

2006-413: BEYOND MEASUREMENT: DESIGNING ENGINEERING OUTCOMES TO FOSTER STUDENT ACHIEVEMENT

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Beyond Measurement: Designing Engineering Outcomes to Foster Student Achievement

Abstract

This paper describes the design of a novel program-level assessment framework consisting of engineering student outcomes and associated developmental levels; this framework has been dramatically influenced by constituent input and the assessment structure and practices of Alverno College. The outcomes have been designed to explicitly address student development; each outcome has four associated developmental levels that describe student progress in achieving the outcome. The outcomes are designed to provide structure to the educational experience for both students and faculty, providing a common language that facilitates a focus on student achievement. To this end, the number of outcomes has been limited to eight and each outcome has a one or two word descriptive title. This paper describes the process used to develop the outcomes, the outcomes structure, and the initial experience of using the outcomes in the Fall 2005 semester.

1 Introduction

This paper describes the design of a novel program-level framework for student assessment in a new multidisciplinary engineering program. This framework, consisting of engineering student outcomes and associated developmental levels, has been dramatically influenced by constituent input and the assessment structure and practices of Alverno College. This framework is intended to play a central role in the student educational experience as well as structure the assessment of student achievement and overall program effectiveness.

The engineering outcomes have been developed in the context of creating a multi-disciplinary engineering program in the new Department of Engineering at Arizona State University's Polytechnic Campus. The team of founding faculty has been given a once-in-a-lifetime opportunity to design a totally new engineering program from the ground up. Given no constraints on its design – other than that it be responsive to the changing needs of the nation at the dawn of the 21st century – this new BSE in Engineering program is designed around three core values: *learning through engagement, agility and focus on the individual*. These values are the focal points of a thorough and innovative redesign of the traditional Bachelor of Science in Engineering degree with the goal of creating a unique and highly effective learner-centered program. The curricular structure is based on contemporary pedagogies of engagement and proven learning strategies (i.e., team-based, cooperative problem-based, mastery-based, and experience-based learning).¹ This curriculum structure, embedded in a pervasive departmental culture that focuses on individual learners and their success, will produce highly prepared, agile engineers who are able to provide technical leadership within a broad range of modern and emerging professional settings.

Beginning in July of 2004, the founding faculty team used an engineering design process to create the new program. This design process included data gathering and analysis on the needs of the program's constituents; development of brand identity and program values; and design of a novel curriculum structure. The engineering program will seek ABET accreditation under the general engineering criteria as soon as possible; ABET requires that programs establish student

objectives and outcomes as a central component of accreditation. Thus, the development of a draft set of objectives and outcomes as a standard to measure student achievement and to evaluate the program effectiveness has been an on-going design activity begun as soon as the brand values were established in late 2004. Components of this design process are described in more detail in several conference papers.²⁻⁴ The Department of Engineering began teaching its inaugural class of freshmen in Fall 2005, providing the first (preliminary) opportunity to evaluate the effectiveness of the outcomes in fostering student achievement.

The founding faculty have come to see individual student assessment as essential to achieving the program values. In addition, the founding faculty agreed that a rigorous and comprehensive system of program assessment and continuous improvement is necessary to ensure long-term program success. The challenge faced by the faculty is to develop student outcomes that both students and faculty understand and systematically use to structure the educational experience. This challenge has been addressed by developing an outcome structure modeled in many respects on Alverno College's abilities.⁵⁻⁷ The engineering program has eight outcomes, and each is identified by a descriptive word or phrase; each outcome is accompanied by four developmental levels describing student progress in achieving the outcome.

In this paper, the process of developing the outcomes is briefly summarized. The outcomes and associated developmental levels are described. The use of the levels in the Fall 2005 semester is described, and some preliminary lessons learned in this semester are discussed.

2 Outcome Design Process

The outcome and level structure described in Section 3 is the result of an engineering design process conducted by the founding faculty. This processes briefly summarized in the following.

