Competency Matrix Assessment in an Integrated, First-Year Curriculum in Science, Engineering, and Mathematics

Claude W. Anderson, Kurt M. Bryan, Jeffrey E. Froyd, Daniel L. Hatten, C. Lynn Kiaer, Noel E. Moore, Michael R. Mueller, Edward A. Mottel, and Jerome F. Wagner
Rose-Hulman Institute of Technology
5500 Wabash Avenue
Terre Haute, Indiana 47803

Abstract

The Integrated, First-Year Curriculum in Science, Engineering, and Mathematics (IFYCSEM) at Rose-Hulman Institute of Technology integrates topics in calculus, mechanics, statics, electricity and magnetism, computer science, general chemistry, engineering design, and engineering graphics into a three course, twelve-credit-per-quarter sequence. In 1995-96, faculty teaching IFYCSEM unanimously agreed to move toward a competency matrix assessment approach advocated by Lynn Bellamy at Arizona State University. Using a competency matrix, faculty establish a two-dimensional grid. Along the vertical dimension of the grid, faculty list the topics and techniques with which they believe students should become facile. Along the horizontal dimension are the levels of learning according to Bloom's taxonomy: knowledge, comprehension, application, analysis, synthesis, evaluation. For each topic in the vertical dimension faculty establish the desired level of learning associated with a grade: A, B or C. For each quarter in 1995-96, the resulting matrix contained about 500-600 elements or blocks. When a student has demonstrated a level of learning for a particular topic, the student marks the block as earned and enters in the competency matrix a reference to his/her portfolio showing where the supporting document may be found. Students maintain their own portfolios and competency matrices and at the each quarter students submit their competency matrix along with a portfolio as documentation. Faculty assign a grade based on the competency matrix.

We present detailed descriptions of the rationale and process. Next, we discuss advantages and disadvantages, including feedback from both faculty and students. Finally, we discuss possible improvements for future implementation.

Introduction

Rose-Hulman Institute of Technology has offered the Integrated, First-Year Curriculum in Science, Engineering, and Mathematics (IFYCSEM) for six years. IFYCSEM combines topics from calculus, chemistry, physics, engineering statics, computer programming, engineering design, and engineering graphics in a three-course, twelve-credit-per-quarter first-year curriculum.

During the past year (1995-96), the faculty team decided to change the assessment scheme on which grades for each twelve credit course were assigned. During the first five years faculty based grades on a points and percentages system in which homework, laboratory reports, design projects, and examinations were assigned points and percentages of the final grade. To replace this system, faculty developed a competency matrix. The rows of the competency matrix are topics and techniques which faculty believe students should understand. The columns of the competency matrix are the levels of learning as defined in Bloom's taxonomy [1]. Associated with each row in the competency matrix is a number and associated with each column in the competency matrix is a letter: K for knowledge level, C for comprehension level, A for application level, N for analysis level, S for synthesis level, and E for evaluation level. Thus, each element in the competency matrix has a shorthand notation which is the row number concatenated with the column letter, for example, 14C, 151K, 98A, or 45N. (Note: Faculty did not require levels of learning beyond the analysis level for this first-year course.) To each block in the matrix, faculty assigned a grade of A, B, or C. Faculty assigned an A to indicate that students expecting to receive an A should be able to demonstrate the topic at this indicated level of learning. Similar statements hold for blocks assigned grades of B and C. Thus, the competency matrix summarizes topics and techniques to be learned and the level of learning expected for a particular grade. (see Figure 1)

				Information		Understanding		Thinking	
				Knowledge		Comprehension		Application	Analysis
				Recall		Know-How			
1	***Multiple Integrals***	Setting up/ choosing limits	Example 1	CBA		CBA		BA	A
2			Example 2	CBA		CBA		BA	A
3			Example 3	CBA		CBA		BA	A
4		Applications	Probability	CBA		CBA		BA	A
5			Mass/charge	CBA		CBA		BA	A
6			Center of mass	CBA		CBA		BA	A
7			Moments	CBA		CBA		BA	A
8			Example 1	CBA		CBA		BA	A
9			Example 2	CBA		CBA		BA	A

Figure 1. Portion of a Competency Matrix

When a student has demonstrated a level of learning for a topic, the student marks the block (and corresponding blocks at lower levels of learning) as earned and provides a reference to the portfolio where evidence of the competency is stored. Students have opportunities to demonstrate competencies on homework assignments, laboratory reports, design projects, in-class quizzes, and examinations. If a student demonstrates a level of learning for a topic, then the student also records the blocks at lower levels of learning for that topic. When presented an opportunity to demonstrate competency, a student who fails to demonstrate competency in a topic at a level, i.e., did not earn a block, is not penalized. In general, students have more than one opportunity to demonstrate each block. At the end of the quarter each student has demonstrated a number of elements in the competency matrix. The number of elements, which faculty refer to as blocks, is used as the basis for assigning grades.

