AC 2011-244: STUDENT LEARNING AND THE CONTINUOUS PROGRAM IMPROVEMENT PROCESS IN A CHEMICAL ENGINEERING PROGRAM

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Student Learning and the Continuous Program Improvement Process in a Chemical Engineering Program

Introduction

The twenty-first century has brought renewed calls for educational reform at all levels. The various stakeholders are seeking improved documentation of accountability through measurable outcomes. Accrediting agencies, such as ABET (Accreditation Board of Engineering and Technology) are now asking Schools of Engineering and Schools of Computer Sciences in post-secondary institutions to meet criteria for accreditation that focus on outcomes at all levels, including program outcomes.

ABET EC 2000 has eight criteria, including Program Educational Objectives (Criterion 2), and Program Outcomes and Assessment (Criterion 3), both of which tie to Continuous Improvement (Criterion 4) [1]. According to the ABET criteria, the focus of an institution's assessment efforts should be on the systematic measurement of student learning outcomes. As a result, outcomes assessment and continuous program improvement should become essential elements of educational programs. An outcome-driven assessment system should provide information on the effectiveness of an educational program, course, project, or activity/lesson. Thus, the specification of student learning outcomes and the tools to assess the achievement of the outcomes has become an increasingly important focus for higher education institutions, not only to satisfy the requirements of accrediting agencies, but also because the specification of outcomes can lead to improved classroom instruction and student learning.

Traditional course syllabi usually include the reading assignments, homework assignments, and grading practices for the course. Some faculty members have now gone further to include course objectives, which are expected to produce the desired student outcomes. While overall course objectives are necessary, they are not sufficient to guide the students in the achievement of the expected learning outcomes. Within the structure of a course, student-centered learning outcomes should be identified for each topic or concept covered in the course syllabi. The articulation of these outcomes provides students with a clear path for the acquisition of the skills and knowledge for the course that can be evaluated through assessments of student work. Traditionally, university faculty/instructors have expertise in their respective field but not necessarily an understanding of alternative instructional practices and curriculum development strategies. These methods can provide their students with clear learning outcomes that are relevant and connected to the subject matter that students are expected to acquire and retain. The challenges for university faculty to undertake changes in their syllabi (i.e. curriculum) and instructional methodologies are very similar to those faced by K-12 teachers working toward the alignment of their curriculum and instruction with state content standards and indicators of academic progress [2]. University faculty will need to realize that, as K-12 teachers have modified their teaching practice and lesson planning, faculty will also need to change their practice to meet accreditation expectations.

An informative parallel exists between the attitudes and behaviors of K-12 teachers when they faced the implementation of state content standards, and those of university faculty who now face new criteria for accreditation of their programs. Commonalities between pre-college and post-secondary instructors include:

- Using the textbook to determine the curriculum and content of the course.
- Considering the course aligned with standards (K-12), or meeting established criteria (undergraduate) if the standard/criteria is a topic in the course.
- Identifying instructional objectives, or outcomes, from the perspective of the instructor, instead of the perspective of the student learner.
- Doing assessments mostly for the sake of doing assessment (for grading purposes) and not using assessment to improve teaching practice or student learning.

But there are also significant differences between the issues facing K-12 and University faculty, primarily due to the nature of the established criteria for the two populations. Indicators of K-12 content standards, aligned with teachers' instructional objectives, specify very discrete skills and knowledge that students are expected to achieve at identified grade levels, with perceived weak or non-existing connections between them within a grade level or between grade levels. Acquisition of these skills and knowledge are usually measured through standardized state-wide assessments, which at best provides discrete aspects or chunks of student performance. This can create an apparent fragmentation of the skills and knowledge that can fail to give a complete picture. On the other hand, ABET Criterion 3 [1] requires the incorporation of a wide range of knowledge and skills that students should acquire over time in several learning experiences, including a broader demonstration of performance. Such an approach provides engineering students the requisite skills and knowledge to be able to think and solve complex engineering problems. Inherent in this description of the differences between the issues facing the K-12 and University faculty is the difference between learning objectives and learning outcomes.