2.1 Initial Process

The founding faculty conducted an initial design process for the outcomes. This process was preceded by a significant amount of reading and discussion to become familiar with the issues facing modern engineering education and the transition of the engineering environment into a global work place. The actual design began with an affinity process that resulted in a list of Desired Outgoing Student Characteristics; this was further developed to become a list of 16 initial outcomes. This initial process and its results are documented in more detail elsewhere.³

Additional input for the refinement of the program student objectives and outcomes was solicited from external program constituents. These constituents included two groups of industry representatives: the advisory committee of JACMET (Joint Alliance of Companies Managing Education for Technology, an industry group working with Arizona's state universities), and the Engineering Department's Industrial Advisory Board. Both groups were asked to answer the two questions "What should students be able to do at graduation?" and "What should graduates be able to do within three to five years of graduation?" Also, two sections of ECE 100 (an introductory engineering course consisting primarily of freshmen and sophomores) in the Ira A. Fulton School of Engineering at ASU at the Tempe Campus were asked the same questions. The responses were collated and compared to the initial program student objectives and outcomes developed by the

founding faculty team; changes to the initial objectives and outcomes were made to reflect those issues that appeared consistently in the industrial and student feedback.

After reflection, it became clear that the initial student outcomes could be succinctly expressed by adopting ABET's Criterion 3 Outcomes a - k (with some slight modifications) augmented by three additional outcomes denoted l - n. With the outcomes so defined, an initial structure to assess student achievement relative to these outcomes was developed. The structure consisted of rubrics for each of the outcomes; each rubric contained a set of competency attributes associated with that outcome and identified characteristics of competency achievement at three different developmental levels (positions): developing, accomplished, and proficient.

2.2 The Alverno College Workshop

During the week of June 20-24, 2005, three founding faculty attended "Connecting Student Learning Outcomes to Teaching, Assessment, Curriculum" at Alverno College in Milwaukee Wisconsin. This workshop profoundly influenced the on-going development of the student outcomes.

Alverno College has developed eight abilities which should result from a successful liberal education; with each ability is a set of developmental levels that describe how students progress to maturity in the ability.⁵⁻⁷ Alverno describes the abilities and levels as follows:

[The abilities] are integrated, developmental, and transferable. They represent an integrated combination of multiple components including skills, behaviors, knowledge, values, attitudes, motives or dispositions, and self perceptions. . . . In order to make the eight abilities work as an organizing frame for a curriculum, the faculty analyzed each of them into a sequence of six levels at which a student would be expected to demonstrate her ability as she progress through her course of studies. . . . We found that, like the abilities themselves, these levels seemed best expressed in generic terms that are free of context. However, we neither teach for nor assess them in that abstract form. We rethink them into the concepts and terms that are informed by a context, either disciplinary or interdisciplinary, that comes as close as possible to a professional or other life situation. [7, pp. 9,11]

While at Alverno, the engineering faculty made a startling observation: both Alverno faculty and students understand and systematically use the abilities to structure the educational experience. The abilities and development levels provide faculty and students a common language, one facilitating a focus on student achievement first and program assessment second. They also foster a culture in which both faculty and students use evidence to support judgments about student achievements and capabilities. This is in sharp contrast to the engineering faculty's previous experience in engineering departments where program outcomes and objectives had little impact on the daily lives of students or faculty.

At the workshop and in subsequent discussions, the faculty concluded that the engineering program student outcomes would be much more effective in engaging students in their educational

process if they were restructured into a model similar to Alverno's. Thus, in the months following the Alverno workshop, the faculty made the following changes:

1. The outcomes were consolidated from fifteen down to eight.
2. Each of the consolidated outcomes was given a one- or two-word title and a short (one phrase or sentence) description.
3. Developmental levels were added to each outcome.

The original fifteen outcomes were renamed rubrics and were retained to provide detailed criteria for the outcomes.

