AC 2012-4584: DEVELOPMENT OF EVIDENCE MANAGEMENT AND GAP ANALYSIS TOOLS FOR CONTINUOUS IMPROVEMENT OF ENGINEERING PROGRAMS

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Development of evidence management and gap analysis tools for continuous improvement of engineering programs

The purpose of this paper is to demonstrate the development and structure of recently created data management tools used to assist in the continuous improvement of both agricultural and biological systems engineering programs. With the arrival of automatic document feeders capable of transforming paper materials in electronic documents, evidence of course contribution to student learning outcomes is easier to map than ever before. Additionally, electronic storage enables the ability to search within documents and connect related data more effectively than could be achieved with paper documentation. As a result, the following paper includes the development of key components for establishing relationships between course evidence (student work, syllabi, lectures, etc.) and student learning outcomes, a critical component of criterion 3 of the general criteria for baccalaureate level programs seeking ABET accreditation. Furthermore, the developed structure includes a means for collecting data and correlating the evidence to specific ABET A-K student outcomes in combination with a modified Bloom's taxonomic scale for classifying competency.

In addition to evidence collection and classification of student outcomes, the design of a data management tool for identifying gaps between achieved and targeted student learning outcome levels for individual courses will also be discussed. The function of the gap analysis data management tool is to inform instructors as to whether a course, based on the supplied evidence, is under or over achieving its specified target of student outcome performance. These tools were recently used for an ABET accreditation cycle and have the potential to be powerful resources for programs hoping to close the loop as part of their continuous improvement process. In summary, this paper will demonstrate the development of a database tool implement for capturing, reviewing, and assessing student output on a course by course basis.

Introduction

The continuous improvement process is a mechanism for adding value to a product or system. When applied to academic programs, the concept of continuous improvement is used to enhance the quality of skills each graduate possesses and the pathways in which he or she acquires these skills. However, continuous improvement is not a procedure that can be conducted *ad hoc*. Rather, it requires careful planning, documentation, review, and adjustment to make progress toward the desired improvement.

Furthermore, many institution and program oversight groups have placed an emphasis on having a continuous improvement system in place to as part of accreditation. For example, ABET, Inc. which is the principal accreditation authority of engineering programs has required that evidence of continuous improvement is a mandatory criterion for accreditation[1].

To demonstrate the improvement process institutions, colleges, or departments typically amass evidence in the form of course notes, syllabi, exams, and other materials to showcase student learning[2]. It is not uncommon that the collection and storage of this evidence can become a time consuming and tedious effort. In addition, simply collecting of evidence is not sufficient to show achievement of student learning outcomes let alone a continuous improvement process. After attaining the evidence, it is through analysis and assessment that conclusions can be reached and proposed actions can be made.

In an effort to improve the continuous improvement process of agricultural engineering (AGEN) and biological systems engineering (BSEN) programs at a Midwest engineering department, an electronic system for course evidence collection and curriculum assessment was initiated. It was the intent that the developed system would be capable of not only being a method for collecting data, but be able to provide feedback about the performance of a course in relation to its own objectives as well as its relationship with desired student learning outcomes.

The purpose of this paper is to discuss the design and development of an evidence management and curricular gap analysis tool for conducting continuous improvement of engineering programs. The objective was to provide a model framework for institutions desiring to transition into electronic evidence collection and analysis of student learning outcomes in courses. The discussion will include sample results of this tool and its utility in preparing a self-study for an ABET site visit. Finally, future goals in relation to continuous improvement practices will be highlighted.

Background

As previously mentioned, the accreditation organization, ABET inc., includes continuous improvement in its list of general criteria for evaluation. Furthermore, the ABET general criteria of student outcomes, program educational objectives, and curriculum are synergistically related through the continuous improvement process. Student outcomes are descriptions of skills that a student should be able to perform prior to graduation[1]. Currently, ABET has identified eleven student outcomes, labeled A-K, that students are expected to achieve (Table 1). Program educational objectives (PEOs) are the descriptions of skills that students will develop a few years following graduation. These objectives are rooted in the expectations of professional roles AGEN and BSEN graduates will attain. PEOs can be oriented to build upon the foundations established by the student objectives.

