PORTFOLIO ASSESSMENT

In Introductory ChE Courses

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As defined by Feuer and Fulton,[1] performance-based assessment refers to assessment techniques that require students to create a final product, such as a written report, oral presentation, or portfolio of their work, as opposed to the more conventional assessment techniques of written quizzes or exams. Performance assessment can also be defined as an assessment method that evaluates a student's ability to perform a specific procedure or task;[2] in this context, the assessment must contain a performance task, a student-response format, and a scoring system. Examples would include judging a student's ability to manipulate laboratory equipment or respond to an open-ended problem.[2] Slater suggests designing a performance task that is "somewhat undefined, complex, and has multiple entry and exit points;" that is, a task that has more than one correct solution path.[2]

The advantages of performance-based assessment techniques have been documented by several studies in the educational literature.[1-6] Many studies emphasize the "real-world" nature of performance assessment;[3] student work is evaluated in a manner that is much closer to what will be encountered in the work environment. Perhaps most importantly, research has shown that alternative assessment helps in the evaluation of students with various learning styles and educational backgrounds, promoting excellence among a more diverse student population.[4]

These "alternative assessment" techniques[3] are not new to engineering education. Traditional performance-based assessment is often used (although not often acknowledged as such) in junior- and senior-level courses in the form of laboratory experiments, written lab reports, design projects, and oral presentations; and the ABET EC 2000 guidelines have brought increased attention to outcomes-based assessment.[7,8] But alternative assessment is not widely used in the freshman- and sophomore-level courses for a variety of reasons. Educators may worry that freshmen and sophomores do not have the depth and breadth of knowledge to complete a design project or written paper, or that there is simply not enough class time to have students give oral presentations...after all, there is barely enough class time to teach these students mass and energy balances and thermodynamics. There is another means of implementing performance-based assessment in these courses, however—one that has remained largely under-used in engineering education: student portfolios.

WHAT IS A PORTFOLIO?

Portfolios are collections of student work, typically selected according to guidelines set forth by the instructor.[3] These guidelines may have a one-to-one correspondence with the course objectives, or an instructor may choose to highlight particular course objectives. An example of required items from the freshman chemical engineering course at UMass, which I will discuss in more detail below, is given in Table 1. Along with each item, students are asked to submit a statement of why the item was chosen. This element of self-analysis or self-reflection is crucial if portfolios are to be more than just "student folders."[9] For comparison, the course ob-

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TABLE 1
Required Portfolio Entries for Freshman Course in Chemical Engineering Fundamentals

1. A problem with a "nonroutine" solution, where students had to employ new strategies or methods of solution
2. A homework problem that involved teamwork or group work
3. A problem that gave the student a good sense of real-world applications
4. A problem involving data analysis or data fitting
5. A problem involving the use of MathCAD
6. A problem involving the use of Microsoft Excel
7. A self-analysis of the student's strengths and weaknesses with regards to concepts learned in class
8. Reflections on chemical engineering, this class, and any thoughts on career choices

TABLE 2
Course Objectives for Freshman Course in Chemical Engineering Fundamentals

At the end of this course, students should

- Understand concepts of engineering calculations, including significant figures and dimensional analysis, and be able to perform unit conversions
- Understand process flowsheets, know how to draw and label a flowsheet, and be able to clearly define subsystems within processes to set up conservation equations
- Understand conservation of mass and be able to solve material balances on steady processes
- Understand thermodynamic quantities such as internal energy, enthalpy, and heat capacity
- Understand the concept behind distillation and be able to perform simple vapor-liquid equilibria calculations using Raoult's Law and Henry's Law
- Understand conservation of energy and be able to set up simple energy balances
- Be able to use software packages (for instance, Microsoft Excel or MathCAD) to set up and solve engineering calculations and aid in data analysis
- Be able to use the principles and tools learned in this course to solve problems not covered in detail as part of the course and to continue learning related material as needed in the future.

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jectives are listed in Table 2.

A widely cited benefit of portfolio assessment is an improvement in communication skills and creative-thinking skills, particularly in mathematics and science, two disciplines where students often have difficulty communicating their results.[3,4,9] These assessment techniques also promote student self-assessment and reflection. This allows students to become better at selecting and presenting their best work, which helps them gain confidence in their abilities.[4]

Studies in college physics classes[6] have shown that portfolios may serve to help students organize work and internalize concepts; however, preliminary studies of portfolio use in undergraduate chemistry courses[10] indicate that there is a disconnect between student performance on exams and in portfolio entries with regard to specific course objectives.

