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Mining Capstone Engineering Experiences for Program Assessment Results*

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Capstone engineering experiences such as design projects, laboratory projects, projects with industry, and research projects are excellent opportunities for program assessment. One method for using capstone experiences for program assessment is to develop rubrics to allow qualitative assessment information to be quantified in a consistent manner between multiple evaluators. The summative results of the assessment process can be used to improve the program, thereby completing the feedback loop to the curriculum. The formative results of the assessment process can be used to develop students' skills over time and make certain that their knowledge and skill base is as desired. An example of how this process is currently used is presented.

INTRODUCTION

IN THE SEARCH for program assessment results, assessment by faculty is essential. Alumni and exit questionnaires and exit interviews are very common measures; however, an assessment plan cannot rely exclusively on self-assessment instruments. There are several reasons why capstone experiences are an excellent opportunity for faculty assessment of learning outcomes. First of all, all engineering programs have some type of capstone experience. Therefore, assessment can be done using something that already exists. Secondly, since the capstone experience is where knowledge gained earlier in the curriculum is applied to the solution of a comprehensive problem or where phenomena learned in class are illustrated in a laboratory experiment, the opportunity exists for assessment of most, if not all, aspects of the curriculum. Finally, since, in many programs capstone experiences involve multiple instructors, the participation of multiple faculty members in the assessment process can be achieved.

The use of capstone experiences for program assessment is not new. Many positive outcomes have been reported. Assessment of the capstone experience in a speech communication program at the University of Tennessee, Knoxville, was the basis for curriculum modifications [1]. Using 'senior assignments' in a variety of curricula at Southern Illinois University, Edwardsville, created faculty ownership of the assessment process [2]. At Truman State University (formerly Northeast Missouri State University), nationally normed assessment tests were required for many years, but faculty initially criticized the test and did not take the results seriously. Eventually, faculty came to believe in the test results and instituted capstone experiences as one method of addressing the deficiencies identified by the tests. An added benefit was another assessment measure for each curriculum [3]. The annual feedback obtained from required capstone business proposals led to documented continuous improvement in the business program at Ball State University [4]. In the Mechanical Engineering curriculum at the University of California, Berkeley, scenario analysis (how students respond to an industrial scenario) was used in the capstone design class to obtain program assessment results [5]. Other examples of program assessment via capstone experiences are also available [6, 7]. These examples suggest that assessment of capstone experiences not only provides important assessment information, but it also can provide the impetus for program improvement and for faculty buy-in.

In this paper, one method for using capstone experiences both for summative program assessment results and for formative assessment to develop skills over time are described. This method has been used successfully for many years in the Chemical Engineering Department at West Virginia University, and the example presented is based on our experiences.

CAPSTONE EXPERIENCES—A BROAD DEFINITION

In the discussion that follows, the term 'capstone experience' is used in a broad sense. Capstone experiences include the senior-year (fourth-year) design projects common to most curricula as well as laboratory experiences, which are often in the junior year (third year) and/or senior year in chemical engineering programs. While design projects are usually exercises done within the

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university environment, there are programs that assign projects in conjunction with industry. These experiences are also excellent opportunities for obtaining program assessment results and have the additional advantage of having practitioners of the profession involved in the assessment process. While a cooperative education experience is not really a capstone experience, if it is used for assessment, it also has the advantage of involving practitioners of the profession in the assessment process. Many programs also involve students in research, either as a requirement or as an elective. These experiences are also excellent opportunities for program assessment and have the potential advantage of involving faculty who might not otherwise be involved in assessment of the capstone experiences.

However, in a broader sense, there can also be a capstone experience for a course, for a semester, or for a year. Many courses require a project, in which course material learned during the semester or year is applied to the solution of a comprehensive problem. Some departments also use projects throughout the curriculum covering material in multiple courses taken simultaneously [8, 9]. These experiences are also excellent opportunities for summative assessment results.

CAPSTONE EXPERIENCES—ADVANTAGES

Why are capstone experiences a good choice for obtaining program assessment results? Some of the advantages were discussed above. They are the location in the curriculum where knowledge learned previously is applied, and several faculty members can be involved in the process. However, one of the key advantages to capstone experiences is that they already exist. Given the existing pressures on faculty time and the difficulty in achieving the necessary faculty buy-in, it is much easier to implement an assessment plan that involves incremental work rather than entirely new tasks. Since capstone experiences already exist, all that is needed is a method to obtain assessment results (one is suggested below).