Each student kept his/her own competency matrix. When student work was returned, the faculty member indicated which blocks had been demonstrated on a particular assignment. This was done by showing the shorthand notation for each block demonstrated, e.g., 132A, on the paper. Then, the student placed the returned work in his/her portfolio. Portfolios were organized with separate sections for homework, laboratory reports, and examinations with pages numbered sequentially in each section. When the student marked an earned block in the competency matrix, the reference to the supporting documentation was simply HW8 (homework, page 8), LAB 17 (laboratory page 17) or E3P6 (examination 3, problem/page 6). The portfolio provides a record of all a student's work during the quarter and the competency matrix summarizes the work against the learning priorities established by the faculty.

Student Reactions

Students overwhelmingly supported the competency matrix approach. Many remarked that it reduced the stress level associated with a twelve-credit class since they have more than one opportunity to demonstrate each block.

During the first quarter many students remarked that they had a harder time understanding where they stood in the middle of a quarter. Although they could count the number of blocks they had earned, they did not understand where they stood relative to faculty expectations or their peers. They didn't really know how many blocks had been offered, how many blocks faculty expected them to have earned by, say the sixth week of the quarter, or how their peers were performing. To help students, faculty began maintaining an on-line copy of the matrix in Microsoft Excel. Cell notes were used to show students the opportunities they had had to demonstrate specific blocks and a count of total available blocks was included at the end of the matrix. This helped, but students still remarked about their inability to know where they stood.

Some students did not like the extra work required to maintain the competency matrix. The competency matrix approach requires a degree of organization on the part of the students, and some students had to develop their organizational abilities as the year progressed.

Some students had doubts about maintaining the only record on which their grade would be based. If a student lost the competency matrix and portfolio, it would be difficult to recreate a complete record of all the blocks which the student had demonstrated. If a student lost a returned assignment before he/she placed it in his/her portfolio and updated the competency matrix, then he/she lost an opportunity to demonstrate the blocks. Recognizing the large number of blocks which could be demonstrated on an exam, faculty summarized the blocks which could be demonstrated on an exam on a single

sheet. When the exam and summary sheet were returned faculty kept a copy of the summary sheet. This back-up procedure appeared to be practical only for examinations.

Students recognized that there were problems with the initial offering. In the first quarter, students did not receive the competency matrix in one piece. Faculty gave students the first few pages of the competency matrix at the beginning of the quarter, listing topics which would be presented in the first few weeks. As the quarter progress, and faculty thought through topics which would be offered later in the quarter, they gave students additional pages of the competency matrix. In subsequent quarters, faculty were able to give students the bulk of the competency matrix at the beginning of the quarter. Students preferred to receive the competency matrix in one piece. Faculty also would have preferred to give the competency matrix in one piece, but more preparation time was required to prepare the entire competency matrix than they had before the beginning of the quarter.

Faculty Reactions

Rationale: Theory and Experience

The IFYCSEM faculty team chose this evaluation scheme for a variety of reasons. We believed it

1. rewards accomplishment rather than punishing failure. Using the points and percentages approach, each test is an opportunity to lose points. Each student begins with 100% and loses from that day on. With the competency matrix approach, the roles of students and faculty shift. A student has opportunities to demonstrate abilities. Students perceive that if he/she has not demonstrated a block, he/she may well have another opportunity. There is an incentive to learn the material. Faculty don't give or take away points, they simply acknowledge what capabilities a student has demonstrated.
2. allows students and faculty to assess strengths and weaknesses.
3. bases a student grade on mastery rather than partial credit.
4. is less competitive than traditional points and percentages systems. Grading based on demonstrating competencies should encourage cooperative, non-competitive behavior among students. One student should not be hurt by helping another student master a competency.
5. helps each student to know where he/she stands.

Although faculty anticipated the preceding benefits, they also believe that the logistics of administering this competency matrix approach could be overwhelming. Tracking earned blocks appeared to be a huge task. Therefore, the task was split among the students who maintained their own competency matrices. However, building and providing the initial pages of the competency matrix as well as ongoing updates appeared to be a challenge. In this case, it was not the sheer effort involved, but getting everyone to work together to issue an update. Faculty did not believe that the amount of paper involved would be significantly different from previous years, but that the task of deciding which blocks could be earned on a specific assignment, awarding appropriate competencies to students, and returning the paper work could be a time consuming task.

Based on the experience of one year, the competency matrix approach accomplished some things that were expected, was less successful at others, but also had benefits and drawbacks that were unexpected.

Reactions will be numbered in the same order as our reasons for selecting the competency matrix.