Educators in chemical engineering may feel uncomfortable with the concept of "student self-reflection"; after all, we are here to teach students, not to ask them how they "feel" about engineering, right? We prefer hard numbers and are more accustomed to quantitative assessment methods. But the utility of portfolios has been demonstrated in several science, mathematics, and engineering courses.[4,6,10-16] Many states require use of portfolios in *all* subject areas for grades four through twelve,[4,5] and portfolios have been successfully used in undergraduate physics, chemistry, and geology courses.[6,9]

The chemical engineering program at the Colorado School of Mines has relied heavily on portfolio assessment for over a decade, and Olds and Miller[14] give an excellent description of the use of portfolios in the ChE curriculum. Both Alverno College[15] and Rose-Hulman Institute of Technology[16] have implemented an electronic portfolio system for all students. Preliminary results from the Rose-Hulman project indicate that students find the electronic portfolio system easy to use, and that use of a web-based system reduced some of the disadvantages of conventional portfolios, including storage, user access, and availability.[16]

It is important to keep in mind the difficulties and limitations associated with portfolio assessment. Portfolios are not appropriate for assessing factual knowledge or recall abilities; thus, they should be used in conjunction with conventional, quantitative assessment techniques.[9] Portfolios can be difficult to manage and time-consuming to grade, which

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makes them easiest to implement in courses with small to medium enrollments. Slater[9] and Wink[10] have reported techniques to extend the use of portfolios to large lecture courses, however.

Although there has been an emphasis on the use of portfolios in upper-level "capstone" courses, such as senior design and the unit operations laboratory,[14] I focus on their use in introductory chemical engineering courses. I believe portfolio assessment has unique benefits to beginning engineering students, as described further in the following paragraphs.

GRADING PORTFOLIOS

Implementing innovative assessment is all well and good, but how are we going to evaluate and grade student portfolios? Since the portfolio entries have presumably been graded as part of a homework assignment or exam earlier in the semester, it does not seem fair to me to place the students in "double jeopardy" by basing the portfolio grade on whether or not the problems are correct. I chose to grade portfolios by giving equal weight to three criteria:

- *Completeness and organization*
- *Quality and style of writing*
- *Level of thought, analysis, and reflection in each entry*

The first two criteria are easy to evaluate. The first refers to whether students have all the required items, including a table of contents and page numbers. The second criterion refers to writing style and grammar, again fairly straightforward to evaluate.

The third criterion is a little more subjective and requires some planning on the part of the instructor. I evaluated the level of thought and analysis by judging the extent to which each entry addressed two to three "thought questions," which are listed in Table 3. Students were given these questions at the start of the semester to help guide them through the self-analysis process.

Slater[9] recommends developing a "scoring rubric," whereby the portfolio grade is based on the extent to which students demonstrate mastery of the required number of objectives. For example, you may require students to have at least eight entries, each of which is related to a specific course objective. A simple scoring rubric could then be an "A" grade for demonstrating adequate mastery in seven or more objectives (as evidenced by the portfolio entries), a "B" grade in five or more objectives, and so on. More detailed examples, developed for a unit operations course, are given by Olds and Miller;[14] see also the examples given by Slater.[9]

EXAMPLE

Portfolios in the Introductory ChE Course

In the spring of the freshman year, students at UMass take a course titled Chemical Engineering Fundamentals. The course content covers units and dimensions, mass balances, simple reactive systems (*i.e.,* CSTRs and PFRs), and forms of energy. The typical enrollment is 40-50 students, most of whom are engineering majors with an interest in chemical engineering. After completing the freshman year requirements, students can apply for admission into the chemical engineering major. Thus, many students in the ChE Fundamentals course are still unsure of their choice of major.

I chose to implement portfolio assessment in this course as an optional assignment. The portfolio assignment could be used to replace a low grade on either of two midterm exams or a low homework grade, but not the final exam. Many instructors give students the option of "dropping" one low grade, so I did not feel that the use of portfolios would cause grade

TABLE 3
Questions for Student Self-Analysis in Portfolio Entries

- What concept or topic was involved with this problem? What skills did you use in solving it?
- How did this problem help you learn something new?
- Did you learn anything about yourself, your thought process, or your strengths and weaknesses as a result of this activity?
- What strategies did you use? What were you thinking as you worked the problem?
- Would you do anything differently if you had more time?
- Can you describe any connections between the activity and other concepts, subject areas, or real-life situations?
- Does the problem represent a special achievement for you, a sense of accomplishment at having learned a particular concept, or a sense of improvement over time?