Table 1. ABET Undergraduate Student Learning Outcomes

A	B	C	D	E	F
An Ability to Apply Knowledge of Mathematics, Physics and the Engineering Sciences	An Ability to Design and Conduct Experiments, as well as to Analyze and Interpret Data	An Ability to Design a System, Component, or Process to Meet Desired Needs	An Ability to Function on Teams Including Multi-disciplinary Teams	An Ability to Identify, Formulate, and Solve Engineering Problems	An Understanding of Professional and Ethical Responsibility
G	**H**	**I**	**J**	**K**	
An Ability to Communicate Effectively	The Broad Education Necessary to Understand the Impact of Engineering Solutions in a Global and Societal Context	A Recognition of the Need for and an Ability to Engage in Life-Long Learning	A Knowledge of Contemporary Issues	An Ability to use the Techniques, Skills, and Modern Engineering Tools Necessary for Engineering Practice	

The ABET criteria for continuous improvement states that a “program must regularly use appropriate, documented processes for assessing and evaluating the extent to which both the program educational objectives and the student outcomes are being attained[1].” Furthermore, the evaluation process must be used to stimulate and justify future education efforts. By participating in continuous improvement practices, a program will have an established means for connecting student outcomes to program curriculum and identify program educational objectives.

In the assessment and evaluation of criteria, the collection of evidence of student learning outcomes is a critical and potentially a time consuming process. For example, in our department’s previous improvement cycles, evidence was collected in hardcopy and correlated with student outcomes using a variety of creative color coding systems and other means. This type of system did not lend itself well to use when an exam, project, or other assignment was used to satisfy multiple ABET outcomes. In view of this challenge, the department desired to establish a paperless system for ease in both data collection and outcome analysis. Furthermore, while the previous assessment system provided an excellent method of concentrating direct and indirect evidence from both external and internal sources, it did not lend itself to the feedback process that is essential to good continuous improvement practices. As a result, data collection and feedback utility became the priority of assessment system refinement.

However, our department has not been alone in attempting to developing better evidence storage and analysis, the use of data systems capable of collecting, retaining, and assessing data has become an ever increasing practice[3]. Examples of such technologies includes portfolio assessments, curriculum embedded assessments, outcomes based framework systems[4,5,6]. Some systems have even developed web-based appications[7]. In light of these examples, many of the tools developed for curriculum analysis are used solely for the purpose of demonstrating compliance with ABET accreditation. Hence, many of the systems appeared to be excellently geared toward demonstrating assessment activity, but often mechanism for conducting continuous improvement appeared to be lacking.

With a history of striving toward better continuous improvement practices, the development of an electronic evidence collection system and gap analysis tool were not the first steps of creating a culture of continuous improvement. Rather, the design of these tools originated from a desire to enhance the processes currently in place as well as establish new channels for providing feedback on course content and curricular objectives. For in 2005, the AGEN and BSEN programs had adopted the practice of utilizing student outcome matrices (SOMs) to map student outcomes to objectives for each course. Additionally, the mappings were rated using Bloom’s taxonomy to describe the level of cognitive skill attained[8].

The use of Bloom’s taxonomy has been incorporated into many education disciplines ranging from business to physics and music education[9,10,11]. Bloom’s taxonomy is a classification of the cognition performed and mapped to a six level scale ranging from (1) Knowledge, (2) Comprehension, (3) Application, (4) Analysis, (5) Synthesis, to (6) Evaluation. As a result, the taxonomy provides a standard for classifying the degree of cognitive competency required by the individual tasks. Additionally, the Bloom’s taxonomy for categorizing and classifying assignments and outcomes has been indicated to be an effective tool for comparing courses[12].

Continuous Improvement Model

To ensure that continuous improvement of both the AGEN and BSEN curricula remained central to the design of the evidence collection and analysis tools, a general schematic for proposed curriculum action system was established (Figure 1). Through oversight by the curriculum committee, instructors were to be informed of the intended student learning outcome targets for their course. Additionally, the curriculum committee's responsibility included setting and modifying program educational objectives and curricular student outcome targets. From that point, it would be the instructor's responsibility to generate the course content and objectives as well as determine how course material would direct students to achieve the desired learning outcomes.

The most significant elements to this model were the evidence collection and gap analysis stages. Nevertheless, one condition for the implementation of these elements was that they would not interfere with the regular course activities. The goal was that, throughout instruction of the course, the instructor would be able to load instructional material and student work to the evidence collection system as proof of student learning outcome attainment.

