Managing Engineering Curriculum For ABET 2000

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Abstract

Many engineering programs are trying to determine how to meet the new ABET 2000 accreditation criteria, which include an emphasis on assessment and documentation of the processes used to achieve desired attributes. This means programs must carefully consider and identify where in the curriculum attributes are addressed and taught. This can be facilitated if educators have a means for understanding and managing the curriculum as a whole.

In the mechanical engineering department of Brigham Young University, we have been experimenting with ways to capture and manage the curriculum to insure that all desired attributes are addressed. We discuss what we have learned to date and the strengths and weaknesses of the methods we have tried. We discuss a web-based software tool for curriculum management that is currently under development. The software will enable us to manage curriculum to insure that all attributes are being developed and to maximize integration across courses. It will help provide consistency in instruction, will be a complete repository of the curriculum that can be accessed at any time, be a catalyst for interaction with outside "suppliers" such as math and physics, and be a means for communicating program objectives to students.

Introduction

In November 1996 the Accreditation Board for Engineering and Technology (ABET) approved *Engineering Criteria 2000, Criteria for Accrediting Programs in Engineering in the United States* (ABET, 1996). The new criteria represent a paradigm shift in accreditation from a highly prescriptive set of criteria to a relatively simplified, flexible set of outcomes-based criteria which focus on the attributes engineering graduates are to have. These attributes are,

- an ability to apply knowledge of mathematics, science, and engineering;
- 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 multidisciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global/societal context;
- a recognition of the need for and an ability to engage in lifelong learning;

•a knowledge of contemporary issues; and
•an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Similar attributes have been suggested by industry (McMasters and Matsch, 1996). Individual programs have some flexibility regarding how these outcomes are met; however, "*Engineering Criteria 2000* encourages programs to clearly state their academic goals and the process by which those goals are to be reached" (Phillips, 1997). Thus, although the process is not prescribed, there is a strong emphasis that programs provide documentation regarding the process used to achieve outcomes.

Many of these attributes are such that they are best learned as they are integrated into the curriculum as a whole. For example, "the ability to function on multidisciplinary teams," is probably best learned not by providing a class on "team-based learning", but by providing opportunities for students to function as teams as part of the learning process in other courses. This means learning activities to support team-based skills will be sprinkled across the curriculum. The same can be said for several of the other attributes (e.g. communication, design, ethics): the skills associated with these attributes are best learned when given a specific engineering context. Thus traditional courses such as Heat Transfer or Fluid Mechanics will have other objectives besides learning the regular subject matter--objectives which are not part of the text. This presents the challenge of insuring consistency and uniformity in meeting these additional objectives.

The competing pressures to include more in the curriculum while keeping the time to complete it reasonable also suggest that the curriculum should be as effective and efficient as possible. This means classes should carefully build on each other, reinforcing the most important principles while eliminating unnecessary redundancy.

All of these motivations--the need to document, the need to coordinate and insure consistency for attributes spread across many courses, and the need to be as effective and efficient as possible, argue in favor of developing a means to specify, organize, manage and document the engineering curriculum for a program of study. In this paper we discuss the efforts in the mechanical engineering program at BYU to do this using a variety of computer-based tools. We start by reviewing related research for computer-based curriculum management. We then review our first attempts to manage curriculum using a curriculum matrix. Finally we discuss a web-based tool under development which builds upon our earlier efforts.

Relationship to Other Research

The most significant attempts to use the computer for curriculum management appear to have been in primary and secondary education, where, in some cases, outcomes-based programs have been mandated for a number of years. Taylor et. al. (1989) discuss the possibilities for computer use in curriculum development and management, including curriculum design, needs assessment, forecasting, selection of objectives, generating test items, monitoring student progress, evaluation, materials selection, analysis of scope and objectives, grouping students, and reporting student progress. They surveyed school districts across the United States and found about 100 that were involved in using computers for curriculum design. The most common application, however, was for monitoring student progress. Sady et. al. (1984-85) developed a relational database on a PC for the curriculum of the University of Kentucky's doctoral program in dentistry, where over 100 courses are involved. The database was used to monitor duplication and avoid omissions as well as to properly sequence content and learning of skills. No graphics were involved, and most information was entered using codes. Mann and Kitchens (1990) describe the development of a curriculum management system for mathematics for the Indianola Public Schools. The program was used primarily to develop individual plans of study for students, perform assessment, and produce reports of student progress. Carter (1995) discusses the potential of Information Management Systems to "allow for the unobtrusive and automatic acquisition of data describing the key operations associated with the interlocking cycle of relationships between curriculum, instruction, and assessment" for use in Australian schools. The idea is not to control all activities but to "direct them differently to learners as needed," i.e., increase flexibility, as well as collect data for assessment purposes. The software used was developed by Texas A & M University and consists of four modules: Curriculum Developer, Lesson Planner, Educational Researcher, and Student Data Manager. In some respects these papers point the way for highly integrated systems that both provide for more individual flexibility in setting curriculum and assist in collecting data for assessment. At present, however, such systems may have too high an overhead to be adopted at the university level. We have decided to start with something that is relatively simple and direct and then move to a broader scope of implementation from there. However, it is intriguing to consider a unified system that would not only allow faculty to set and manage curriculum but would also track student performance, provide feedback to students and faculty, and allow a student to customize the program of study to maximize learning.