TABLE 4
Student Evaluation Survey

0. Did you complete the optional portfolio assignment for this class?
1. (If "Yes" to the first question) I enjoyed completing the portfolio assignment.
2. (If "Yes" to the first question) I felt that I learned more about myself and my strengths and weaknesses in chemical engineering and problem solving as a result of completing the portfolio.
3. (If "Yes" to the first question) My written communication skills have improved as a result of completing the portfolio assignment.
4. I feel that the use of both qualitative (*e.g.*, written reports, oral reports, and portfolios) and quantitative (*e.g.*, exams and homework) methods of assessment were appropriate for this class.
5. I dislike qualitative methods of assessment (*e.g.*, written reports, oral reports, and portfolios) because I feel that they are subjective.
6. I feel that quantitative methods of assessment (*e.g.*, exams and homework) are most appropriate for engineering and science classes.
7. I would like to see qualitative methods of assessment (*e.g.*, written reports, oral reports, and portfolios) incorporated into other science and engineering classes.

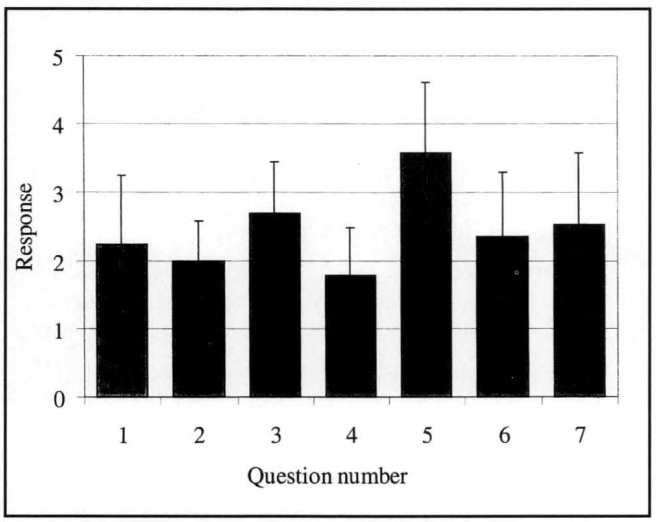

Figure 1. *Results from student surveys after completing course. Responses to questions are as follows: 1 - Strongly agree; 2 - Agree; 3 - No strong opinion; 4 - Disagree; 5 - Strongly disagree. Columns and error bars represent the average and standard deviation for each question, from a sample size of 13 surveys for questions 1-3 and 28 surveys for questions 4-7. Question numbers correspond to those given in Table 4.*

inflation.

On the first day of class, I gave students a handout describing the portfolio assignment, including the information in Tables 1 through 3, and a summary of the grading protocol for portfolios. I also held a short class discussion on what portfolios are and why they were being used for this course.

Students were required to have at least eight portfolio entries, which are listed in Table 1. Six of these entries were related to course objectives or outcomes, with a focus on objectives that are difficult to assess using conventional exam techniques (*i.e.*, the use of Microsoft Excel, data-fitting techniques, etc.). These entries were expected to be copies of problems, either from the homework or exams. Students were required to attach a copy of their solution to the problem and a short (one paragraph to one page) explanation of why the problem was chosen.

In addition, two one-page essays (the last two items in Table 1) were required. I also handed out a list of questions to keep in mind as they wrote their portfolio entries (listed in Table 3). Finally, students were asked to organize their entries, number each page, and include a table of contents in the portfolio. Periodically throughout the semester, I reminded students to work on the portfolio assignment and to come see me if they had questions on the assignment.

RESULTS

Student Feedback and Assessment Survey

The class enrollment was 41 students. Forty-one percent of the students (17 students) completed the portfolio assignment. Grades on the portfolios were roughly in the low "C" to high "A" range. For most students, the portfolio grade was used to replace a low homework grade, but the difference in the final grade for the course with and without the portfolio was never more than a letter grade.

I was somewhat distressed to find that several students counted on the portfolio to bring up their low homework grade and thus did not spend as much time on the homework assignments throughout the semester as I would have liked. I have since altered the portfolio guidelines to allow students to replace a low midterm exam grade, but not the final exam or a low homework grade.

I found that grading of the portfolios was time consuming, but I did not feel that it took longer than grading exams. The time commitment is similar to that required for evaluating written reports, and I made comments on all portfolios regarding grammar and writing style.

Students were asked to complete a survey upon completion of the course, and the survey questions and student responses are given in Table 4 and Figure 1, respectively.

Portfolios can be particularly useful for beginning chemical engineering students, who often do not have class projects that require them to synthesize concepts and present their results in a written format.

These are preliminary results; obviously, data need to be taken on a larger sample size before conclusions can be drawn. The results also may be biased due to wording of the survey questions. This needs to be addressed before definitive conclusions can be reached, and I am currently updating and redesigning the survey questions for future classes.