Another popular method for obtaining program assessment results is the portfolio. However, it is not sufficient merely to gather portfolios. They must be evaluated [10]. This requires multiple faculty members evaluating portfolios annually, which is an additional activity that would not normally be done other than in an assessment context. Assessment of capstone experiences can be done simultaneously with their evaluation for a grade. Therefore, an important advantage to using capstone experiences for program assessment is the incremental effort involved in obtaining the necessary assessment results.

CAPSTONE EXPERIENCES—WHAT CAN BE ASSESSED?

What can be assessed using capstone experiences? The simple answer is that anything in ABET EC 2000, Criterion 3, a–k [11] can be assessed if the experience includes every topic as a component. By default, the Application of Math, Science, etc., and the Design of a Component, and the Solution of Engineering Problems (a, c, e, respectively) are involved in all capstone design projects.

In a capstone laboratory experience or in a capstone research experience, Experimental Techniques (b) may be added to or replace Design of a Component (c). Since most capstone experiences involve oral presentations and written reports, Communication (g) is included. Since capstone experiences are usually open-ended and they often require students to identify material they have not learned in class, search for the necessary information, and teach themselves this material, Lifelong Learning Skills (i) are included. Since capstone projects and laboratories are usually done in teams, Teamwork (d), though not necessarily multidisciplinary—depending on one's definition of the term—is involved. Since most laboratories include modern equipment and most design projects include the use of sophisticated software, the Use of Modern Tools (k) is included. If safety and environmental issues are included in the assignment, it could be argued that aspects of Contemporary Issues (j) and Professional and Ethical Responsibilities (f) are included. Finally, a project with a social component could include Global Impact of Engineering Solutions (h). Therefore, it is straightforward to include at least seven of the eleven outcomes in capstone experiences, and it is not too much of a stretch to include nine or ten of the outcomes.

How to get assessment results from capstone experiences

One method for obtaining assessment information from capstone experiences is the use of a rubric. One definition of the term rubric is a procedure. In the context of assessment, a rubric refers to a set of procedures or guidelines used to ensure uniformity in obtaining quantitative assessment results from what is inherently a qualitative assessment. For example, consider the four-point scale:

1. not acceptable
2. below standards
3. meets standards
4. exceeds standards.

Now, consider the attribute for a written presentation 'report format'. In the absence of clearly defined guidelines, that is, a rubric, different evaluators might have different opinions regarding the level a report's format deserved or the exact definition of the term 'report format'. Now,

consider the rubric illustrated in Table 1. Here, different characteristics of the attribute 'report format' are defined, and a description of each level is given. Using this rubric, multiple evaluators should be able to evaluate the same report consistently. In our application of this rubric, we assign one overall score for the 'report format' attribute, but it is also possible to assign scores for each characteristic under the attribute. We use the former method because, after trying the latter method, our faculty expressed a preference for fewer entries. The complete rubric for written reports as well as similar rubrics for oral presentations, design projects (technical aspects), and laboratory experiments (technical aspects) used in the Chemical Engineering Department at West Virginia University are available on the web [12].

One procedure for developing a rubric is relatively straightforward. For what it is desired to evaluate, all characteristics of a truly outstanding result and all characteristics of an unacceptable result are listed. It will probably be observed that there are pairs of characteristics, one in each category. If not, the missing descriptions can be added. When all characteristics have pairs, they can be grouped to form components of broader attributes, and then the middle ground can be filled in. It is not necessary to have entries for all levels of a characteristic, especially for exceeding expectations. For example, there is no entry for exceeding expectations for spelling in Table 1. This is because if it is believed that for a report to meet expectations it should have no spelling errors, it is not possible to exceed this expectation. Hence, there is no entry at that level of exceeding expectations.

When rubrics are developed, care must be taken to avoid ambiguous wording. It may take several iterations of developing a rubric, using the rubric, and modifying the rubric before an entirely satisfactory rubric is obtained. Some suggestions for developing rubrics are available [13]. An example of another rubric developed for portfolio assessment, but used for assessing a laboratory experience is also available [10].