3 Student Outcomes

For many engineering programs, the primary impetus for developing student outcomes has been the requirements associated with ABET accreditation. The ABET definition of a student outcome⁸ is: "outcomes are intended to be statements that describe what students are expected to know or be able to do by the time of graduation from the program." For example, a student outcome on critical thinking might be phrased as "Graduates have an ability to think critically, clearly identifying and using evidence, criteria, and values." The ABET definition of outcomes focuses on the "output" of an engineering program. In the experience of the founding faculty prior to joining the engineering department, outcomes were used primarily to measure a program's effectiveness and secondarily as a final quality check on graduates; program outcomes were not clearly and explicitly linked to the students' experiences as they progressed through the curriculum.

ABET accreditation at the earliest possible opportunity is a goal of the engineering program. Thus, the founding faculty have designed the program assessment processes to be compatible with the ABET definition of program outcomes. However, accreditation is not the primary purpose of the engineering program outcomes. The founding faculty have come to see *individual student assessment* as essential to achieving the core program values of learning through engagement and focus on the individual. Also, the founding faculty believe that it is essential that the outcomes reflect the developmental nature of student growth as they progress through the curriculum.⁹ In the past, many engineering curricula have been designed according to a conventional wisdom that "suggested that after first teaching a vast body of fundamental mathematics and science – which students absorbed like sponges – [faculty] were free to teach engineering principles, drawing as necessary on the deep well of basic knowledge internalized by the students. This was (and is) a lovely idea, but depressingly unrealistic."¹⁰ This approach ignores the developmental nature of student learning.¹¹ In contrast, the engineering program has designed outcomes that explicitly address student development. In this respect, the engineering program outcomes are similar to the competencies developed at Olin College.¹²

ENGINEERING OUTCOMES AND DEVELOPMENTAL LEVELS

<p>Design—An ability to design a system, component, or process to meet desired needs within realistic constraints.</p> <p><i>Level 1</i> Recognizes need for and can recite information flow in design methods and process steps.</p> <p><i>Level 2</i> Can carry out and communicate design process steps in constraint-based hypothetical design situation.</p> <p><i>Level 3</i> Evaluates design steps and resulting design quality and can revise them to improve a particular design scenario.</p> <p><i>Level 4</i> Can customize design process and communication for varying design situations.</p> <p>Problem Solving—An ability to identify, formulate, and solve engineering problems.</p> <p><i>Level 1</i> Articulate the problem solving process by making explicit the steps taken to approach a problem.</p> <p><i>Level 2</i> Performs all phases or steps of the problem solving process including evaluation and real or simulated implementation.</p> <p><i>Level 3</i> Independently analyzes, selects, uses, and evaluates various approaches to develop solutions.</p> <p><i>Level 4</i> Applies methods and frameworks of problem solving adapting them to a wide variety of situations and transferring group processes into effective performance in collaborative problem solving.</p> <p>Professionalism—An understanding of professional and ethical responsibility and a commitment to on-going professional competence.</p> <p><i>Level 1</i> The student plans to engage in systematic study to gain specialized knowledge that will allow them to provide services that others are willing to pay for.</p> <p><i>Level 2</i> The student can describe the major professional and ethical responsibilities that arise from the specialized knowledge of engineers.</p> <p><i>Level 3</i> The student can explain why engineers have these professional and ethical responsibilities in light of common moral theories and concepts.</p> <p><i>Level 4</i> The student can effectively guide their own efforts at gaining and maintaining their professional competence and their professional reputation.</p> <p>Communication—An ability to communicate effectively.</p> <p><i>Level 1</i> Recognizes own needs, strengths, and weaknesses in communication.</p> <p><i>Level 2</i> Can apply individual steps of communication processes.</p> <p><i>Level 3</i> Purposefully uses communication processes to address the needs of their audience.</p>	<p><i>Level 4</i> Appropriately employs and adapts communication processes to fully engage an audience.</p> <p>Perspective—An understanding of the role and impact of engineering in contemporary business, global, economic, environmental, and societal contexts.</p> <p><i>Level 1</i> Understands that technological change and development has both positive and negative effects.</p> <p><i>Level 2</i> Can identify and evaluate the assumptions made by others in their description of the role and impact of engineering on the world.</p> <p><i>Level 3</i> Can select from different scenarios for the future and appropriately adapt them to match both current science and current social, economic and political concerns.</p> <p><i>Level 4</i> Has formed their own model for the probable future of our society and makes decisions about their life and career that is informed by this model.</p> <p>Engineering Practice—An ability to use the knowledge, techniques, skills, and modern tools necessary for engineering practice.</p> <p><i>Level 1</i> Students are able to describe the essential elements of good engineering practice.</p> <p><i>Level 2</i> Given a problem statement, students are able to identify the necessary tools (e.g., computer software, and workshop or studio hardware), and characterize a plan, that together will produce a technical solution.</p> <p><i>Level 3</i> With direction, students are able to identify an appropriate set of engineering tools and apply them in a real world professional context, to develop a valid solution to a technical problem.</p> <p><i>Level 4</i> Students are able to independently identify the appropriate set of design and analysis tools and apply them within the context of the principles and method of sound professional practice to obtain optimal (defensible) solutions to engineering problems.</p> <p>Critical Thinking—An ability to think critically, clearly identifying and using evidence, criteria, and values.</p> <p><i>Level 1</i> Articulate the critical thinking process.</p> <p><i>Level 2</i> Identifies assumptions, criteria, and evidence to make informed decisions.</p> <p><i>Level 3</i> Evaluates alternative perspectives, contexts, and the quality of evidence in making informed judgments.</p> <p><i>Level 4</i> Examines and cultivates own value system relative to making informed decisions.</p> <p>Technical Competence—An ability to apply knowledge of mathematics, science, and engineering as well as collect, analyze, and interpret data.</p>
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Table 1: Student Outcomes and Levels