At this point, it is necessary to understand that there are issues with the language used for any process that is designed to meet the ABET requirements. The terminology, such as: goals, objectives, and outcomes, are used interchangeably with no operational definitions in various reports and papers [3]. As previously seen, there is a definite distinction between objectives and outcomes. Both specify observable behaviors which are measureable. But, an objective, such as a learning objective specifies what students will be able to (i.e., intent) accomplish, whereas an outcome, such as a learning outcome specifies what students have been able to accomplish. ABET criteria [1] does not appear to clearly distinguish between the two terms, as they seem to use "Program Educational Objectives" (Criterion 2) and "Program Outcomes" (Criterion 3) interchangeably. It is apparent that in any activity, it is necessary to define terms precisely. In this paper as applied to undergraduate engineering education, it is appropriate to use "learning outcomes" for the classroom and "course outcomes" for the course in order to minimize confusion among the faculty.

Specification of learning objectives and assessment of specified skills and knowledge actually became a substantial part of educational reform of K-12 education about 20 years ago, with the publication of national content standards in mathematics [4] and science [5], as well as other disciplines. Adoption of content standards by states, informed by the national standards, quickly followed. Since then, New Jersey Institute of Technology (NJIT) has been working with teachers and public school systems across the state to aid them in aligning their curriculum and instructional practices with the state content standards [2]. Accomplishing changes such as these has been challenging for the teachers. For the most part, curriculum developers and textbook publishers have simply "referenced" the standards to topics in the published curriculum or textbook. However, curriculum topics aligned to standards alone are not sufficient [2,6]. Alignment with standards must also include the authentic assessment of student achievement of the skills and knowledge defined by the standards. When teachers prepare authentic standards-based lessons, their teaching is focused on student achievement in relation to specific standards and indicators [6,7].

A working protocol for the creation, implementation, and assessment of standards-based lesson plans has been developed and professional development programs to train teachers how to utilize the protocol have been established [2]. The protocol includes identification of measurable student-focused learning objectives [8]; specification of the expected progress indicator from the corresponding content standards statement; adaptation of the learning experience (activity) that provides the student with the opportunity to acquire the skill and/or knowledge specified by the learning objective; and the expected student learning outcome/performance that provides the evidence that the student has acquired the skill and/or knowledge. Evidence of success in the implementation of the protocol has been documented over a two-year period [9]. Continued efforts in this area have led to the development of rubrics to evaluate teacher's standards-based lesson plans[10], and the resulting student work products.

This paper describes an initial effort to extend the K-12 protocol to the post-secondary environment transforming the instructional practices and student learning outcomes for undergraduate experiences in the Chemical Engineering program at NJIT. Thus, students are expected to attain specified learning outcomes such that they are able to retain, synthesize, and apply the knowledge to other situations. Assessment of the student learning within a course documents student acquisition of the skills and knowledge specified by the learning outcomes. The learning outcomes can then be linked to course objectives and eventually program outcomes as required by ABET [1,11,12]. The assessment is linked to the process of continuous program improvement so that the assessment is not merely producing a document, but is documenting the acquisition of skills and knowledge by the students.

A classroom of students and instructor can be thought of as a simple educational system of inputs and outputs [13]. Inputs would represent what the students bring into the classroom, their skills and knowledge, as well as the knowledge of the instructor, and resources available to the students, such as a textbook. However, inputs, while important to the learning process, do not provide the connection to the assessment of student learning. Student learning can only be measured when learning outcomes are identified, and demonstrable results are obtained that show whether students have achieved the skills and knowledge specified by the learning outcomes. These measures should be meaningful to the instructor, reliable and valid, and assess observable behaviors of students. These learning outcomes are for skills and knowledge students should be acquiring from the learning experiences in the course. Whereas the learning outcomes are defined for the concepts students are studying in the course, there is also a "course outcome" for each of the units in the course. That is, one or more learning outcomes would be part of a group within a course outcome. Thus the educational system can be expanded as the learning outcomes become a subset of course outcomes, and course outcomes become a subset of program outcomes. The system allows for a connection across the courses in a program, so that the transfer of knowledge and skills can be observed throughout a curriculum.

The Process

The process is based upon the use of "outcomes-based assessment" [14] in order to determine whether the students in a course are learning what they are supposed to be learning. It uses the "Backward Design Approach" [15]. In the traditional approach, the learning experiences and instruction are usually planned first. Using backward design, the desired results are considered first, and then the evidence of learning is decided, before the instruction strategies are determined. The process involves the

- Specification of clearly written, observable learning outcomes of the knowledge and skills students are expected to achieve as a result of being enrolled in a course, and as a result of successful completion of that course.
- Design of learning experiences within the course that provide the students with the opportunity to achieve these skills and knowledge.
- Assess the achievement of these skills and knowledge by the students.
- Use the results of these assessments to improve teaching and learning; i.e., continuous program achievement.