Curriculum Management at BYU: First Attempts

Curriculum Matrix

It became obvious after much discussion regarding an outcomes-based program that we needed some way to identify where in the curriculum the desired attributes would be taught. It was also clear that we could not afford to add a bunch of new courses; rather, we would need to fold activities into existing courses to address many of the attributes. To see where the attributes would be covered, we developed a "curriculum matrix." For the matrix, courses are listed as columns and attributes are given as rows. An element in the matrix represents an activity that is covered in the course that supports that attribute. By looking at columns it is easy to see which attributes a particular course includes; by examining rows it is easy to see in which courses an attribute is covered. Gaps become obvious--a row of mostly blanks means the attribute is not being covered anywhere. This matrix was made on an 8 ft. long by 12 ft. wide sheet that we installed in the department conference room and which rolls up. This matrix was large enough that a brief description of the activity which addresses the attribute could be entered in a cell. As we discussed changes in our courses faculty taped notes in the cells for new activities which they proposed to implement. A "wallet-size" version of the matrix was also developed; one page of the four page document is given in Fig. 1.

Use of the curriculum matrix makes it possible to provide for much better coverage of attributes with only a minimal impact in terms of requirements for students; indeed, no new courses were added. Rather, there is incentive to develop learning activities which address several attributes at once since these are highly efficient. As an example, a lab activity which previously focused only on having students learn about viscous flow was modified such that they work in teams and learn some of the steps of the design process as they design a device to measure viscosity.

Attribute	ME 372	ME 435	ME 440	ME 475/476
Fundamental Physical Phenomena	**(Elasticity, Materials)** plane stress, plane strain, axial and bending stress, Mohr's circle, principal stresses, stress concentrations, deflection and stiffness; strain energy, Castigliano's theorem, static failure (max normal stress, max shear stress, von Mises stress), failure of ductile and brittle materials, fatigue failure (crack propagation, endurance limit, fatigue life).	**(Motion)** time response of mechanical systems, resonance, bandwidth and stability, 3D rigid body motion **(E&M)** response of electrical and electro-mechanical systems **(Fluid Flow)** hydraulic and electro-hydraulic systems	**(Heat Transfer)** relation of heat tran. to thermo., three modes, general conduction eqn., steady state conduction, transient conduction, free and forced convection, radiation, heat exchangers	
Define, Model and Solve Problems	Mohr's circle, freebody diagrams	concepts of modeling, 1st and 2nd order diff. eqns., lumped mass, spring, dashpot, lever systems,. bond graph models, numerical soln to diff. eqns, frequency response and transfer functions, Laplace transform, Bode plot , systems with multiple degrees of freedom, Lagrange's method	diff. eqns, numerical solns to partial diff. eqns.	
Design System or Component	design process review, safety factors, fasteners, gearing, springs, bearings, clutches, shafts, keys, belts, design: 1) optimum gear reduction 2) sizing gear teeth, 3) shaft and bearing 4) clutch	DC motors, variable field motors, transducers and actuators, kinematic linkages		defining customer needs, product specification, concept generation and selection, predicting design behavior, layout design, parameter design, process design, prototyping
Plan and Conduct Experimental Program	several tests using MTS system	experiment modeling DCmotor system and validating with data, experiment measuring Bode plot of shock absorber	plan and conduct several tests measuring temperatures and heat flows	
Use Engineering/ Computer Tools	spreadsheet for fatigue failure of preloaded bolts, estimate stiffness of clamped members in bolted joint, SN and Goodman diagram, gearbox design	numerous MATLAB applications	spreadsheet, HEATRAN	heavy use of CAD, some CAE software, scheduling software, presentation software
Fabrication Processes and Planning	effect of manufacturing processes on fatigue strength, build friction clutch			design for manufacture, process plans
Oral and Written Communication Skills	oral presentation.		oral and written presentations of special problems	oral presentations, several written deliverable reports, design documentation
Work with Others	team activity on finding design information, practice centroid, MOI calculations, deflections, fatigue failure		able to solve special problems in teams	multidisciplinary teams work on design all year
High Ethical Standards				
Global, societal context	discussion of failure, failure case studies			economics, intellectual property, contracts, safety in design
Lifelong Learning and Service	intro. to LRC and Thomas register			
History, Lit, Arts			historical methods	case studies
Hands-on activities, labs	weight drop test, torsion test of bolts, tension test of welded and riveted joints, failure test of simple part, examine fatigue samples, static failure samples	demonstration of mech. system, measure magnitude and phase response of physical system (rock shox), measure spin down response of DC motor system,	several labs and special problems that require hands-on experience in heat transfer.	CAD, work in shop