3.1 Outcomes and Developmental Levels

Program student outcomes were developed using the design process described in Section 2. In this process, eight outcomes were identified (Table 1). Each outcome has a title and a short description (a phrase or sentence). The title and description facilitate student and faculty use of the outcome in courses and other components of the curriculum; it is easier to remember and use the title “Communication” than “ABET Outcome g”.

Each outcome (except Technical Competence) has four associated developmental levels that describe student progress in achieving the outcome. The developmental levels are similar to the model developed by Alverno College.⁵⁻⁷ It is expected that students will typically progress from lower to higher levels, but that this progression will not always be linear or proceed at a constant rate. The primary approach to assess student progress in the outcomes is the requirement that students demonstrate achievement of several specific levels in each course as described in Section 3.3. Generally, students are required to demonstrate achievement of a given outcome level in multiple contexts or settings (e.g. courses), insuring that their learning will be generalizable and transferable to new contexts.

The levels in Table 1 are the result of the initial design process and have not yet received extensive testing and use. These levels will be refined as the faculty better understand student development through experience in each of the outcome areas.

3.2 Rubrics

Following the Alverno model, the outcomes and levels have been developed as fairly abstract descriptions of student performance so that they can be applied in the many different contexts that exist in the curriculum. To provide the detail necessary to structure and assess student learning, each outcome is further defined by one or more *rubrics* that embody detailed criteria by which achievement of some component of the outcome can be evaluated.

It is also at the level of the rubrics that the mapping between our eight outcomes and the ABET Criterion 3 a-k outcomes is established. Primarily for historical reasons described in Section 2, the rubrics are structured similarly to ABET Criterion 3 a-k with some modifications and two additional topics denoted l and n. The relationship between the rubrics and the student outcomes is shown in Figure 1. Additions and modifications to the ABET a-k are shown in italics in this figure.

These rubrics have been developed in some detail to describe the many different facets of a given outcome. They are also structured to evaluate developmental progress. Portions of the rubric for the communication outcome are shown in Tables 2 and 3. As described in Section 4, one significant difficulty experienced using this level of detail was managing all of the information necessary to assess achievement of a given level; determining an appropriate level of detail is an ongoing area of investigation.