After placing the evidence in the location of evidence collection, an evaluator would review the submitted materials. The evaluator would also analyze the course's achieved outcomes in relation to other courses to ensure that no gaps in the curriculum exist. A gap was determined to be any point where collected evidence demonstrated that the Bloom's level assessed did not align with the courses desired target Bloom's level. Analysis for gaps would be performed at the course and curricular levels. The evaluator would also assess the relationship between the student outcomes and their contribution to the program educational objectives. Following the assessment, suggestions would be given to the curriculum committee and instructors as to possible modifications of outcomes or course content.

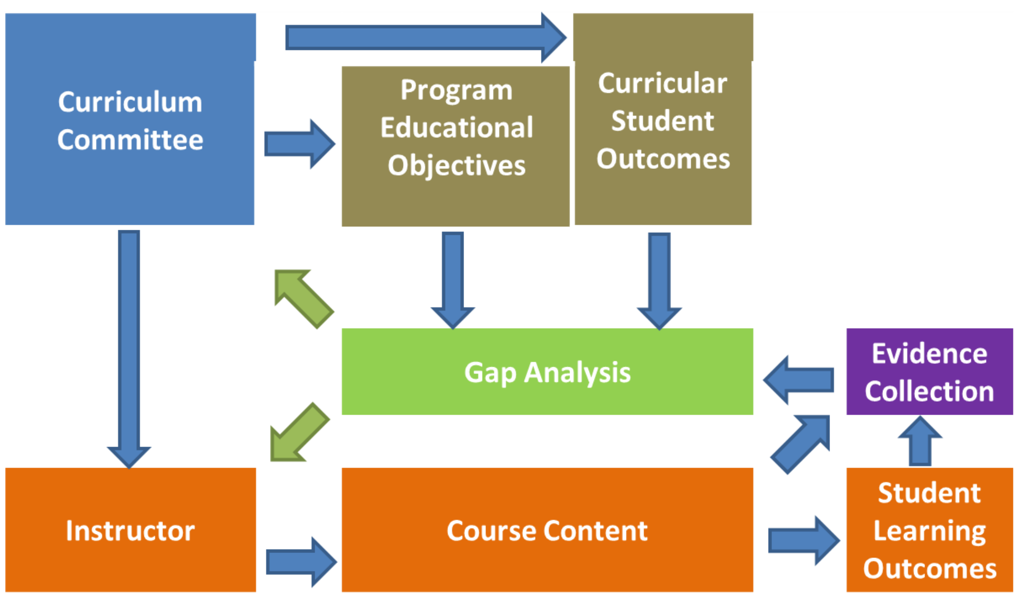

Figure 1. Framework for continuous improvement of curriculum. The proposed system provides an evidence based feedback system to both curriculum administrators and instructors.

Evidence Collection

For the database structure of the evidence collection system, it was determined that Microsoft Access would provide a suitable environment for simple centralization of data collection. Additionally, by placing the database on the department's shared network drive it would be possible for instructors to upload evidence at his or her convenience.

The back structure of the database consisted of three tables for storing the general course description information, student learning outcome targets, and outcome evidence (Figure 2). The abbreviated catalog name and course number served as the primary key for each table. The user interface consisted of a form that would display the course name and two filtered subforms that would query to match the course active on the main form (Figure 3). Within the main course form, a subform called the target subform provided a region for the instructor or assistant to input the target Bloom's level for each course objective and applicable student outcomes (Figure 3.B). The other subform was designed to be the evidence subform and was the location to which all evidence for a course was to be stored.