Figure 1. Mapping the Curriculum to the Attributes: Example Page

The curriculum matrix is a means to view how the entire curriculum supports the desired attributes. However, as might be supposed, only a very brief description of the learning activity can be entered. Also, since some activities support several attributes, they are entered into multiple cells in a single column. This makes it somewhat difficult to understand what is covered in a particular course, where usually material is organized in a sequential fashion. Thus it is only one way to view the program. Another way we have captured the curriculum is in a relational database.

Relational Database

The Curriculum Matrix is a useful way to view the entire program of study, but it does not provide enough detail. To capture in detail what is in a particular course and organize it in a more sequential fashion, a relational database was developed which uses "learning segments" or "learning activities" as the basic record of data entry. The template for creating a record is shown in Fig. 2. The database was created using the commercial software Filemaker Pro for the Macintosh.

A learning segment is similar to a main topic of a course or a chapter of a book. A course would usually have 6-15 learning segments. Each learning segment could have attached to it several specific learning activities. Initially we have asked faculty to fill out learning segments only. The example shows that in one record the segment title, objectives, competency, attributes, reading, homework, lab exercises, first principles (conservation principles), math, and computer tools are entered. When all segments have been entered, the database contains relatively complete documentation for a course.

Because this is a relational database, data can be viewed numerous ways. For example, in Fig. 3 a summary is given for ME 435, Dynamic Systems, of all learning segments, the primary objective for the segment, and the attributes it supports. If enough detail were given, it would be possible to directly produce a course syllabus from the information.

Once the data is entered, which admittedly takes some time (1-2 hours per course), the ability to view it in different formats is a powerful tool. We are able at a glance, for example, to print out descriptions of activities that support each attribute across all courses or we can list where and how computers are used in our program.

Name: ActivityName ○ Activity ○ Segment

Description including sub-topics: ActivityDescription

Primary Objectives: PrimaryObjectives

Secondary Objectives: SecondaryObjectives

Competency: Competency

Attributes: ☐ Thermal Science ☐ Mechanics ☐ Materials ☐ System Integration

If any of these are selected, explain below

- At understand fabrication processes
- At model and solve problems
- At design system, process or component
- At conduct an experimental program
- At use engineering tools, techniques
- At effective communication skills
- At work with others
- At appreciate history, art, music, etc.
- At have high ethical standards
- At understand global societal context
- At commitment to lifelong learning

Explanations: Explanations

Associated Reading and Homework: ReadingHomework

Associated Laboratory Activities: LabActivities

First Principles: FirstPrinciples

Mathematics: MathConcepts

Computer Tools: ComputerTools

Class Periods: Class P(**Out of class time (hrs):** OutOfC **Identifying Number:** IdentifyNumber

Prepared By: PreparedBy **Date:** Date

Fig. 2 Example Record for Database

Principles of Modeling

Why model? Modeling is introduced as a supportive activity to synthesis. The concept of lumped modeling as a low frequency approximation to real behavior. Requirements of a modeling strategy.

Instill motivation to understand principles that govern behavior of physical things and learn how to use them to predict. Importance of design as a driver for learning.