Another method for obtaining summative assessment results from capstone experiences is from the question-and-answer session that usually follows presentation of a project solution. Using questions and follow-up questions, the depth of student understanding can be revealed. At times, a student solution might look good on the surface and in the presentation, but questioning can reveal results obtained by faulty logic; from multiple, offsetting errors, or by accident. This method of obtaining assessment results has been described in detail elsewhere [14]. This method for obtaining assessment results must be used with care, since it can be perceived by students as being tantamount to an oral exam. Oral exams have many advantages as an assessment tool; however, the pressure students face during such an exam is a disadvantage [15].

Another method for obtaining assessment results from capstone experiences is to have students keep a journal of their work. They would document everything they tried, why they

Table 1. Portion of a rubric for assessment of a written report. The full rubric as well as other rubrics are available at http://www.cemr.wvu.edu/~wwwche/outcome/index.html

Attribute	1-Not acceptable	2-Below expectations	3-Meets expectations	4-Exceeds expectations	Score
Report Format					
Organization	inappropriate content of most sections of report	some content in inappropriate section of report	content appropriate to all section of report	unique organization enhances readability and/or understandability of report	
Complete Story Told	no story told, very incomplete	aspects of complete story missing	complete story told	additional material enhances quality of report	
Aesthetics	unacceptable—e.g., tables and figures cannot be read/ understood, fonts difficult to read	some portions are sloppy and difficulty to read	text, tables, figures readable and understandable	text, tables, figures so clear and understandable as to enhance report impact	
Format	so many format errors as to make report useless	some format errors	format followed	unique format, aspects that enhance report impact	
Spelling	any spelling errors	only spelling errors are different spellings for same pronunciation	no spelling errors		
Grammar and Punctuation	too many grammar and punctuation errors	grammar and punctuation errors	only a very few grammar or punctuation errors	no grammar or punctuation errors	
Length	far too long or too short	too long or too short	appropriate length		

rejected some ideas, and why they chose other ideas. Another possibility is interim presentations or meetings where the questioning discussed above is used to reveal students' thought patterns and understanding of key concepts. Still another method might be to videotape students working on a project to gain insight into how they use their knowledge to attack the problem [16].

USE OF ASSESSMENT RESULTS

One use for assessment results is to demonstrate that the desired outcomes have been achieved. The quantitative results obtained from the rubric can be used for this purpose. If a series of experiences is used to develop a skill, communication or design, for example, the results from the rubrics can be used to document the improvement in skills as students develop these skills with each experience.

To close the feedback loop on the assessment process, the results obtained from assessment of capstone experiences must be used for program improvement. The loop must be closed with feedback to faculty as well as feedback to students. The former permits faculty to improve their teaching and may suggest curriculum improvements, while the latter permits students to develop their skills over time, and correct errors and gaps in their knowledge.

Feedback to students is essential. The American Association for Higher Education has developed principles of outcomes assessment [17], and they include:

- Assessment requires attention to outcomes, but also and equally to the experiences that lead to these outcomes.
- Assessment works best when it is ongoing, not episodic.

These principles suggest that if students are to develop, for example, communication skills, design skills, and/or laboratory skills, they should have multiple experiences within a course or throughout the curriculum from which they can obtain feedback and further develop these skills. For assessment of technical knowledge, it should be documented, in a capstone experience, if a significant number of students make the same error, have the same misconception, or have not yet developed a skill they should have mastered prior to the capstone experience. If this occurs, then it is likely that the material was not learned properly at the appropriate point in the curriculum, and feedback to both faculty and students is essential.

Results from the rubrics provide a guide to the topics on which feedback is needed. When student misconceptions or gaps in their learning are revealed, class time should be found to address the problem in the capstone class, completing the feedback loop to the students. Therefore, it is recommended that time be built into the schedule or syllabus for this process. When there are multiple experiences in a class, as is often the case in a capstone laboratory, students should get feedback after each experience. This requires rapid turnaround of graded reports so students can obtain feedback from one experience before beginning the next experience.

Another form of feedback, especially when this process is first initiated, is the realization that the first rubric developed needs to be improved. Most likely, there will be some attributes that were omitted or for which the descriptions were not as desired. Another possibility, one that we observed, is the downgrading of oral and written reports for technical content. This is because the original rubrics for oral and written reports incorrectly included technical attributes.

Evolution of rubrics is a normal process for the first few times they are used. Eventually, a rubric will be developed that remains constant for a period of time, but this is unlikely to occur until the rubric is tested in practice. It is important to realize that rubrics, like all assessment instruments, should be periodically re-evaluated and updated, if necessary.