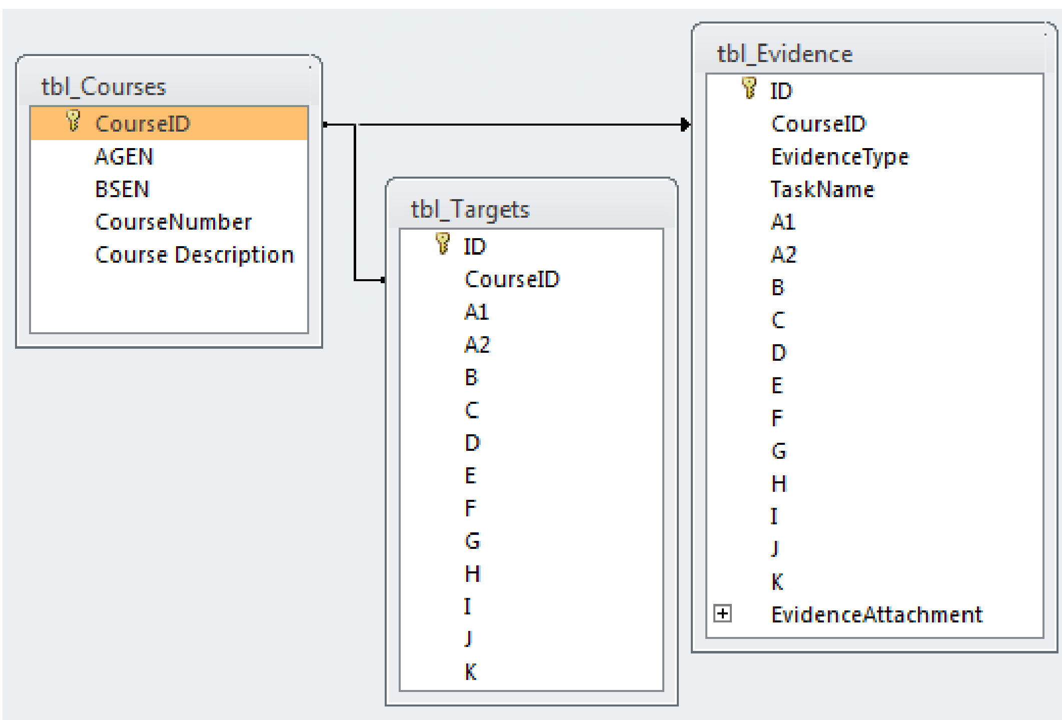

Figure 2. Database table infrastructure. The main courses table (tbl_Courses) was linked to the table of course targets (tbl_Targets) and the table of course evidence (tbl_Evidence) through the CourseID field of each course.