The process focuses on student achievement in relation to outcomes. To demonstrate achievement of competencies expected of students graduating from a program in engineering, it is necessary to identify outcomes for courses that are needed to achieve identified program outcomes. Thus, student learning outcomes, based on program outcomes and course outcomes must be continually assessed and would serve as the basis for plans to improve programs and curricula in the programs. Improvement in program outcomes will depend on changing and improving the curriculum through the course outcomes.

Available literature indicates a focus on course outcomes as the way to demonstrate achievement of program outcomes [16-19]. But course outcomes can give only limited information on what skills and knowledge students need to be improved and what strategies can be used to achieve these improvements. Course outcomes lack the specifics to understand where and how course improvements can be implemented. A consistent set of syllabi are needed for the courses that define course outcomes, including student learning outcomes, classroom strategies and actions, and assessment methods. Only when course outcomes and student learning outcomes are specified for all courses, can these course outcomes, student learning outcomes and the assessment of student achievement be linked to program outcomes.

Effective change can occur only through a focus on what happens in the classroom through the instructional practices, establishment of learning experiences, achievement of student learning, and assessments of acquired skills and knowledge that results throughout the operation of the course and subsequent courses. Assessment and a continuous program improvement process must be an integral part of educational programs. Adequate documentation is necessary for the outcome assessment data that is collected can be analyzed and used for continuous improvement in the program. The assessment process is meaningful only when it is a feedback process so that the results are used to inform decision making to enhance student learning. The feedback loops must take into account the vertical levels of assessment activities that must exist at:

- The classroom level,
- The course level,
- The program level.

Activities that occur at the classroom level are at the heart of the assessment of student acquisition of requisite skills and knowledge. A variety of assessment tools can be used for changes and improvement in course design and instructional practice, including journals, exam questions, student projects and reports, and student achievement in the laboratory. The challenge is to link the assessments at the classroom level and changes that result from this level of assessment, to the achievement of course outcomes and program outcomes by the students.

In terms of outcome-based language the process for continuous program improvement involves identification of measurable learning outcomes for the concept that is to be taught. The learning outcomes provide the assessment criterion for student mastery of the content of the instruction (e.g. level of acceptable competence), and are used for the analysis of student behaviors and work products, which provide evidence that the student has acquired the skill and/or knowledge of the learning outcomes. For each learning outcome, specific strategies/actions required to support these outcomes are developed. The listing of specific strategies and actions serve to identify the instruction to be provided in order for students to achieve the stated learning outcome. The assessment tool is then used to define the student work product that will document the achievement of the learning outcome. The course outcomes become the link between the learning outcomes and program outcomes.

The key to the process is the identification of the learning outcome(s) that should be achieved by students and documented through student work that can be evaluated. The results of this assessment process are applied to the further development of the courses and the program, including the documentation that the outcome assessment data collected has been analyzed and used for continuous improvement in the program. As the course progresses, the instructor can determine for each learning outcome whether the strategies and actions are providing the students the opportunity to achieve the skills and knowledge specified by the learning outcome and whether the assessment is providing the information on student achievement. Needed changes and modifications can be made as part of the continuous program improvement. Documentation of student achievement of course outcomes and program outcomes would also be available. Figure 1 provides a flow chart for the process.

