterion 3 covering Student Outcomes (Latucca, Terenzini, & Volkwein, 2006). Approximately 35 percent of recently evaluated programs were cited with shortcomings in Criterion 3 (Gurocak, Chen, Kim, & Jokar, 2009). Two potential pitfalls that have been identified in recent literature are: not conducting assessment in a *sustained, continuous* manner, and not articulating the expectations for attainment of student outcomes in a way that is specific enough to be useful. This section expands upon these potential problems, and the remainder of the paper describes the approach to student outcomes assessment that has been adopted by the Chemical Engineering program at Rowan University. Aspects of this assessment process have been published in previous ASEE conference proceedings (Dahm, 2010, 2011).

### *Continuous Assessment and Continuous Improvement*

ABET evaluations are scheduled to occur every six years. Shryock and Reed (2009) note that "some programs treat the six-year time lag between visits with the following timeline:

- Year 1 – Celebrate success of previous ABET visit.
- Years 2-4 – Feel that ABET is a long time away.
- Year 5 – Begin to worry about ABET visit the following year, and survey every class imaginable to be ready for year 6 with the ABET visit."

At best, this approach will produce evidence that student objectives were being met at one particular time. Even if this evidence is compelling, the approach is not compliant with the ABET criteria, since it is not continuous and incorporates no real mechanism for improvement of the program. Significantly, ABET recently separated what was "Criterion 3-Program Outcomes" into two distinct accreditation criterion: "Criterion 3- Student Outcomes" and "Criterion 4- Continuous Improvement," (ABET, Inc., "Criteria"). This change was presumably motivated by the need to emphasize the importance of assessment and evaluation as continuous, ongoing activities.

A more subtle point raised by the comments of Shryock and Reed (2009) concerns the strategy of surveying "every class imaginable." Dr. Gloria Rogers ("Assessment blog"; "Assessment tips"), when serving as ABET's Managing Director of Professional Services, called attention to the fact that collecting data from all courses, besides being time-consuming, is contrary to the intent of the ABET criteria. Program objectives are summative in nature; they concern not the capabilities of students in specific courses, but the capabilities of *graduates*. Thus, Dr. Rogers asked: "Why do we collect data in lower level courses and average them with the data taken in upper level courses and pretend like we know what they mean? Are we really saying that all courses are equal in how they contribute to cumulative learning and that the complexity and depth/breadth at which students are to perform is the same in all courses for any given outcome? *Why not only collect 'evidence' of student learning in the course where students have a culminating experience related to the outcome."* (emphasis added) (Rogers, "Assessment blog").

Thus, the 6-year cycle described by Shryock and Reed (2009) is contrary to the intent of the ABET criteria in at least two essential respects. Nonetheless, if assessment activities are perceived by faculty as time-consuming and thankless, even well-intentioned engineering departments could fall into the trap of approaching assessment and accreditation as Shryock and Reed describe. A sustainable assessment plan is one that makes efficient use of faculty time. The strategy used by the Chemical Engineering program at Rowan University integrates student outcomes assessment with other necessary tasks, rather than creating new data-gathering tasks that exist for the sole purpose of outcomes assessment.

### *Strategies for Assessing Student Outcomes*

Assessment instruments can be subdivided into direct and indirect instruments (Shryock & Reed, 2009). Surveys of students, alumni and/or employers are examples of common indirect instruments. The Rowan Chemical Engineering program, for example, administers the survey shown in Appendix B every year immediately prior to graduation. This anonymous survey asks students to rate the abilities of their teammates in the capstone design course with respect to each of the program's student outcomes. The department feels this data has some value and plans to continue administering the survey annually. However, the obvious concern about using an indirect instrument like this one as the *primary* vehicle for student outcomes assessment is that it obtains a subjective opinion that lacks a clear, specific context or basis. By contrast, direct instruments measure attainment of student outcomes through an evaluation of actual student work product.