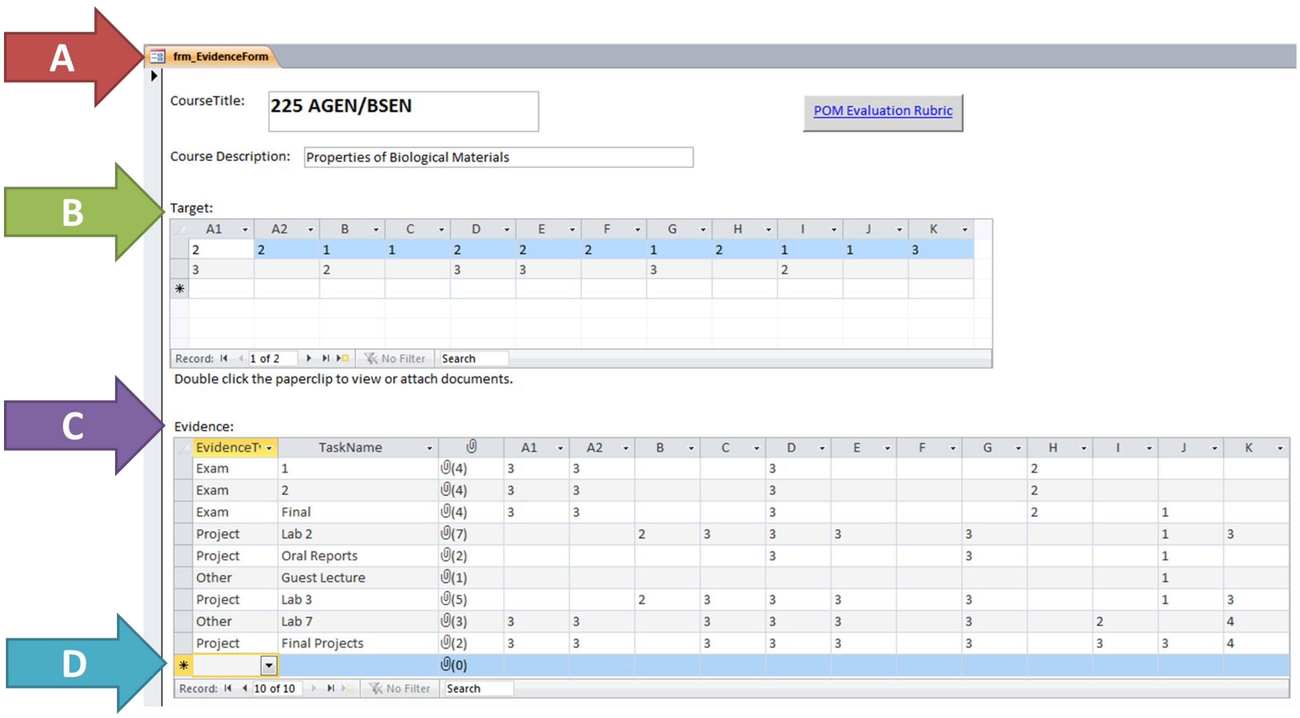

Figure 3. User Interface for evidence collection. The design of the main course form (A) contained locations for the Target subform (B) and Evidence subform. Each row of the Target subform corresponded with a different course objective. For example, the course shown has two course objectives. In the Evidence subform, the user has the ability to upload new evidence (D) to the subform by double clicking on the paperclip icon. Also, the fields EvidenceType and Taskname allow the user to provide additional labeling to the evidence.

To establish target student learning outcomes for a course, the curriculum committee selected not only the student learning outcomes that must be achieved by the course but also the degree to which students must demonstrate their understanding. For each A-K student outcome, the target was defined using Bloom's taxonomy. The Bloom's level for a specific outcome was determined to be the maximum cognitive demand of an assignment or course with the expectation that the lower levels were also achieved. Once information was determined, it was stored in the evidence collection form (Figure 3.B). For implementation, it was left up to the instructor on how he or she would attain the target student learning outcomes set by the curriculum committee and what course material and student work would be placed into the evidence subform.

To collect evidence, an instructor was expected to save a digital copy of exams, projects, or assignments to the Access database (Figure 3.C). If a piece of evidence was in hardcopy form, the use of a document scanner enabled the conversion of the document into a PDF. Evidence came in the form of homework, exams, projects, presentations, videos, course syllabi and even lecture notes from students and professors. The evidence was then scanned and stored electronically in class specific folders within a shared continuous improvement assessment folder. For use in identifying the mapping of Bloom's levels of cognition to outcomes, a Bloom's mapping rubric was applied for matching each target and with its corresponding outcomes. Collection and uploading of evidence from students was the only task required of the instructor.

Gap Analysis

Following the collection of evidence, it was decided that a set of evaluators would review the collected materials and determine the student learning outcomes achieved in a specific piece of evidence and determine if the evidence satisfied the level of cognition indicated by the instructor. The evaluators also determined if the evidence resulted in the students having a high or lower competency than the target indicated by the instructor. Evaluators had the ability to leave suggestions to instructors on how assignments could be modified to satisfy the desired learning outcome.

To conduct the evaluation tasks a Microsoft Excel spreadsheet system was designed to store evaluation critiques of course evidence in correlation with the desired student learning outcomes. Due to Excel's capacity to contain large datasets and dynamically relate values with a simplistic input system, it was deemed an appropriate platform for developing a curriculum and course gap analysis tool. On a course assessment sheet, evaluators would have the ability to provide their own reassessed values of evidence as well as input whether the evidence item was higher, lower, or satisfied the target Bloom's for a certain student learning outcome (Table 2). From the Bloom's Level analysis, the sheet would also identify the maximum Bloom's level achieved of each student learning outcome. Adjacent to the maximum achieved Bloom's level column was a column containing the target Bloom's level for each outcome. A column was also established for evaluators to provide feedback to instructors on possible modifications to course material to better align with course targets.

A comprehensive understanding of the evidence provided by the instructor was accomplished by reading each piece of evidence and discovering the instructor's intended breadth and complexity for the assignment, exam, or other material. Moreover, evaluators were asked to examine assignments from a student's perspective, to assess if a student would grasp the methods, tools, skills, and knowledge necessary for completion of the work.

After analysis, specific pieces of evidence were selected based on the course evaluation rubric that matched achievement of the maximum Bloom's levels for each of the student learning outcomes. In cases where the evidence fell outside the wording parameters set by the rubric the original definitions of Bloom's taxonomy for each classification were evaluated using professional judgment, and in special cases course instructors were consulted.