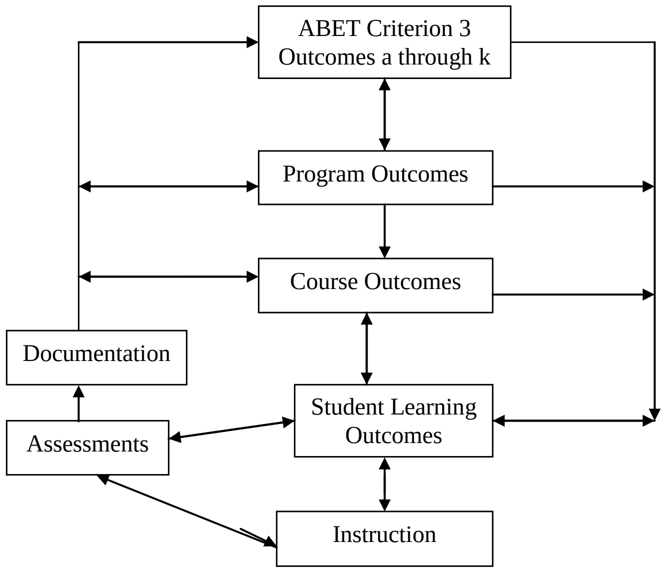

Figure 1: Process flowchart

A matrix is used to organize the definition of learning outcomes for the students and for assessment of students' achievement. As student learning issues are identified, the process of continuous improvement allows for modification for course improvements. Learning outcomes for a course provide the vehicle for instructors to improve their classroom practice. First, instructors would have to do a careful analysis of the topics, and, aligned with course-based outcomes, specify for each topic which concepts the students must acquire from the course. In addition, the students can then know what the expectations are for the time they spend in the class. The instructor is then able to provide the students with the his/her expectations, i.e., what skills and knowledge are the students expected to acquire during the course, how the acquisition of those skills and knowledge will be measured, and what will be considered as evidence that they have been achieved.

For example, a matrix relating learning outcomes to several course outcomes and aligned with ABET program outcomes for a freshman engineering design course for chemical engineering students is shown in Table 1. The matrix is utilized to define learning outcomes for the students and for assessment of students' achievement. As student learning issues are identified, the process of continuous improvement allows modification for course improvements.

Table 1: Learning outcomes as related to course outcomes

Outcome # 1. Students design and construct a flow system that meets certain objectives within constraints.			
Strategies & Actions	**Criterion 3**	**Learning Outcomes**	**Assessment Methods**
Present students with written flow system requirements but no	a, b, c, e, k	1. Students design a piping system within specified constraints.	1. A rubric will be used to grade the design of the piping system.

detailed schematic. Describe common piping and component requirements. Review safety rules.		2. Students construct a piping system within specified constraints.	2. A visual inspection of and grading of the quality of final construction and whether or not each student group's system met the objectives within the constraints.
Outcome # 2. Students use various software packages including Visio, Excel, Word, and PowerPoint.			
Strategies & Actions	**Criterion 3**	**Learning Outcomes**	**Assessment Methods**
Begin with survey on student software capabilities. Intro to Visio: flow diagram & system components.	b, k	1. Students use **Visio** to draw preliminary layout. 2. Students use **Excel** to tabulate dry / wet column pressure drops vs. flow rates, do column pressure drop calculations, draw pump curve.	1. Student work diagram) showing the operation of the constructed piping system. 2. Students' graphs will show the quality of the experimental data obtained from the experiment.
Outcome # 3. Students utilize a complicated engineering formula for data analysis.			
Strategies & Actions	**Criterion 3**	**Learning Outcomes**	**Assessment Methods**
Students are introduced to the Ergun's Equation. They are given a sheet filled with known values for most of the variables.	a, b, e	1. Students use the Ergun's Equation for the calculation of the pressure drop in a vertical packed column.	1. Students' calculations of the pressure will be reviewed.

Consider the first learning outcome "Students design and construct a piping system within specified constraints. Over 90% of the students were able to complete the assignment satisfactorily. The group projects were built to the correct specifications, stable, and leak-free. In this analysis, one minor leak was allowed to qualify as adequate.

Consider the learning outcome "Students use **Visio** to draw preliminary layout." For the student work product students complete a Visio flow diagram of the constructed piping system. It was found that only about 33% of the students were able to complete the assignment satisfactorily. Common mistakes were labeling errors, connection errors, and placing items into the diagram in the wrong order. Given a second opportunity, 58% % of the students were able to complete the assignment satisfactorily. To improve student achievement, the instructor plans to change his instructional strategy for the next semester. Students will be given a hand-out when they start working on their systems detailing proper connectivity and labeling. An example should serve as a model for them to use in designing their own systems.

Looking at selected outcomes of two other courses is informative. Student achievement of the outcomes in both courses is determined by questions in the final exams of each course. Both were open-book exams so that the equations for solving the problems were available.

Two outcomes were considered for the junior level Thermodynamics II course:

1. Students are able to calculate equilibrium constants for chemical reactions.
2. Students are able to correlate activity coefficient data using various models, such as the Van Laar equation.

For the first outcome, students were given a chemical reaction, the initial amounts of reactants and the conditions at equilibrium, and they were asked to determine the composition of the system at equilibrium. Only 64% of the students were able to score at least 15 points out of 20 points (75%) for the problem.
In general, the students were able to se the correct equations. Those who were not successful in solving the problem had difficulty in using the equations correctly. Either they were unable to set up the problem correctly or they were unable to manipulate the variables.

