

**Curriculum Innovation and Renewal****Donald E. Beasley, D. Jack Elzinga, Michael S. Leonard****Clemson University / University of Florida / Clemson University**

Engineering as a discipline has been taught for centuries. Over the years, a standard engineering curriculum (with many variations) has evolved. However, engineering curriculum development has not followed a structured approach. While accreditation agencies have provided general guidelines, courses were often created and taught by the instructor most interested in the subject area. The result is often a fragmented curriculum in need of more focus and cohesion. Even so, little regard was given to creating a methodology for engineering curriculum development until after World War II.

Since that time, several curriculum design methods have been developed. As yet there is no universal agreement on a methodology for curriculum innovation or renewal, and in fact there is significant variation in opinion as to what constitutes a good curriculum. One reason for this lack of a universal methodology is the large number of constraints involved in developing any particular engineering curriculum (e.g., budget, facilities, identification of employer needs, and available faculty time), and effects of these constraints are almost certain to be different from campus to campus.

In this paper, we present a framework for continuous improvement concepts that can be applied to engineering curriculum innovation and renewal. While it is neither possible nor desirable to develop a universal engineering curriculum, a systematic means of assessing and continuously improving an existing curriculum as a whole should be valuable to department chairs and engineering faculty.

This methodology has been developed to enhance efforts by a department's faculty, led by its chair, to analyze and understand an existing curriculum, to measure and assess input from a variety of informed sources, and to design an improved curriculum in response to the input received. This method delivers a new curriculum aligned with the strategic directions of the department.



## The Process

For our purposes the curriculum renewal process can be modeled as a six-stage procedure (see Figure 1):

Stage 1 -- Preparation

Stage 2 -- Strategic Planning

Stage 3 -- Identifying Curriculum Renewal Objectives, Performance Measures,  
Goals and Milestones

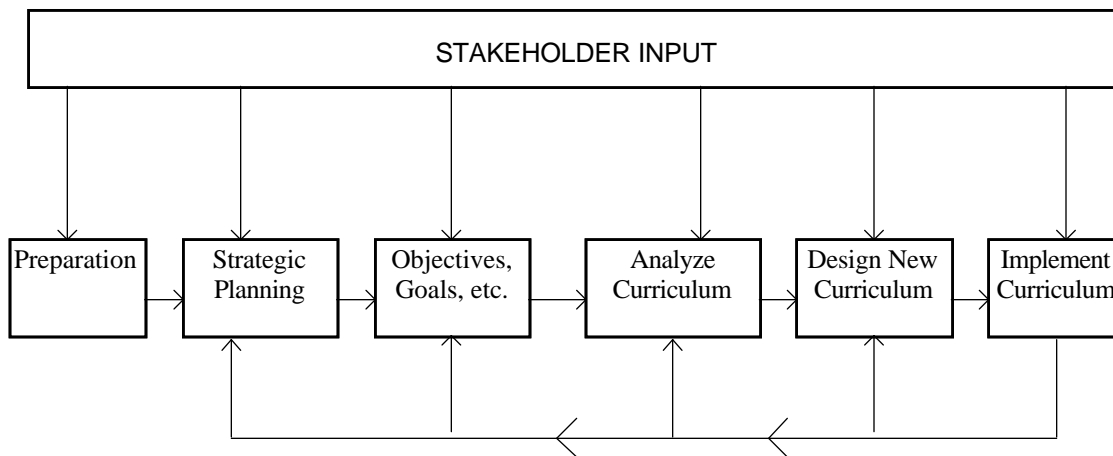
Stage 4 -- Analyzing the Existing Curriculum

Stage 5 -- Designing the New Curriculum

Stage 6 -- Implementing the New Curriculum

Continuous curriculum improvement is institutionalized by planned, periodic recycling through the activities of Stages 2 through 6. Continuous improvement of specific courses is done by formal methods for obtaining student needs and expectations and feeding them back to course instructors. Both the conduct and the content of courses are addressed.

### PROCESS FLOW DIAGRAM



### CONTINUOUS IMPROVEMENT

**Figure 1:** Graphical Display of Curriculum Renewal Process

The process begins with preparation activities (Stage 1) in which leadership commitment and faculty buy-in are obtained and the Curriculum Design Team (CDT) is formed. The process continues, facilitated by the CDT, with strategic planning (Stage 2) in which the department's overall strategic objectives are developed. From the strategic objectives for the academic unit, basic objectives are established which the new curriculum must meet (Stage 3). The CDT reviews the unit's strategic objectives in light of any expectations that stakeholders (alumni, students, and employers) may have expressed in order to develop a set of curriculum renewal objectives.

Once the curriculum renewal objectives have been determined, Stage 3 continues by selecting performance measures, goals and milestones. The performance measures serve as yardsticks by which the existing curriculum is measured.

An analysis of the existing curriculum (Stage 4) provides a set of graphical illustrations which indicate the relative concentrations of topical areas and the time phasing of the teaching of these areas across the current curriculum. From these graphical illustrations of the existing curriculum, group consensus-development processes are used to aid the faculty in selecting a new curriculum (Stage 5) which reflects the organization's strategic objectives and which satisfies relevant constraints.

In the design of the new curriculum, performance measures and goals serve as constraints. Similarly, milestones serve as constraints in the implementation of the new curriculum (Stage 6).