Once evidence was assessed at the course level to determine the average cognitive performance of an outcome, evaluation shifted to the curriculum level. For this purpose a spreadsheet was designed to programmatically compile the student learning outcomes and courses for the purpose of mapping courses across the student learning outcome spectrum (Table 3). The spreadsheet would accomplish this task by placing the three digit course number into the corresponding maximum Bloom's level achieved for each outcome. Through this design, analysis of curriculum was used to map courses into their respect Bloom's level for each outcome. To identify where courses were performing in relation to curriculum targets, a conditional formatting was applied to shade the cell containing the Bloom's level target for each outcome.

The intent of evaluating across the curriculum was to observe the progression of Bloom's level cognition throughout the program's pathway and identify potential gaps. Additionally, the tool was used to identify the most frequent Bloom's level found for an outcome, the weighted average Bloom's level, and the maximum Bloom's level reached by each outcome. For a more balanced assessment of achievement, an average of these three results was used to determine the achieved curriculum Bloom's level.

Table 2. Student learning outcome gap analysis with suggestion for course improvement

Course:	225 AGEN/BSEN											
Curriculum Outcomes	Bloom's Level						Max Bloom's Level	Intended Bloom's Level	Higher level than goal (H)	Lower level than goal (L)	Level Not Found (N)	Comments:
	1	2	3	4	5	6						
A1			x				3	3				
A2			x				3	2	H			
B		x					2	2				
C			x				3	1	H			
D			x				3	3				**Suggestion:** Students could state strengths seen by group member in their lab group on exam. Midway through the semester each student could write a short essay about their group, including themselves, and address individual strengths, weaknesses, professional responsibility, and effects of lack of professional responsibility.
E			x				3	3				
F								2			N	**Suggestion:** Add professional or ethical questions regarding industry applications of materials and/or methods used in the lab.
G			x				3	3				
H		x					2	2				
I			x				3	2	H			
J			x				3	1	H			
K				x			4	3	H			The students used multiple engineering tools in analysis. The matrix needs adjusted. Does not seem to be over teaching.

Student Outcomes	Bloom's Level							Curriculum Target	Most Frequent Level found	Weighted average	Max Bloom's Level Reached	Achieved Bloom's Level
	1	2	3	4	5	6						
A1		100,	112,206, 225,244, 326,350,	303,317, 321,	344,446, 470,480,	416,453, 460,		5	3	4.12	6	4.37
A2		100,	112,225, 244,326, 350,	303,317, 470, 480,	344,446,	416,453, 460,		4	3	4.07	6	4.36
B	112,	225,		303,317, 321,453, 480,	350,416,	460,		4	4	3.90	6	4.63
C		317, 326,	100,225, 244,344, 350,	416,446, 470,		303,453, 460,480,		6	3	3.93	6	4.31
D		112,	100,225, 303,317, 350,460,	470,		480,		4	3	3.33	6	4.11
E			100,112, 225,244,317, 416,446	206,321,32 6, 350,470,	344,	303,453, 460,480,		6	3	4.12	6	4.37
F	112,	100, 416,	317,326,350,	453,		470,480,		3	3	3.33	6	4.11
G		112,	100,225, 303,317, 350,446, 453,460,			416,470, 480,		5	3	3.67	6	4.22
H	112,	100,206, 225, 244,303, 317, 326,	470,480,	350,416, 453,				3	2	2.54	4	2.85
I	303, 460,	317,326, 453,	225,350,446,	344,		416,		2	2.5	2.70	6	3.73
J	112, 321,	100,326,	206,225,244, 446,	453,470,	303,317, 480,	350,416, 460,		5	3	3.69	6	4.23
K	100,		112,206,244, 326,416,	225,317,32 1,350,446,4 53,470,480,	303,344,	460,		4	4	3.76	6	4.59

Discussion

The development of an evidence collection and gap analysis tool demonstrated to be a valuable tool for the continuous improvement process. By centralizing data collection, both instructors and evaluators had a common location for storing and assessing course materials. Additionally by moving to an electronic format, course material from students could more readily be used to demonstrate outcome fulfillment for multiple student learning outcomes in a single course.

The feedback provided by the gap analysis tool was also greatly appreciated by instructors. For those instructors who had exceeded the Bloom's level for a specific student learning outcome, they valued knowing that they could decrease the demand in some course activities in order to provide more time in other needed areas of instruction. Similarly, instructors whose course failed to attain or lacked sufficient evidence to attain a set level of cognition for a student learning outcome, agreed to many of the suggestions by the evaluators. Since implementation, the feedback provided by the gap analysis tool has provided notable positive changes to both the AGEN and BSEN curricula.