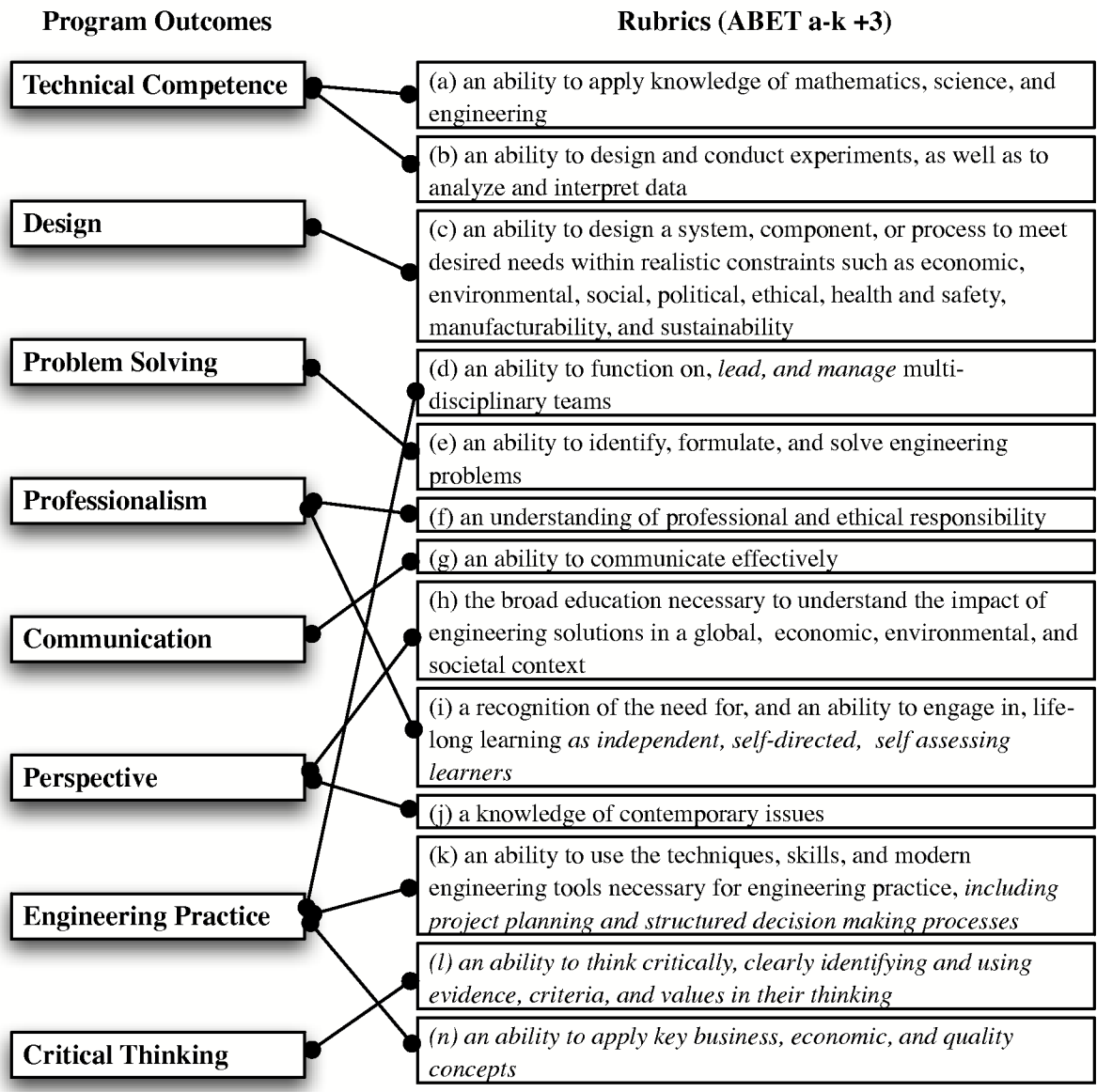


Figure 1: Relationship between outcomes and rubrics.