An outcome is a broad statement such as ABET outcome A: "Students will demonstrate an ability to apply knowledge of mathematics, science, and engineering," (Latucca, Terenzini, & Volkwein, 2006). According to Dr. Rogers ("Assessment tips") most programs "...tend to go from broad outcomes to data collection without articulating specifically what students need to demonstrate." To illustrate this point, consider that the final reports in the Rowan Chemical Engineering capstone design course are typically 40-60 pages long, plus hundreds of pages of appendices. Such a report certainly contains much evidence of whether the student authors have "the ability to apply knowledge of mathematics, science and engineering." However, if "direct assessment" consists of nothing more than the faculty member reading the report and making a single, holistic evaluation of "ability to apply knowledge of mathematics, science and engineering," then this direct assessment has exactly the same shortcomings as the indirect assessment obtained from the survey in Appendix B: the evaluation is subjective and has no clear, specific basis.

In 2003, Felder and Brendt (2003) outlined the use of assessment *rubrics* to create clear, specific and measurable expectations regarding broad student outcomes. An example of a rubric, which was published previously in *Chemical Engineering Education*, is shown in Table 1 (Newell, Newell, & Dahm, 2002). The rubric was produced and used as follows:

- For each student outcome, several *indicators* were identified. While outcomes are very broad, indicators are focused and specific examples of accomplishments that relate to the outcome.
- For each indicator, four different levels of achievement were described. Because the goal of the rubric was to collect definitive evidence that students were or were not meeting student outcomes, there was deliberately no "neutral" descriptor: achievement of level 3 or 4 constituted evidence of students meeting or exceeding expectations, while achievement of level 1or 2 constituted evidence that the desired outcome has not been achieved.
- When reviewing a sample of student work (exam, lab report, etc.) the evaluator simply moved from left to right until he/she found a descriptor that was considered accurate.

Table 1 shows one of the rubrics used by the Rowan Chemical Engineering department during the 2000-2006 accreditation cycle; a similar rubric was crafted for each student outcome. The department also conducted a study that proved there was excellent consistency among ratings assigned by different readers evaluating a particular exam or report, with no specific training in the use of the rubrics required (Newell, Newell, & Dahm, 2002). This result highlights the merit of defining indicators. Inter-rater repeatability would likely not be present if the evaluator were rating broad outcomes rather than specific indicators.

During the 2000-2006 accreditation cycle, data obtained from the assess-

| *Indicator* | *4* | *3* | *2* | *1* |
|---|---|---|---|---|
| Formulates appropriate solution strategies | Can easily convert word problems to equations. Sees what must be done | Forms workable strategies, but may not be optimal. Occasional reliance on brute force | Has difficulty in planning an approach. Tends to leave some problems unsolved | Has difficulty getting beyond the given unless directly instructed |
| Identifies relevant principles, equations, and data | Consistently uses relevant items with little or no extraneous efforts | Ultimately identifies relevant items but may start with extraneous info | Identifies some principles but seems to have difficulty in distinguishing what is needed. | Cannot identify and assemble relevant information |
| Systematically executes the solution strategy | Consistently implements strategy. Gets correct answers | Implements well. Occasional minor errors may occur | Has some difficulty in solving the problem when data are assembled. Frequent errors. | Often is unable to solve a problem, even when all data are given |
| Applies engineering judgment to evaluate answers | Has no unrecognized implausible answers | Has no more than one if any unrecognized implausible answers. If any it is minor and obscure | Attempts to evaluate answers but has difficulty. Recognizes that numbers have meaning but cannot fully relate. | Makes little if any effort to interpret results. Numbers appear to have little meaning |

**Table 1: Sample rubric for the outcome "Students will demonstrate an ability to apply knowledge of mathematics, science, and engineering (ABET - A)"**

ment rubrics served as the primary basis for assessing whether or not student outcomes were attained. The survey shown in Appendix B provided supplemental information, and demonstrated that student perception matched faculty evaluations quite well. While the department was accredited in 2006 with a very favorable response to the assessment program, the use of these assessment rubrics was found to be time-intensive. Portfolios were assembled, and each sample of student work in the portfolio was read and individually evaluated with the rubric. A more time-efficient strategy is *using information that is already available* for outcomes assessment.