[model]: Students are asked to model some common devices. Examples: toilet flush and refill system, pot on stove, automobile acceleration. Concepts of force, velocity, voltage, current, pressure, flow rate.

Modeling Mechanical Circuits

Newton's second law applied to lumped mass, spring, dashpot and lever systems. Constitutive relations, free-body diagrams and systems of equations.

Develop skill and confidence in this restricted domain so that it can be used as a basis to build a more general strategy.

[model]: Students model, using equations of motion, the physical behavior of simple mechanical systems.
[tools]: Students use free-body diagrams and Newton's 2nd law to derive equations of motion for simple mechanical systems.

Bondgraph Models

Development of bondgraph modeling methods with mechanical circuits as the context for application.

Introduce bond-graph modeling approach. Students acquire the ability to represent linear translational and single-axis rotational mechanical systems in bondgraph form. Students should be able to generate sets of first-order nonlinear differential equations to represent these systems.

[model]: Students model mechanical systems using bond graphs.
[tools]: Bond graphs are presented as a tool for modeling systems.

Computer Simulation

Use of computer to simulate physical phenomena by numerical solution of ordinary differential equations.

Develop student confidence in MATLAB as a tool for simulating the transient response of physical systems.

[tools]: Some specialized training in the use of MATLAB for the solution of equations of motion.

Frequency Response & Transfer Functions

Laplace transforms as a tool for calculating transfer functions from equation of motion. Development of ability to predict frequency response of lumped models of dynamic systems. Comparison of predicted and experimental data in the frequency domain.

Conceptual understanding of the transfer function as a method for representing system dynamic behavior. Prediction of low-order frequency response with approximate sketches as an aid in thinking about dynamic systems. Treatment of high order systems using MATLAB.

[model]: Understand transfer functions a modeling approach.
[experiment]: Measure magnitude and phase response for a real physical system.
[tools]: Use Bode plot sketching techniques.
[tools]: Use MATLAB to plot frequency response.

Electrical and Electromechanical Systems

Bondgraph modeling of electrical and electromechanical systems: simple electrical circuits, DC motors, variable-field motors, transducer models. Comparison of experiment and simulation.

Fig. 3. Partial Summary of Learning Segments for ME 435 (Dynamic Systems)

First Attempts: What We Have Learned

Besides just providing and managing information, both the matrix and database have served as a catalyst for other important activities. Completing the segments for courses provided by "outside suppliers" (i.e. physics, chemistry, math, etc.) was the first time we understood in detail what was being taught and what kinds of homework and laboratories the students completed in these courses. The segments for these outside courses were completed by our own faculty who obtained information from syllabi, textbooks or discussions with the outside faculty involved; as the software is refined we will invite these outside faculty to help complete the database. This will provide a means for them to better understand our needs and desires and how their courses integrate into our curriculum. In general we have found these faculty to be anxious to accommodate us if we can just specify better what it is we want. The database helps us to do this.

Completing the database provided an opportunity for faculty to discuss and agree on what should be contained in a particular course. Previously different faculty felt free to alter a course as they saw fit, regardless of the ramifications. After obtaining consensus regarding what should be in the database, the faculty agreed that they will teach to it--a faculty member is free to substitute an *equivalent* activity, i.e., an activity that teaches the same material in a different way, but segments cannot just be dropped or changed arbitrarily. In this way the database helps provide consistency.

The database is also a means to capture the ideas and knowledge of our experienced faculty and make them available to younger faculty or to those teaching a course for the first time. Admittedly it is not perfect in this respect--in some cases faculty would like to provide more detail than the database allows or in a different format--but it is significantly better than nothing.

We anticipate that information in the relational database will be an important part of our assessment activities. Note that the relational database contains a field for "competency" for each learning segment, where the competency the students should reach is given. This information will then be used to assess whether students are meeting course objectives.

Despite these benefits, however, our experience with the curriculum matrix and the relational database has mostly helped us see the possibilities. Ideally we would like one tool that can do both--allow us to enter detailed information such as we have done in the relational database and immediately switch to a more global, graphical view. The ability to have hypertext links would be helpful. These desires have led to the beginning development of a web-based curriculum management tool.