Feedback to faculty must be done cautiously, since faculty members do not necessarily want to hear that students did not learn what they were supposed to learn in an earlier class. A common response is 'I covered that in my class, so it is not my fault'. Faculty members need to become comfortable with the concept that, in an outcomes assessment-based environment, the issue is what was learned, not what was covered. A written assessment report circulated to faculty outlining strengths of student work, weaknesses, and recommended methods used to correct any problems is one method for providing this feedback [14]. A follow-up faculty meeting, during which the results of a single assignment are discussed, is a possibility. An annual faculty meeting where all assessment results are discussed is essential. Over time, a culture can develop where faculty members are more interested in the results of student learning and feel less threatened by assessment results.

EXAMPLE OF IMPLEMENTATION OF THE PROCESS

In the Chemical Engineering Department at West Virginia University, design projects are assigned each semester for all chemical engineering classes taken simultaneously [8]. The same chemical process is used for the project for the sophomore year (second year) and the junior year (third year). Students begin to develop their design skills over the two-year period of these projects, and their design skills are developed more fully in the capstone design class. In this formative assessment component in the sophomore and junior years, students receive feedback each semester to help them improve their skills. A written report is

required each semester, and an oral report is also required (though not always in the first semester of this sequence). Even though the department has written and oral report guidelines, in our experience, student reports do not begin to reflect adherence to these guidelines until they complete one or two reports and receive feedback. The improvement, particularly in communication skills, is apparent with each assignment, and is documented from the rubrics used for all evaluations. Students work on these projects in teams, and we have just begun to evaluate teamwork using instruments available in the literature [18, 19].

In the senior (fourth) year, there is a sequence of design projects and laboratory experiments. Since this is the 'true' capstone experience, this is summative assessment, and the results of evaluation of the design projects provide feedback to faculty and students. Feedback to faculty is in the form of a report discussing the issues involved in the project and how well students did in addressing these issues. These issues are also discussed in a faculty meeting, if it is deemed necessary. All assessment results are discussed at the annual faculty 'retreat' devoted to outcomes assessment. In the design class, if there is an aspect of the project that students do not do particularly well, a follow-up assignment is given so that students can correct their errors after the project is reviewed. By doing this, formative and summative assessment is done simultaneously.

In the laboratory class, both communication skills and the technical aspects of the laboratory are evaluated, and feedback is provided to students and, if necessary, faculty. In one part of the design course, it is required that all students watch a tape of themselves giving one oral presentation, followed by a critique by peers and faculty. This is another example of formative assessment.

The result of this assessment process is that students develop design and communication skills over time. They receive feedback at every step of this process (formative assessment) to ensure that their skills improve with each experience. The faculty also receives feedback with each experience, and the summative assessment in the senior (fourth) year allows the assessment loop to be closed by providing information on how well students learned the material required to complete the capstone project.

Here are some examples of the type of feedback obtained from the capstone projects and the subsequent changes made. In one instance, the oral and written report guidelines were modified when it was observed that students did not understand some of the directions. In another example, it was observed that a basic concept (vapor pressure) that all students should have understood was not completely understood in the senior year. After a discussion among the faculty, the concept was repeatedly emphasized at multiple points in the curriculum. Subsequent observations showed that students' understanding of this concept improved significantly. There are other examples of concepts that students seemed to miss, and these concepts change from year to year, often depending on the instructors in earlier classes and/or the content of the capstone project. These items are always highlighted in the assessment report; although, it is not possible to state for certain that there is always a response from the faculty members in question. However, these items are always addressed in the in-class project reviews and in follow-up assignments.

In yet another example, it was observed that students lacked perspective on the relationship between reaction kinetics and reaction equilibrium. This was observed in design projects in which kinetics were needed and there was also an equilibrium limitation. It was observed that reaction equilibrium was taught in thermodynamics while reaction kinetics were taught in physical chemistry, reviewed in reaction engineering, and used in reaction engineering. We have made a curriculum modification to put these two topics in the same class, in part because of this assessment result. As a final example, students made an approximation in the senior (fourth) year that they were permitted in the sophomore (second) year because they had not yet encountered the correct method for doing the calculation. The decision was made to give the students the formula for doing the correct calculation when needed in the sophomore year, even if they did not understand its origin, so they would not erroneously (or carelessly or lazily) think the approximation could be applied injudiciously later in the curriculum. This error has never resurfaced since this change was made.