The most obvious "direct" assessment instrument available is student grades. However, ABET points out that a grade is a holistic evaluation of whether a student has met *all* of the instructor's expectations. Thus a class of students that has very specific and widespread shortcomings may earn good grades while failing to attain one or more student outcome. There are several recent examples of programs,, that address this concern by identifying tasks, such as individual homework problems or individual questions on exams, that are specific enough that they do reflect single outcomes (Koh, Rodriguez-Marek, & Talarico, 2009; Alaraje & Irwin, 2009; Murray & McGrann, 2009; Welch & McGinnis, 2010). Shryock and Reed (2009) call these "embedded indicators" and note that "it is important for the score of the activity to directly correlate to a specific outcome." Thus, while "the fraction of students who earned at least a B- in capstone design" is probably not a useful metric for assessing any specific student outcome, "the fraction of students who got question 3 correct" might be, if question 3 was well chosen.

The assessment tool described in this paper combines the strategies of using assessment rubrics and using embedded indicators. Recent literature includes several examples of rubrics used for programmatic assessment (Al-Massoud, Baumann, & Gates, 2009; Ossman, 2010; Kalaani & Bernadin, 2010). Other publications include examples of rubrics that were used to evaluate individual student assignments, or student performance in specific aspects of a project (Stansbury & Towhidnejed, 2009; Steiner, Kanai, Alben, Gerhardt, & Hsu, 2010; Golter, Brown, Thiessen, Abdul, & Van Wie, 2010). This paper illustrates how a single rubric can be used for both purposes. The instructor evaluates a student report or project using the rubric, and this evaluation is the basis of assigning a grade. Portions of the rubric are also used as embedded indicators for assessing student outcomes. Thus, it is no longer necessary to assemble portfolios of student work and evaluate them through a separate assessment task, as was done at Rowan during the 2000-2006 accreditation cycle.

## Approach to Assessing Measurable Student Outcomes

For the 2006-2012 ABET cycle, the Rowan University Chemical Engineering department used an assessment strategy that focused on two project-based courses that represent the best reflection of real engineering practice found in the curriculum:

- Chemical Plant Design- the program's capstone design experience.
- Junior/Senior Engineering Clinic- a multidisciplinary, project-based course in which most projects are sponsored by government agencies or local industry.

These two courses clearly offer what Dr. Rogers described as a "culminating experience" in that both require students to apply content from a variety of courses to an open-ended, long term project.

The department's assessment program also included senior exit interviews and student focus groups, and the survey shown in Appendix B, but the remainder of this paper focuses on the process of direct assessment of student outcomes through the two project-based courses noted above. For each of the two courses, the following tasks were completed:

1) Identify the essential elements of the project
2) Craft rubrics that evaluate student achievement with respect to each element
3) Map the elements of the projects to the department's student outcomes
4) Evaluate the final reports and final presentations using the rubrics
5) Use the data obtained from the evaluation both for assigning grades to individual students and for assessing performance of the cohort overall with respect to student outcomes

The execution of these five tasks was described in detail previously and is summarized here (Dahm, 2010 [1], 2011). The department regarded this assessment strategy as a substantial improvement over that used in the 2000-2006 ABET cycle and expects to continue using it through the next ABET cycle.

## Selection of Courses for Assessing Student Outcomes

The capstone design course provides a natural opportunity for assessing student outcomes. Students take it in the final semester of the senior year, and synthesize information learned throughout the four-year Chemical Engineering curriculum. However, the capstone design course cannot realistically be the only mechanism for assessing achievement of student outcomes, because:

- One student outcome is "the ability to function effectively on multidisciplinary teams." While students typically work in teams of 4-5 in Chemical Plant Design, neither the teams nor the design problems can be well described as "multidisciplinary" in the course as it is offered at Rowan. Nationally, however, a significant and growing number of schools are incorporating cross-disciplinary collaborations into capstone design experiences (Howe & Wilbarger, 2006; Bannerot, Kastor, & Ruchhoeft, 2010).
- Some student outcomes are related to ability to perform hands-on experimental and laboratory work. Chemical Plant Design at Rowan University makes extensive use of process simulation but has never been taught with a wet-lab component.