A Web-Based Curriculum Management Tool

We are currently developing a web-based software tool that will include a database, graphics, and hypertext links. The web provides a rich software environment with tools capable of producing what is envisioned; furthermore, it is extremely accessible and platform independent. The web-based tool allows the curriculum to be viewed in several different ways. Each view is built from an underlying database so that data is only entered once and is consistent regardless of the view. These views are described below. Interested readers can access the software, which is still under development, at `http://curriculum.et.byu.edu`

<u>Flowchart View</u>

The flowchart view is primarily for students to help them develop a plan for the courses they will take each semester until graduation. An example flowchart view is shown in Fig. 4. The courses are represented by boxes and arranged in a suggested sequence. Clicking on a box brings up a detailed listing of what is in that course.

<u>Matrix View</u>

The matrix view is similar to the curriculum matrix previously described, but with hypertext bullets in cells where attributes are supported, as shown in Fig. 5. Clicking on a row will list all activities in the curriculum that support that attribute (the "Attribute View"), as shown in Fig. 6. Clicking on a column gives all topics included in the course (the "Course View").

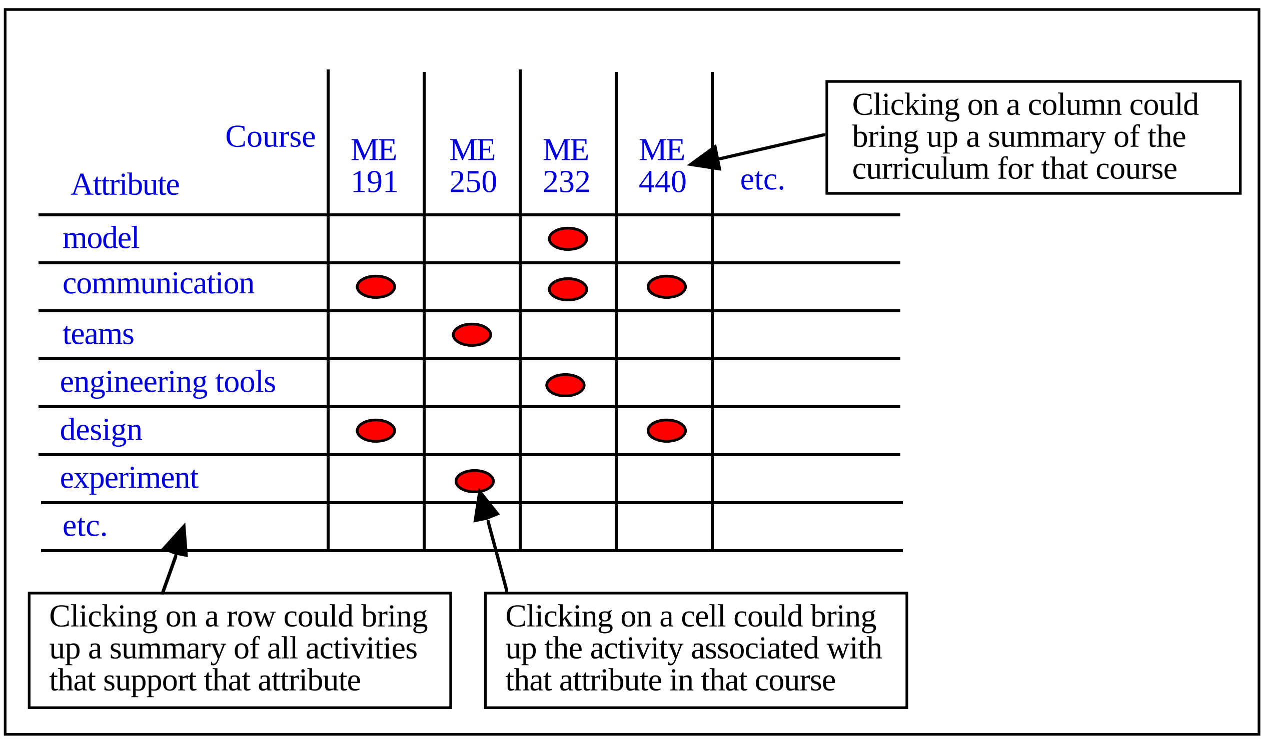

Fig 5. A Possible Matrix Layout Using Hypertext

MECHANICAL ENGINEERING DEPARTMENT -- BS Degree Program

FOR NEW STUDENTS STARTING FALL SEMESTER 95 OR LATER

The ABC printout shows official requirements for each student

Course Key: Number, hours / Course Title / Prerequisites

Semesters 5–8: ← Professional Program, Acceptance Required →

	Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8
General Education Program	First-Year English Requirement 3	Biology Requirement 3	Arts & Letters Elective 3	American Heritage Requirement 3	Engl 316 Technical Writing 3	Social/Beh Science Elective 3	History of Civilization X201 3	History of Civilization X202 3
		Wellness Requirement 2						
Religious Education Program	Rel A 121 2 Book of Mormon 1	Rel A 122 2 Book of Mormon 2		Rel A 2 211 or 212 N Testament	Rel C 2 324 or 325 Doct & Cov	Religion Elective 2	Religion Elective 2	Religion Elective 2
Major Requirements	Math 112 4 Calculus 1 [AM]* Math 110, 111	Math 113 4 Calculus 2 Math 112	Math 312 3 Engr Math 1 Math 113	Math 313 3 Engr Math 2 Math 312	MeEn 363 3 Measurement Phscs 221, Math 313	MeEn 312 3 Fluid Mech MeEn 273, 321, 363	MeEn 440 3 Heat Transfer MeEn 312	
	MeEn 191 0 New Student Seminar	#Phscs 122 3 Physics 2 [PS]* Math 113 concurrent CEEn 103 concurrent	Phscs 221 3 Physics 3 [NS]* CEEn 103 CEEn 204 concurrent	MFE 232 3 Mfg Process CEEn 203, MeEn 250	MeEn 321 3 Thermo Phscs 221, Math 313	MeEn 322 3 Appl Thermo MeEn 273, 321, 363	MeEn 475 3 Capstone 1 Fall semester See note on right	MeEn 476 3 Capstone 2 Winter semester See note on right