Table 2: Example of a rubric: the components of the Communication rubric

Professional Communication: Engages with individuals and in small groups, both speaking and listening effectively.

Audience Engagement: Engages both technical and non-technical audiences with appropriate consideration of audience background, culture, knowledge, and interests.

Visual Communication: Engages and meets the needs of the intended audience through visual communication of information, concepts, and ideas.

Written Communication: Employs the writing process to effectively engage and meet the needs of the intended audience.

Oral Presentations: Engages and meets the needs of the intended audience through oral presentations.

3.3 Mapping Levels to Courses

The developmental levels associated with each outcome describe a possible path for a student to achieve mastery of that outcome. A critical part of the assessment process for each student is to track their development through the levels as they progress through the program. The mechanism used to track student development is that the outcome levels are mapped to one or more courses in the curriculum, and that student achievement of these levels is assessed in the corresponding courses. A student can pass a given course (and proceed forward in the curriculum) only after demonstrating mastery of all of the outcome levels associated with the course. Each course is designed to support student mastery of the levels associated with that course. Table 4 shows the current mapping of levels to courses.

4 Initial Experience With the Outcomes

In the Fall 2005 semester, the department began courses with its inaugural freshman class. The department taught three courses:

- EGR 101–Introduction to Engineering (offered as EGR 194)
- EGR 103–Technology and Society (offered as EGR 194)
- EGR 294–Applied Project (A one credit-hour class to support a renewable energy project conducted with the Hopi Nation)

The outcomes were used most extensively in EGR 101; they structured much of the student work, and some data on their effectiveness was collected.

Table 3: Developmental Levels for the Written Communication Component of the Communication Rubric

Written Communication: Employs the writing process to effectively engage and meet the needs of the intended audience.		Level 1	Level 2	Level 3	Level 4
<i>Process</i>	Evidence that some steps of the writing process were used.	All major steps of the writing process are used.	The effectiveness of the writing process is evaluated.	The writing process is adapted to meet audience needs in particular circumstances with individual abilities.	Gives audience a clear sense of purpose and the relationship between own thoughts and the audience's needs and expectations. Appropriately quotes and attributes sources.
<i>Context</i>	Gives audience some sense of document's purpose ("What?", "To whom?"; "Why?").	Recognizable structure that is appropriate to the document's purpose.	Articulates necessary ideas, facts, data, etc.	Generally uses appropriate style and tone.	Language usually conveys meaning while consistently following appropriate conventions.
<i>Structure</i>	Recognizable introduction, body, and conclusions.	Articulates major ideas.	Language shows some awareness of appropriate style and tone.	Language generally conveys meaning while usually following appropriate conventions.	Document includes visuals.
<i>Content</i>	Articulates necessary ideas, facts, data, etc.	Generally uses appropriate style and tone.	Language usually conveys meaning while consistently following appropriate conventions.	Visuals are used purposefully to enhance document.	Shows awareness of some strengths and weaknesses relative to document's purpose.
<i>Expression</i>	Language shows some awareness of appropriate style and tone.	Language generally conveys meaning while usually following appropriate conventions.	Document includes visuals.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are an integral component of the text that effectively meets audience needs.
<i>Word Choice and Conventions</i>	Language generally conveys meaning while usually following appropriate conventions.	Document includes visuals.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are used purposefully to enhance document.	Evaluates performance in all critical areas.
<i>Visuals</i>	Document includes visuals.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are used purposefully to enhance document.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are used purposefully to enhance document.
<i>Self-Assessment</i>	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are used purposefully to enhance document.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Shows awareness of some strengths and weaknesses relative to document's purpose.	Visuals are used purposefully to enhance document.