The Rowan University Junior/Senior Engineering Clinic presents students with real engineering research and design projects, most of which are externally sponsored. Project teams usually consist of 3-4 students; sometimes drawn from a single engineering discipline but usually representing more than one, depending on the needs of the particular project. While all project teams need to apply relevant engineering principles learned throughout the curriculum, there is no stipulation that any *specific* chemical engineering subject (e.g., heat transfer, mass transfer, thermodynamics, chemical reaction kinetics) be a substantial aspect of every project. Consequently, Junior/Senior Engineering Clinic is also not suitable as the sole mechanism for assessing student outcomes. Note that Task 3 below is a mapping of student outcomes to the student expectations in the two project-based courses. Had this mapping revealed that some student outcomes were not sufficiently represented, additional courses would have been added to the assessment program, following the same five tasks described below.

### *1) Identify the Essential Elements of Each Project*

The specific project in Chemical Plant Design is different every year, but throughout the last (2006-2012) accreditation cycle, every project had the same general structure: design a complete chemical process to synthesize X million pounds per year of chemical product Y from raw materials. Consequently, one can readily identify elements (economic analysis, environmental impact assessment, etc.) that are integral components of any Chemical Plant Design project. Similarly, while every Junior/Senior Engineering Clinic project is unique, there are expectations that are always present, such as collection of relevant data, analysis of that data to form valid conclusions, safety, professionalism, etc. The complete list of "essential elements" currently used for these project-based courses is shown in Appendix C.

### 2) *Craft rubrics that evaluate student achievement with respect to each element*

The elements identified in the previous section are broad, and with no further guidance, are no easier to assess than are ABET student outcomes themselves. Consequently, consistent with the strategy outlined in the Background section, detailed rubrics have been crafted for each of the essential elements of projects in both courses. Example rubrics are provided in Tables 2 and 3. The complete rubrics are available on request from the author, in the form of EXCEL spreadsheets.

In Chemical Plant Design, the final report and final presentation are always heavily weighted in the course grading. Similarly, by College policy, all Junior/Senior Clinic projects include a mid-semester review presentation, a final written report and a final presentation, and the weighting of each in the course grade is also specified by College policy. Individual instructors in both courses have the freedom to assign other deadlines and assignments (memos, progress reports, etc.) as they see fit, but only these common assignments are integrated into the Chemical Engineering department's assessment program.

Note that for each project element, three levels of performance are described. Recall that the old rubrics shown in Table 1 had four described levels of performance. The new rubrics only have three because the department consensus in 2006 was that "unacceptable" performance on these projects had proved to be comparatively rare, so having two distinct levels of "unacceptable" wasn't necessary. The three levels in the new rubrics can broadly be described as "outstanding," "minimum that is considered acceptable," and "unacceptable." However, in communications with students, they are presented as "10/10, 7/10 and 5/10," for reasons explained further under task 4 below.

### 3) *Map the elements of the projects to the department's student outcomes*

The Chemical Engineering program has 15 student outcomes, as summarized in Appendix A. The final reports and presentations in Junior/Senior Engineering Clinic and Chemical Plant Design contain evidence regarding whether or not these student outcomes have been attained. This evidence is organized through a systematic mapping (a portion of which is illustrated in Table 4) of the expectations for individual project reports and presentations to the measurable student outcomes which they reflect. Note that, while some project elements (e.g., "Professional Conduct" and "Professional Attire") do not map to any of the four sample outcomes shown in Table 4, all project elements do map to at least one of the 15 student outcomes. Thus, in effect, each of the "essential elements" of a project is used as an "embedded indicator" for one or more student outcome.