	MeEn 172 3 Graphics Engr & Tech Majors		MeEn 250 3 Material Sci Chem 105	MeEn 273 3 Computing Math 113 Math 312 concurrent	MeEn 372 3 Machine Comp CEEn 203 MeEn 172, 250, 273	MeEn 337 3 Kinematics Math 313 CEEn 204, MeEn 273	MeEn 435 3 System Dyn CEEn 204 MeEn 273, 363	Technical Elective 3
	Chem 105 4 Chemistry [PS]* Math 110	CEEn 103 2 Statics Math 113 concurrent 204	CEEn 204 3 Dynamics CEEn 103	CEEn 203 3 Mech of Mat'ls CEEn 103	ECEn 301 3 Electrical Engr Math 313, Phscs 122	Stat 361 3 Statistics Math 113	Technical Elective 3	Technical Elective 3
Semester hours	16	16	15	17	17	17	17	14 /129 total credit hours

Professional Program
1. To apply, the following courses must be completed: Math 112, 113, Phscs 122, MeEn 172, CEEn 103, Chem 105.
2. No MeEn courses 300-level or above may be taken until accepted into the professional program.

Technical Elective Courses
Three courses (9 hrs) required.
Limitations:
1. At least 2 in ME.
2. At least 2 at 500-level.
3. None below 300-level.
4. Courses of acceptable level in the following areas: engineering, math, statistics or science.
5. No duplicate of required course.
6. Limited credit in ME 595 with approval.

Capstone prerequisite
Will complete all major classes, except tech electives, by end of sem MeEn 476 is taken.

Superscripts
* Course also fills General Education requirement.
# Students without high school physics should start with Phscs 121.

8/29/97

Fig 4. Flowchart View of Curriculum

Course View

The course view is similar to a class syllabus--it shows the sequence of topics, associated homework and laboratories, etc.

Attribute View

This view shows the sequence of activities that span all courses to support an attribute, as given in Fig. 6. This view helps faculty make sure all attributes are adequately addressed and also facilitates the development of some structure for the development and coverage of attributes.

Record View

This is the view that is used to enter data. It contains all the information that is needed or displayed in the other views. This is similar to Fig. 2.

Attribute: An ability to design a system, component or process to meet desired needs

ME 191: Introduction to Mechanical Engineering

Students are introduced to the steps of a structured design process.

ME 250: Engineering Materials

Students go through a materials design case study.

ME 372: Machine Design

Students design a gearbox or clutch. Concept generation, Concept evaluation, and Analysis design steps are discussed.

ME 337: Kinematics

Students design a four linkage to function according to provided specifications.

ME 312: Fluid Mechanics

Students design a device to measure viscosity. Concept generation, Concept evaluation, and Analysis design steps are discussed.

ME 475: Capstone Design

Students work in teams on industry-provided design problem. Students gain experience will all design steps.