1. The payoff was substantial in this area. Most students understood that their work was their demonstration of understanding and tried hard to demonstrate understanding rather than merely obtain an answer. An unexpected, related benefit was a reduction in "quibbling."
2. With only limited access to student portfolios, this potential benefit was realized to only a small degree. However, if students kept their matrix current, they knew their strengths and weaknesses at a glance, and faculty advisors, when working with marginal students were better able to advise.
3. There was a fear on the part of the faculty that a "C" student might not actually be able to do anything, that the "C" grade could reflect partial credit on virtually all work. While it is not clear that this fear was well-founded, most faculty now believe that "C" students are, in fact, able to succeed at some tasks.
4. Students did not see the competency matrix approach as non-competitive. Some saw it as less competitive. In fact, it was less competitive, in that faculty generally established the number of blocks needed for each letter grade before it was known how many blocks each student had earned. However, since faculty did not know until the end of the term how many blocks would be available, students did not know what their targets were. The target vaguest in the Fall Quarter when no one could even guess at the order of the magnitude of the total number of available blocks. By the Spring Quarter everyone knew that the total number of available blocks would be in the upper 500's.
5. It has already been mentioned that students were less clear about where they stood during a quarter.

Logistically, it is difficult to determine whether more or less work was required. It was difficult to

prepare and issue new pages to the competency matrix in a timely fashion. Grading homework did not appear to consume any more (or less) time than the points and percentages approach. However, processing the competency matrices at the end of the quarter and assigning grades required almost more time than was available at the end of the quarter. Faculty tried to check student portfolios to determine that blocks had been correctly entered and counted. In some instances, students entered fewer blocks than they had documented in their portfolio, in some instances more. In some instances, students counted more blocks than they had entered, in other instances less. In general, faculty could not check every portfolio, but sampled the portfolios to determine if there were problems. When problems were detected, faculty scrutinized every entry to determine a correct block count. One instance of blatant cheating was detected. Overall, processing the portfolios at the end of a quarter was a time-consuming, tedious task.

Expected the Unexpected

One unanticipated benefit was that the faculty working with a fairly mature, but still innovative program were forced to think again about what students should be learning. In addition, the approach encouraged faculty to forge stronger links across disciplines. For example, students earned competencies in mathematics for curve fitting on their chemistry and physics laboratory activities and demonstrated their understanding of kinematics on calculus problems. A second benefit is that the competency matrix makes it much easier for a faculty member joining the team to understand what is being taught in IFYCSEM. A third benefit is that the on-line matrix allows faculty to compares their original objectives for the course with what really happened. Since opportunities to demonstrate each block are recorded in a text note attached to the block, faculty can review the matrix, assess what they proposed to offer against what was really offered, and revise their schedule for topics and activities. A fourth benefit is the opportunity to assess students in new ways. Faculty members devised new assessment methods to take advantage of the unique opportunities afforded by the competency matrix. For example, since the competency matrix sets forth expectations for students, faculty members offered in-class and outside-class opportunities to demonstrate competencies which had been previously offered on homework and examinations. Students could take advantage of these opportunities to earn blocks they had previously missed. As quizzes in the traditional points and percentages system, these opportunities would have just been more opportunities to lose points. However, with the competency matrix approach, many students viewed these new methods as alternative opportunities to demonstrate what they were learning. IFYCSEM faculty are now considering different approaches to assessment for the 1996-97 academic year.

Opportunities for Improvement

Faculty have identified several aspects of the competency matrix approach which should be improved. First, the system seemed unexpectedly rigid. It was difficult to reward a creative solution to a problem. Second, "habitual" competencies such as units, significant figures, and neatness were difficult to assess, evaluate, reward, and nurture. Third, the logistics of adding competencies during the quarter were imposing. A faculty member needed to be sure that no one else had assigned a row number to a topic he/she was considering. Several different solutions were devised to circumvent this obstacle, but all created more confusion for faculty and students. Fourth, using the competency matrix approach for laboratory activities was a disaster in the Fall Quarter, particularly in physics. Faculty designed the matrix to include rows for laboratory techniques and skills, e.g., effective graphs, data analysis. However, once students earned these blocks, they stopped demonstrating these skills and techniques in their laboratory reports. As a result, IFYCSEM laboratory reports for physics laboratories were the worst in the history of the IFYCSEM program. The head of the Department of Physics and Applied Optics decided that IFYCSEM students would not receive credit for their laboratory work in physics if they transferred from IFYCSEM to the traditional curriculum and took PH125 Mechanics. In response, faculty prepared rows in the competency matrices for the Winter and Spring quarters for specific laboratories. Students would have only one opportunity to demonstrate these competencies. They would have to demonstrate competencies for these rows in the laboratory report for the specified experiment. Students on the IFYCSEM Council questioned this change in policy. However, when faculty members described the status of the laboratory reports in the Fall Quarter, students understood the need for change. Laboratory reports in the Winter and Spring Quarter were significantly better than the Fall Quarter.

World Wide Web

Versions of the competency matrices for Fall, Winter, and Spring Quarter can be found at:

http://www.rose-hulman.edu/~froyd/ifcysem/compet.htm

References

1. Bloom, Benjamin. *Taxonomy of Educational Objectives, Handbook I: Cognitive Domain*. Longmans, Green and Co., 1956.