### 4) *Evaluate the final reports and final presentations using the rubrics*

At the end of the semester, each team's project is evaluated with respect to each element. Logistically, this is done using Microsoft EXCEL spreadsheets; the professor rates the team on a scale from 1-10, using the rubrics as a guide,

| *Project Element* | *Outstanding (10/10)* | *Adequate (7/10)* | *Unacceptable (5/10)* |
|---|---|---|---|
| *Capital Costs* | Estimates of capital costs are thorough and based upon sound calculations. Assumptions are clearly stated and reasonable. Uncertainties are acknowledged. | Estimates of major capital costs are broadly complete and realistic. Some minor contributions to capital cost may be overlooked. Some assumptions may be unnecessary or dubious. Uncertainty not acknowledged. | Capital cost estimate is unrealistic; based on incomplete or inaccurate calculations. |
| *Operating Costs and Revenues* | Estimates of costs and revenues are thorough and based upon sound calculations. Assumptions are clearly stated and reasonable. Uncertainties are acknowledged. | Estimates of major operating costs and revenues are complete. Some minor costs may be overlooked. Some assumptions may be unnecessary or dubious. Uncertainty not acknowledged. | Operating cost and revenue estimates are unrealistic; based on incomplete or inaccurate calculations. |
| *Overall Economic Analysis* | Multiple logical metrics (internal rate of return, net present value, payback period) for overall economic analysis are chosen and accurately applied. Sensitivity analyses are performed to account for uncertainties. | Overall economic analysis is accurate based upon capital and operating cost estimates, but impact of uncertainties are not accounted for. | Overall economic analysis is wrong based upon stated estimates of capital cost, operating cost and revenue. |
| *Tier 1 Environmental Analysis* | Emissions and their environmental impact are effectively minimized or remediated. The contents and destination of all exit streams are documented. | Quantifies emissions and acknowledges their environmental impact but misses some opportunities for reduction or remediation. | Tier 1 analysis is cursory or missing. |

**Table 2: Sample rubric for evaluation of Chemical Plant Design projects**

| *Project Element* | *Outstanding (10/10)* | *Adequate (7/10)* | *Unacceptable (5/10)* |
|---|---|---|---|
| *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.<br>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. |
| *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;<br>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 3: Sample rubric for evaluation of Junior/Senior Engineering Clinic projects**

and enters the ratings into specific cells. Thus, if an instructor thinks that a student team's performance represents aspects of the "10/10" level of performance and aspects of the "7/10" level, he or she can assign a score of 8 or 9.

In Chemical Plant Design, the final report is a comprehensive document. The final presentations are short (~12 minutes long) and the students' objective is to simulate a concise "business meeting" presentation that is suitable for both technical and non-technical audiences. Key results are summarized but the presentation doesn't provide a good forum for evaluating the completeness and accuracy of the work. Consequently, the project elements specifically related to oral communication are assessed through the final presentations and all other project elements are assessed through the final reports.

In Jr/Sr Engineering Clinic, however, the situation is more complicated. Students are involved in unique research projects, and work with close faculty supervision and interactions throughout the semester. Some of the project elements in this course are not best assessed through formal assignments. For example, the "Project Goals" rubric (first row of Table 3) places great emphasis on the level of student initiative in defining the goals. While a final report and/or presentation should contain information on the project goals themselves, it probably won't well represent the nature of the faculty-student interaction that led to defining those goals.

Consequently, the mechanism for assessment varies from one project element to another; they are assessed by the final report, the final presentation, and/or an overall evaluation by the instructor based on the entire semester project. For some elements, such as "Interpretation of Results," the instructor evaluates the team's success three different times: based on what is said in the presentation, based on what is written in the final report, and based on the project overall. The instructor uses the same rubric (see Table 3) for all three evaluations.