Table 4: Mapping of Levels to Courses in the 4-year Curriculum

Outcomes	ENG 101	ENG 102	CHM 114	PHY 121	MAT Calc I	MAT Calc II	ABS 294 Biology for Eng.	EGR 101 Intro. Eng. Des. I	EGR 102 Intro. Eng. Des. II	EGR 103 Tech Soc	EGR 104 Critical Inq Eng I	EGR 201 Eng Studio I	EGR 201 Companion Course	EGR 301 Eng Studio II	EGR 301 Companion Course	EGR 304 Critical Inq Eng II	EGR 305 Primary Studio	EGR 306 Primary Studio II	EGR 310 Eng Statistics	EGR 401 Capstone I	EGR 402 Capstone II
Design								1	2			2		3			3	4		4	4
Problem Solving								1	2		2		2		3		3			4	4
Professionalism								1	2	2				3		3				4	4
Communication	1	2						1	2	1	2	2		3		3				4	4
Engineering Practice								1	2	1		2	2	3	3		3	4		4	4
Critical Thinking	1	2						1	2	1	2	2		3		4	3	4	3	4	4
Technical Competence			1	1	1	1	1		2			2	2	3	3		3	4	3	4	4
Perspective	1	1								2	2					3		3	3	4	4

4.1 EGR 101–Introduction to Engineering

EGR 101 was team taught by all seven engineering faculty and thus provided an excellent laboratory to apply the outcome levels and develop assessment methods. The course was structured around two team-based projects. The outcome levels associated with EGR 101 in Fall 2005 are shown in Table 5. These outcome levels were introduced to the students in the beginning of the semester. The rubrics for each outcome were made available to students on the class web page but were not specifically covered in class; in practice, assessment of student performance on written reports, oral presentations, and the oral exams was conducted using fairly small subsets of the criteria contained in each rubric. The outcome levels, in conjunction with other material covered in class, were used to structure midterm and final oral exams. In these exams, each student met with two faculty members who assessed the student development relative to the course content and components of the outcome levels. Each oral exam was preceded by a written student self assessment exercise in which they described their progress in areas related to the outcomes associated with the course. The final self assessment exercise also included questions to gauge the students understanding of the outcome structure and to obtain feedback relative to the effectiveness with which the outcomes were used.

4.2 Lessons Learned

On January 9, 2006, the department held a one-day retreat to assess the first semester. Prior to the retreat, the student responses in the final self assessment document relative to the outcomes and levels were collated and distributed to the faculty. Most students demonstrated a general knowledge of the outcomes and associated levels and of the role played by the outcomes in the curriculum. Most students demonstrated understanding of the relationship between achieving the

Table 5: Outcomes and levels for EGR 101

Outcome	Level
Design	1
Problem Solving	1
Professionalism	1
Communication	1
Engineering Practice	1
Critical Thinking	1

necessary outcome levels and their grade in the course, although there was often some inaccuracy in their understanding of details in this relationship.

However, several issues were identified by the faculty both from the student responses and their own experience. These issues included:

- There were too many levels assigned to each course, and the rubrics for each level were too complex; in EGR 101, most students were unable to determine from the rubrics what was expected from them to achieve the required levels.
- Rubrics had too many items; there is no effective way for faculty to assess all of the items on each rubric for each level.
- Outcomes and levels were not clearly tied to assignments and class activities. Students were often unclear and confused about what was necessary to achieve the required levels in the course.

After discussion, the faculty felt that there was no need to change the outcomes, but several potential changes to the levels and rubrics were identified, and several improvements in the way the levels and rubrics are used in courses were suggested. These included:

- Limit the number of outcome levels to be achieved for each course; three was suggested as an appropriate number. With this constraint in mind, revise the course/levels matrix in Table 4.
- Give reading and writing assignments specific to the outcomes, levels, and rubrics in early courses.
- During the spring 2006 semester, reevaluate each rubric to determine where it can be simplified.
- Tie grading criteria to the levels and rubrics at the time each assignment is made.

Finalizing and implementing these changes will be completed in the Spring 2006 semester.

5 Conclusions

This paper describes the design of outcomes and associated levels for the purpose of fostering student achievement as they progress through the engineering curriculum. Initial application of these outcomes in the Fall 2005 semester has been generally successful; several areas for continued development and improvement of the outcomes structure have been identified.

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