On the whole, the response from students was quite positive. The strongest and most uniform response was to Questions 2 and 4; 86% of students who completed a portfolio strongly agreed or agreed that the portfolio helped them to learn more about themselves and their strengths and weaknesses in chemical engineering and problem solving, and 89% of all students felt that the use of both quantitative and qualitative assessment methods were appropriate in the course. It remains unclear whether or not the portfolio assignment helped students improve their written communication skills.

Several of the written comments that accompanied portfolio entries were quite encouraging, and I have listed some of the more memorable comments in Table 5. There were also comments both positive and negative, that were useful to me as an educator. Students were very honest about components of the class that they liked and disliked. Most of these comments were made in response to Item 8, Table 1, reflections on chemical engineering and the class. Examples of these comments are also given in Table 5.

CONCLUSIONS AND RECOMMENDATIONS

Portfolios can be particularly useful for beginning chemical engineering students, who often do not have class projects that require them to synthesize concepts and present their results in a written format. Interestingly, students did not feel as though the assignment improved their written communication skills, but the portfolio assignment did seem to give these incoming students an opportunity to reflect on their abilities and their choice of major. Portfolios can also be used to assess course objectives that are difficult to evaluate using traditional techniques.

Based on my experience, I have some guidelines and recommendations for implementation of portfolios:

- Be prepared to read up on assessment techniques. Several of the references listed contain excellent examples of student entries and grading schemes.[4,5,9,11] I found the National Institute of Science Education *Field-Tested Learning Assessment Guide* website particularly useful. (Found at <http://www.wcer.wisc.edu/nise/cl1/flag/default.asp>.)

- Be clear about expectations for portfolios at the start of the semester. You may want to give students sample entries.

- Remind students that they should be saving homework sets and collecting problems for entries in their portfolio. This is extremely important for freshman-level students who are still learning how to organize their coursework.

- If you allow students to use a portfolio grade as a replacement, make sure their expectations are realistic. One fabulous portfolio assignment will not pull a final "D" grade up to an "A"—as I mentioned above, the overall effect on the final grades in the course was never more than a letter grade.

  It is worth noting that implementing portfolios as a "replacement" for a poor exam could allow a student to bring a failing grade up to a "D." Instructors need to decide for themselves whether this is permissible and to develop their own guidelines accordingly.

  For example, I specified that if students received a zero grade on an exam or homework due to academic dishonesty, this grade could not be "replaced" under any circumstances. One could imagine extending this rule to any failing grade to prevent the above scenario. Finally, I found that it was problematic to allow students to replace a low homework average with the portfolio grade.

- Create a grading scheme that places emphasis on what you think is most important, whether this is good writing, clear organization, self-reflection,

TABLE 5
Sample Comments from Student Portfolios

New Strategies of Problem Solving (Item 1) and Self-Analysis (Item 7)

- "I now have more confidence knowing that if I can't solve a problem using the accepted method of solution, I will be able to come up with a new method, perhaps something nonroutine, in order to solve the problem."
- "This problem showed me that I should have more confidence in my ability to find a solution when it doesn't simply present itself after a series of steps."
- "I could apply things I had learned in a completely different context to other situations. This is actually quite comforting, as I've always wondered if I'll be able to use the things I learn now later on in life when I might actually need them."
- "I've had trouble [with] time management, as I have usually been able to understand the problems but have not left myself enough time to gather it all in a presentable format."
- "My weakness is that every time I hit a wall, I tend not to do anything about it. I can only blame myself for not attempting, [but] I already made my choice in staying in this major and it is all up to me in keeping that choice."

Reflections on Chemical Engineering and The Fundamentals Course (Item 8)

- "All in all I enjoyed the class, I enjoy being a chemical engineering student, and I look forward to the day when I am employed as a fabulous chemical engineer."
- "I dislike computers and I dreaded using them for this class. I probably would have stuck with this major if it were not for MathCAD and Excel. I do not think being taught [MathCAD] for one class period is enough class time."
- "Since the class is almost over, I feel a real sense of accomplishment. I know that it is only a freshman level class, but I put a great deal of effort and time into the class...It makes me proud to say that I'm a chemical engineering major when people ask me."
- "I feel like I've gotten a much better idea about what chemical engineers do through the various assignments and from the oral presentations of my peers."
- "I feel that we did not [spend] much time on using the computer."
- "Before taking this class I wasn't positive that chemical engineering was the right major for me. I felt that perhaps I would not be able to handle the workload or grasp all of the material that I needed to know. However, I now feel that I am actually capable of becoming an engineer."
- "I love going to my chemical engineering classes, they are the only ones that I don't purposely skip."
- "As a result of this class I am much more confident about my choice of major and the preparation it will give me to succeed in the career I want to pursue."

or assessment of a specific course objective. Make sure your grading scheme is clear to the students at the start of the semester.

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