The complete rubric spreadsheets are also distributed to the students in both Chemical Plant Design and Junior/Senior Engineering Clinic during the first week of class. Thus, the assessment rubrics serve a secondary purpose of clarifying to students the expectations for these project-based courses. In most Rowan University courses, grades of 90-100% represent A's, 80-89% B's, 70-79% C's, etc. Consequently, while students are unaware of the dual purpose of

| | Ability to apply knowledge of mathematics, science, and engineering. | Design and conduct experiments; collect and analyze data | Working knowledge of chemistry principles | Working knowledge of chemical engineering principles |
|---|---|---|---|---|
| Deadlines | | | | |
| Project Goals | | | | |
| Teaming | | | | |
| Project Organization | | X | | |
| Record Keeping | | X | | |
| Professional Conduct | | | | |
| Professional Attire | | | | |
| Safety | | X | | |
| Execution of Project Plan | | X | | |
| Technical Awareness | X | | X | X |
| Underlying Principles | X | | X | X |
| System or Apparatus Design | X | | | |
| Laboratory Functions | | X | | |
| Modern Engineering Tools | | | | |
| Interpretation of Results | X | X | | |
| Societal/Global Perspectives | | | | |
| Conclusions | | | | |
| Recommendations | | | | |

**Table 4: Mapping of elements of Junior/Senior Clinic projects to four student outcomes (the Chemical Engineering Program at Rowan has 15 total outcomes).**

the rubrics, they recognize the implications for course grading: 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. A previous study demonstrated that the overall performance of teams in Junior/Senior Engineering Clinic improved when the practice of distributing grading rubrics in the first week of class was first implemented, though the improvement was not dramatic enough to be statistically significant with the relatively small sample size available (~12 teams per semester). This result was actually obtained in 2003, using a set of rubrics that was originally designed strictly for assigning grades, and was subsequently modified into the consolidated rubric tool described here (Newell, Newell, & Dahm, 2003).

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

The faculty evaluations of final reports and presentations are used to inform the assignment of grades to student teams and to individual students, though there is no single explanation of how this is done. The weighting of each aspect of a project in the grading of assignments varies from one project to another, and is at the discretion of the instructor. The strategy used by the author personally is as follows: (1) characterize each project element as "essential," "of secondary importance" or "not applicable" to the specific project, (2) weight all "essential" elements equally in the grade, and (3) combine all "secondary importance" elements and give them, as a group, the same weighting in the grade as a single "essential" element.

Note that prior to the introduction of a common grading rubric that was agreed upon by the department, most of the Chemical Engineering faculty assigned Jr/Sr Clinic grades by a holistic evaluation of the team's work. Since the use of grading rubrics was first introduced, faculty members have reported feeling more confident that the grades they assign are legitimately fair reflections of student performance (Newell, Newell and Dahm, 2003)

The instructor also has discretion in how to impose individual accountability on team members, and in determining whether individual team members will receive a higher or lower course grade than that assigned to the team deliverables. One strategy involves the multiple evaluations described under Task 4: when evaluating the final report or final presentation, the instructor assigns a single score to the entire team, but the instructor can assign different scores to different individuals when making an "overall" evaluation. Other strategies for individual accountability in team projects are well documented in the literature. Historically, most Rowan engineering faculty have used a peer evaluation form described previously by Kauffman, Felder and Fuller (2000). More recently, the online tool CATME has become available to assist faculty in both forming and evaluating student teams.

After the grading of individual students is completed, the data is used for program assessment as follows. The department's assessment coordinator col-

| Element | Average Score | #Teams scoring below 7 |
|---|---|---|
| Executive Summary | 8.8 | 0 |
| Report Organization | 9.3 | 0 |
| Clarity and level of detail | 9.2 | 0 |
| Illustrations, Figures, Tables | 9.0 | 0 |

**Table 5: Assessment of outcome "Students in the Chemical Engineering program will write effective documents," as measured in Chemical Plant Design**

| Element | Average Score | #Teams scoring below 7 |
|---|---|---|
| Executive Summary | 8.9 | 0 |
| Report Organization | 9.6 | 0 |
| Clarity and level of detail | 9.0 | 0 |
| Illustrations, Figures, Tables | 9.9 | 0 |

**Table 6: Assessment of outcome "Students in the Chemical Engineering program will write effective documents," as measured in Jr/Sr Engineering Clinic**

lects the evaluations of each team project in each course and compiles them into a master spreadsheet. The mapping of student outcomes to project elements is programmed into the spreadsheet, such that when the data is compiled, a summary of student performance with respect to each of the program's student outcomes is automatically generated.