CONCLUSIONS

Capstone experiences are excellent assessment tools because they are already a part of the curriculum and because several faculty members often participate in them. A good method for using capstone experiences for program assessment is to develop rubrics describing the attributes desired in these experiences. These rubrics allow qualitative assessment results to be quantified. If the summative results of the assessment process are used to improve the program, the feedback loop to the curriculum is completed. If the formative results of the assessment process is used to develop students' skills over time and make certain that their knowledge base is as desired, then the feedback loop to students is completed.

REFERENCES

1. T. W. Banta, J. P. Lund, K. E. Black, and F. W. Oblander, *Assessment in Practice*, pp. 79–82. Jossey-Bass, San Francisco, CA (1999).
2. T. W. Banta, J. P. Lund, K. E. Black, and F. W. Oblander, *Assessment in Practice*, pp. 82–86. Jossey-Bass, San Francisco, CA (1999).
3. T. W. Banta, J. P. Lund, K. E. Black, and F. W. Oblander, *Assessment in Practice*, pp. 101–104. Jossey-Bass, San Francisco, CA (1999).
4. T. W. Banta, J. P. Lund, K. E. Black, and F. W. Oblander, *Assessment in Practice*, pp. 135–138. Jossey-Bass, San Francisco, CA (1999).
5. F. McMartin, A. McKenna, and K. Youssefi, Scenario assignments as assessment tools for undergraduate engineering education, *IJEE Trans. Educ.*, **43**(2), May 2000, pp. 111–119.
6. C. A. Palomba and T. W. Banta, *Assessment Essentials*, pp. 124–126. Jossey-Bass, San Francisco, CA (1996).
7. B. Fong, Assessing the department major, in *Assessing Students' Learning New Directions for Teaching and Learning*, #34, (J. H. McMillan, ed.), pp. 71–83. Jossey-Bass, San Francisco, CA (1988).
8. R. C. Bailie, J. A. Shaeiwitz, and W. B. Whiting, An integrated design sequence; sophomore and junior years, *Chem. Eng. Educ.*, **28**(1), Winter 1994, pp. 52–57.
9. D. E. Hirt, Integrating design throughout the ChE curriculum: lessons learned, *Chem. Eng. Educ.*, **32**(4), Fall 1998, pp. 290–295.
10. B. M. Olds and R. L. Miller, Using portfolios to assess a ChE program, *Chem. Eng. Educ.*, **33**(2), Spring 1999, pp. 110–114.
11. ABET, *Criteria for Evaluating Engineering Programs*, Accreditation Board for Engineering and Technology, 3/18/00 revision, available at http://www.abet.org/eac/2000.htm.
12. http://www.cemr.wvu.edu/~wwwche/outcome/index.html
13. N. Picket, *Guidelines for Rubric Development.* http://edweb.sdsu.edu/triton/july/rubrics/Rubric_Guidelines.html
14. J. A. Shaeiwitz and R. Turton, Acetone production from isopropyl alcohol: an example debottlenecking problem and outcomes assessment tool, *Chem. Eng. Educ.*, **33**(3), Summer 1999, pp. 210–215.
15. J. Prus and R. Johnson, A critical review of student assessment options, in *Assessment and Testing: Myths and Realities New Directions for Community Colleges*, # 88, (T. H. Bers and M. L. Miller, eds.), pp. 69–83, Jossey-Bass, San Francisco, CA (1994).
16. D. DiBiasio, W. Clark, A. Dixon, and L. Comparini, The process of learning chemical engineering: what works and what doesn't, *ASEE Annual Conference*, St. Louis, MO, June 2000, Session 3513.
17. AAHE, Best assessment principles, American Association of Higher Education, reprinted in *How Do You Measure Success? Designing Effective Processes for Assessing Engineering Education.* p. 45, ASEE Professional Books (1998).
18. C. Walker and T. Angelo, A collective effort classroom assessment technique: promoting high-performance in student teams, in *Classroom Assessment and Research: An Update on Uses, Approaches, and Research Findings New Directions for Teaching and Learning*, #75, (T. Angelo, ed.) p. 101. Jossey-Bass, San Francisco, CA (1998).
19. D. B. Kaufman, R. M. Felder, and H. Fuller, Accounting for individual effort in cooperative learning teams, *J. Eng. Educ.*, **89**(2), April 2000, pp. 133–140.

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