For the second outcome, the problem involved the calculation of the Van Laar constants for a system, and to evaluate the activity coefficients and the composition of the vapors. None of the students were able to score at least 15 points out of 20 points (75%) for the problem. Only 25% of the students were able to score at least 12 out of 20 (60%). Some students were unable to find the correct equation for the problem. Most students used an incorrect approach to the problem, including wrong assumptions or incorrect variables.

In reflection, it appeared that students were unable to apply prior knowledge to different situations or to different models. As a result the instructor believed that more reinforcement may be necessary in working with different models and in different situations. The next time he teaches the course, he plans to have group work in the classroom, where he has groups of students working on problems while he circulates among the students offering tips or hints if the students are not solving the problem correctly. In addition, a short survey has been used at the beginning of the following semester to ascertain students' conceptual understanding of thermodynamics and what students are expected to know upon completion of a first course in thermodynamics.

The survey used the model of the Thermodynamics Concept Inventory [20]. Development of the survey focused on questions that reflected fundamental concepts of thermodynamics. For example, students were asked to "Define coefficient of performance of a refrigerator". Seventy-nine percent responded with the correct definition either in words or by formula. However, when the students were asked to "Sketch and label the vapor-compression refrigeration cycle, only 50% were able to sketch and label the cycle. Others omitted key components of the cycle. When students were asked to "Sketch and label the Linde liquefaction process", only 50% of the students were able to describe the process. The results of this survey should assist the instructor in the identification and review of important concepts students have not really understood.

The other course, a sophomore level course on Fluid Flow showed similar issues. A learning outcome:
Determine how momentum flux is related to stresses (normal and shear) was assessed by student responses to three problems on an exam.

Most students were able to solve the problem that was almost identical to one that the instructor did with the students in class. However, 14 of 23 students (61%) had difficulties with the other two problems which were applications in different situations than the other one. It appeared that students had difficulty with the concept of stress.

We have found that many, if not most students are visual learners. Typical textbooks do not provide the visual portrayal of a process necessary for student understanding. As a result, a strategy to help students visualize concepts in the fluids course, such as stress, is to use demonstrations and have students work in groups on hands-on, real-life problems during the class, while the instructor circulates around the class. Simple demonstrations, such as using two sheets of cardboard as plates, can help students to visualize the processes.

Both of these lecture courses do reflect the typical assessment methods of university faculty, i.e., the use of exams. However, in this project, we see the movement of faculty away from "assessment of the sake of assessment", as faculty realizes that exams can be used for more than providing grades for students. They now can analyze the responses to specific questions to determine whether or not students understand the concepts needed to solve the problems, and seek alternative instructional strategies when necessary. Faculty also begins to realize the importance of developing appropriate questions for an exam that can elicit students' responses that demonstrate students' acquisition of requisite skills and knowledge. And the faculty members begin to understand the need to use other instruments for assessment, such as the concept survey for the Thermodynamics course.

Conclusion

A process has been initiated in the Department of Chemical Engineering in several courses that aligns the student learning outcomes within a course to the course outcomes and ABET outcomes within Criteria 3, and ties the outcomes to the process of continuous program improvement. Descriptions of outcomes and assessment of student work are used to determination student acquisition of skills and knowledge, and suggestions for improving student learning outcomes.

A change in instructional strategy for students having difficulty in applying acquired knowledge to different situations or models would be to have students working in groups in class to solve problems. Here the instructor can observe approaches that students are using and offer tips and hints when he see them moving in the wrong direction. In addition, students helping students could improve overall student achievement of the outcomes. Another issue appears to be the inability of many students to retain and transfer knowledge from one course to the next. The solution will be to look at syllabi of prerequisite courses and talk with instructors of those courses so that they can make adjustments as needed, including prior science and mathematics courses. In addition, short tests given at the beginning of the semester can help identify those concepts that students may have failed to understand in previous courses, and should be reviewed before moving on to new concepts.

The fact that the process can have an impact on the teaching practices of the instructor as well as align expectations of students entering the field of chemical engineering with program outcomes was evidenced by the remark of instructors who realized for the first time that the questions on exams can be used for more than determining course grades for students. The use of learning outcomes and examination of student work can provide direction for the instructors in improving their teaching practices.

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