## Interpretation of Example Data

This section examines the data collected from both project-based courses in 2010. The discussion will focus on the outcome of effective written communication. In each course four elements of written communication are assessed, and these are summarized in Tables 5 and 6.

The first step in evaluating whether student outcomes are being met is establishing a minimum threshold for "success" of the students in meeting an outcome. All of the rubrics discussed in this paper were constructed with a 1-10 scale, with 10 defined as outstanding student performance and 7 defined as "the minimum that is considered adequate." Consequently, the department established two benchmarks for success:

- EVERY team scores at least 7/10.
- The AVERAGE score attained is at least 8/10.

Tables 5 and 6 show that the 2010 cohort meets these criteria, for all indicators of "effective written communication." Analogous data is tabulated for all 15 student outcomes, with respect to each indicator related to that outcome. For written and oral communication skills specifically, an additional evaluation is conducted. Recall that certain project elements, such as formulation of meaningful conclusions, are assessed three separate times: based solely on the final report, based solely on the final presentation, and based on the entire semester-long project experience. Table 7 compares the results of these three separate assessments. In this case student performance was above the acceptable threshold with respect to all indicators. However, if there was a problem, the comparison in Table 7 would help diagnose the problem specifically. A genuine shortcoming in student ability to formulate meaningful conclusions would be reflected by uniformly low scores on the "Conclusions" element. If students were capable of formulating conclusions but poor at explaining and justifying them in a formal written document, this would be reflected by a large discrepancy between the "overall" assessment and the "final report" assessment.

The data shown in Tables 5-7 are representative of the 2006-212 accreditation cycle; every cohort met the minimum expectations with respect to every indicator in every outcome. Consequently, no examples of interventions stemming directly from this data are available for the 2006-2012 accreditation cycle. However, during the 2000-2006 accreditation cycle, one common shortcoming was identified. In one cohort, the Junior/Senior Clinic reports were good overall, but several had mediocre literature reviews. This result further highlighted the importance of using indicators. All reports would have been judged adequate by a more holistic evaluation of "effective written communication skills," and no problem would have been identified. However, the assessment strategy described here can detect widespread shortcomings that are much more specific in nature, such as the relative weakness in ability to write a literature review. The steps that were implemented to correct this shortcoming were described in detail previously(Dahm 2010b), and focused on modifications to the Sophomore Engineering Clinic, a course that combines

| Element | Overall | Presentation | Report |
|---|---|---|---|
| Execution of Project Plan | 8.7 | 8.7 | 8.9 |
| Apparatus or System Design | 9.7 | 9.8 | 9.7 |
| Technical Awareness | 9.3 | 9.3 | 9.3 |
| Underlying Principles | 9.1 | 9.1 | 9.0 |
| Results | 8.5 | 8.8 | 8.7 |
| Conclusions | 8.7 | 8.7 | 8.7 |
| Recommendations | 8.1 | 8.3 | 8 |

**Table 7: Comparison of average student achievement for several elements of Jr/Sr Clinic projects, as measured by reports, presentations, and overall performance.**

engineering design with technical communication. Cohorts who experienced the updated Sophomore Clinic demonstrated improved ability to write literature reviews in their upper level classes, and no shortcoming in this area has since been detected in the Rowan Chemical Engineering program.