Fig. 6. Example Listing of all Activities that Support a Particular Attribute

Issues to be Explored

Some of the questions that are still being explored include,

What is the appropriate balance of detail?

What are the best ways to graphically display the curriculum?

How can hypertext be most effectively used to hide information not needed at a particular level? How can the software be most useful for students? Can it help students understand better why they are studying what they are studying and place it more into the context of their entire education? How can the software best help an individual faculty member?

Context of Application at BYU

The software is just one part of a much broader revision of the undergraduate program which involves all the elements shown in Fig. 7 below. Thus it is one element of a much broader picture to achieve educational excellence in our program.

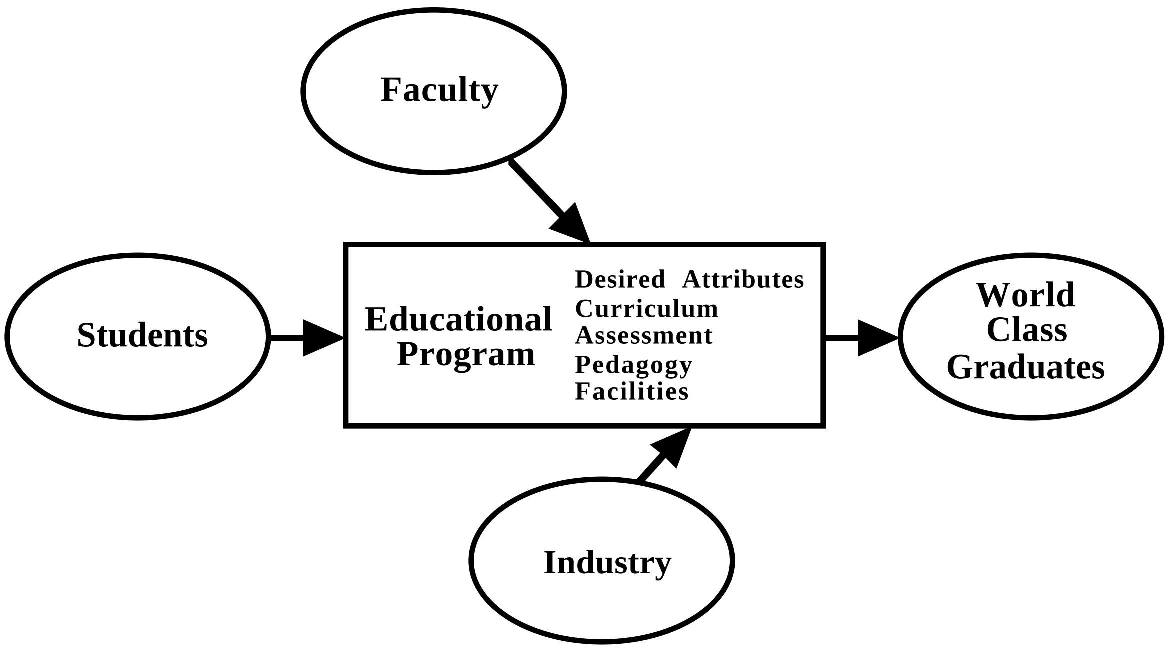

Fig 7. The larger context for the use of the software.

Summary

This paper has discussed methods and tools for managing the curriculum of an outcomes-based engineering program. Because many of the desired outcomes are best developed and learned within a specific engineering context, and because there is little room in most engineering programs for additional courses, we believe that numerous attributes will need to be addressed as part of existing courses. In order to gain the efficiency needed to cover these additional objectives, insure consistency and integrate across courses, the entire curriculum needs to be carefully managed and organized. We have looked at several ways of doing this using computer-based tools, including a curriculum matrix and relational database. We are in the process of developing a new web-based tool which combines the advantages of both of these approaches. We anticipate that by using this tool we will be able to, capture the content of a course, including content not covered in a text.

manage the instruction of attributes which are sprinkled across several courses.

coordinate across courses in general, insuring that courses build carefully on each other and that concepts are well integrated across courses.

view the curriculum as whole.

help insure consistency in instruction

provide a complete repository of the curriculum.

communicate to students what they will be studying and how it all fits together.

manage or integrate the courses provided by suppliers (math, physics, etc.)--and be a means of communicating with them about program objectives.

Although not discussed in this paper, the software could potentially be expanded to track student progress and to manage assessment. These other possibilities will be explored in the future.

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