In addition to feedback on course student learning outcome satisfaction, curriculum committee members appreciated the ability to visualize the cognitive development of student learning outcomes across the curricula (Figure 4). Through these tools it was possible for the curriculum committee to have sufficient data for providing guidance to instructors as well as plotting curriculum expectations. The curriculum committee also appreciated the contribution of the data management system to ensuring students were attaining the competencies intended by the BSEN and AGEN programs.

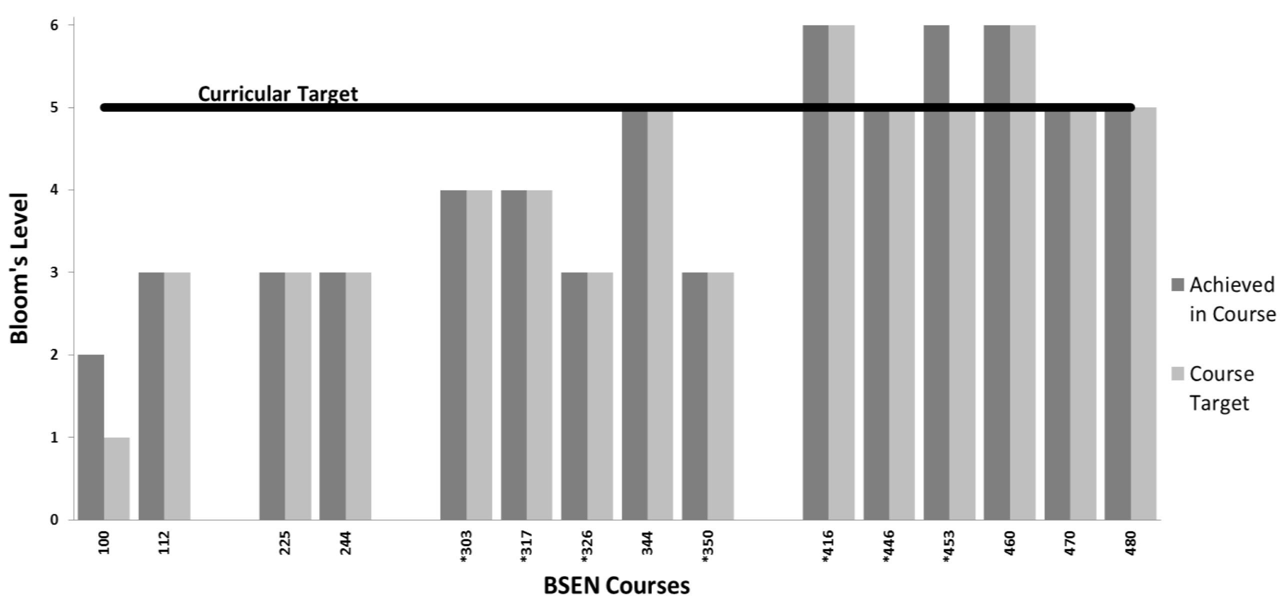

Figure 4. Progression of Bloom's level cognition though the BSEN curriculum for a sample outcome.

Future Direction

For future development of the continuous improvement process, it is the intent of the department to explore how these tools could be more streamlined and tightly packaged for future uses. Microsoft Access and Excel provided an opportune platform for developing the structure of both data management tools; however, it is likely through MySQL or other server based interfaces that greater utility can be achieved. A development toward web-based servicing would enable instructors the ability to manage course outcome evidence in an even more convenient fashion. In addition to demonstrating continuous improvement in accordance with ABET criteria, future versions of these tools will also seek to integrate institutional assessment measures for demonstrating academic centered achievement.

Conclusion

The purpose of this paper was to discuss the design and development of evidence management and curricular gap analysis tools for conducting continuous improvement of engineering programs. By making these tools the center of the continuous improvement system, it was possible to provide instructors and the curriculum committee with the feedback needed in order to justify curricular actions. Moreover, the design of a database for electronic storage provided a common location for instructors to store evidence of student outcome achievement. However, it was the gap analysis tool that enabled the continuous improvement process to come full circle and provide instructors with feedback on what could be done to better meet the needs of student learning outcome targets. It is by providing methods such as these for feedback that continuous improvement systems will continue to provide a means of further enhancing the quality in engineering education.

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