## Summary

This paper outlines an efficient strategy for the direct assessment of the achievement of student outcomes. Rubrics were developed for evaluating student performance in two project-based courses. A team is evaluated once using the rubric, and the data obtained from this evaluation is used both for grading the students in the course and for the assessment of student outcomes. Thus, fairly detailed data for programmatic assessment of student outcomes is obtained, but its collection is integrated into the routine activity of grading student reports and presentations; very little "extra" faculty time is required for assessment.

The Chemical Plant Design rubrics are only suitable for direct adoption by a Chemical Engineering program, but the general approach described here can be adapted to the capstone design course in most any engineering program. While the 8-semester Engineering Clinic model is specific to Rowan University, the Jr/Sr Clinic rubrics could be applied to other project-based undergraduate research experiences. Beyond serving the need for assessment of student outcomes, the use of detailed rubrics of this kind has an additional benefit when applied to undergraduate research: clarifying the expectations to the students in open-ended project-based courses likely leads to better performance.

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# Appendix A: Chemical Engineering Program Student Outcomes

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).

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.

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.

5) 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).

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

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

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

9) 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).

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

11) 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.

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

13) 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).

14) 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).

15) The Chemical Engineering Program at Rowan University will produce graduates who demonstrate effective oral and written communication skills (ABET - G).

# Appendix B: Peer Assessment Administered Annually to Graduating Seniors

The Department of Chemical Engineering is gathering information as part of its on-going assessment plan. Please complete one of these sheets on each of your fellow team members and return the sheets-in the sealed envelope provided- to Dr. Dahm. Please do not include your name or your team members' names on this form. All information will be kept confidential and will not impact anyone's grade; the envelope will not be opened until after graduation. Therefore, please give a thoughtful and honest assessment.

Please rate your team member on each of the following attributes on a scale from 1-5. Circle the number that best describes your assessment of your team member in these areas. If you do not feel capable of providing an accurate rating, circle N/A. If you would like to provide any additional comments related to this team member or these attributes, please do so at the bottom or on the back of this form. Thank you!

**1 = Incompetent 5 = Exceptional**

| | | | | | | |
|---|---|---|---|---|---|---|
| **A**. Ability to apply knowledge of mathematics, science and engineering | 1 | 2 | 3 | 4 | 5 | N/A |
| **B.** Ability to design and conduct experiments, as well as to analyze and interpret data. | 1 | 2 | 3 | 4 | 5 | N/A |
| **C.** Ability to design a system, component, or process to meet desired needs. | 1 | 2 | 3 | 4 | 5 | N/A |
| **D.** Ability to function on multi-disciplinary and/or diverse teams | 1 | 2 | 3 | 4 | 5 | N/A |
| **E.** Ability to identify, formulate, and solve engineering problems | 1 | 2 | 3 | 4 | 5 | N/A |
| **F.** Understanding of professional and ethical responsibility | 1 | 2 | 3 | 4 | 5 | N/A |
| **G.** Ability to communicate effectively. | 1 | 2 | 3 | 4 | 5 | N/A |
| **H.** Understand the impact of engineering solutions in a global and societal context | 1 | 2 | 3 | 4 | 5 | N/A |
| **I.** Recognize the need for, and an ability to engage in life-long learning | 1 | 2 | 3 | 4 | 5 | N/A |
| **J.** Knowledge of contemporary issues of relevance to the field of Chemical Engineering | 1 | 2 | 3 | 4 | 5 | N/A |
| **K.** Knowledge of Chemistry and Advanced Chemistry | 1 | 2 | 3 | 4 | 5 | N/A |
| **L.** Knowledge of Chemical Engineering Principles | 1 | 2 | 3 | 4 | 5 | N/A |
| **M.** Skill and experience in working with bench and pilot scale Equipment | 1 | 2 | 3 | 4 | 5 | N/A |
| **N.** Experience in Undergraduate Research. | 1 | 2 | 3 | 4 | 5 | N/A |
| **O.** Ability to use modern engineering tools | 1 | 2 | 3 | 4 | 5 | N/A |

Comments:

# Appendix C: Essential Elements of Project-Based Courses

*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