## **Stage 1: Preparation**

As in all change processes, the most important stage is the first one in which the foundations are laid which will insure success of the effort. The most crucial aspect is leadership commitment which in most cases means commitment by the department chair to lead and complete all of the stages of the renewal process. It is at this point that efforts should be made to gain buy-in from the faculty since they are the owners of the process and its product, the curriculum.

The formulation of the CDT is critical. The CDT should be representative of the professional interests of the faculty in the academic unit as a whole and should enjoy the respect of the faculty and chair. Teams should typically consist of approximately five members. The team should be balanced with different personalities and leadership styles. The CDT will employ a group consensus approach throughout the curriculum renewal process. To reach consensus, each group member must have the opportunity to participate fully in each phase of decision making.



## Stage 2: Strategic Planning

Engineering education programs must teach the fundamentals of engineering theory, experimentation, and practice. Engineering curricula must also be relevant and attractive to stakeholders such as faculty, students, parents, alumni, and employers of curriculum graduates. One way of assuring relevance and attractiveness is to use strategic planning as a driving force for curriculum renewal.

There are four basic components of strategic planning in any setting: scope, resource deployments, competitive advantages, and synergy<sup>7</sup>. Related to engineering curriculum renewal, these components correspond to the environmental opportunities and concerns associated with the specific engineering department under study and the discipline specialties and subspecialties of the faculty, the curriculum changes required to satisfy the needs of stakeholders, the areas of the curriculum that meet or exceed stakeholder requirements, and the resources necessary to make curriculum revisions<sup>2</sup>.

A useful view of strategic planning is provided in a simple definition provided by David J. McClaskey<sup>5</sup>, Quality Management Coordinator for the Eastman Chemical Company, manufacturing enterprise winner of the 1994 Malcolm Baldrige National Quality Award.

Strategic planning is the process of developing responses to opportunities for growth and challenges to survival, to strengths and weaknesses, and to the likely actions of competing organizations.

This stage in the curriculum renewal process presents a "quick" approach to strategic planning which an engineering department can use to create a first set of strategic objectives or an initial strategic plan. An appendix to this paper gives a brief chronology describing the application of the "quick" approach in the Department of Industrial Engineering at Clemson University.

### Steps in the Strategic Planning Process

To begin the strategic planning process, the academic department must have a mission statement that is been recently reviewed by the faculty as a whole, and there should be general consensus among the faculty on the appropriateness of this statement. Then, the basic steps in the strategic planning process are as follows:



1. Preparation: Identify a group of faculty members (and staff members, if desired) who will serve as participants in the strategic planning process. Note that if strategic planning is being done solely for curricular purposes, this planning group could be, but does not have to be, the CDT. From this group, select four teams (with two to four individuals on each team) to address the following questions and to develop summaries of their observations and findings:

- a. What are the organization's strengths and weaknesses?
- b. What future projections can be made concerning the practice of the discipline(s) taught in the organization. For example, what areas of knowledge and skills are practicing engineers likely to need in the workplace of the future?
- c. What is the competition doing now and what is it likely to be doing in the future (specifically, what are other academic organizations in the same discipline(s) and in related disciplines likely to do, and in what other ways, if any, might industry find individuals to practice in the profession(s) under study)?
- d. What choices must the academic organization make in the next one to five years?

2. Dissemination: Distribute the summaries of the four reports completed in Step 1 to all members of the planning group. Ask the group members to carefully study each summary.

3. Retreat: Convene a "retreat" for all the members of the planning group to accomplish the following tasks:

- a. Have each team formed in Step 1 present a report on their observations and findings. Allow time for the group as a whole to consider additions and deletions to the summaries. Be sure that the report on choices that the unit must make is scheduled as the last of the four team presentations.
- b. Have the group identify alternative actions for each choice that the organization must make. Group brainstorming can be used to accomplish this task.
- c. Evaluate, rank, and make selections from the alternatives considered for each choice the organization must make. A group discussion of each alternative followed by the use a nominal group voting system can be used to accomplish this task<sup>8</sup>.



- d. The group may believe that some choices cannot be made without additional information. In the case of choices requiring additional information, attempt to reach group consensus on the nature of the "knowledge gaps" and make team member assignments for data collection and summary.
  - e. Recess the "retreat" at this point.
4. Fill Information Gaps: When knowledge gap information has been collected and all of the members of the planning group have had the opportunity to review the collected information, reconvene the group to accomplish the following tasks:
- a. Complete the process of making critical choices for the organization, developing alternatives, evaluating these alternatives, and making a selection from among the alternatives.
  - b. Identify strategic objectives for the organization. A nominal group process can be used for this effort.
  - c. Identify critical short-term (typically, upcoming year) major improvement areas that the organization will commit to act upon, and select measures that will be used to assess performance in the improvement areas and goals that the organization will meet in terms of the selected measures.
5. Documentation: Assign to a committee(s) the responsibility to document the results of the strategic planning effort in terms of
- a. a statement of strategic objectives for the academic organization,
  - b. a list of short-term major improvement areas selected by the organization and the organization's commitments in terms of performance measure goals,
  - c. if the planning group desires, a formal strategic plan in the form of a document summarizing critical issues and actions that the group has agreed to take.

The actual amounts of time required to conduct the steps in this "quick" process will vary among engineering departments, but the following estimates may be useful in preparing to begin the strategic planning effort. Two weeks should be adequate for the teams formed in Step 1 to develop reports summarizing their observations and findings. The retreat described in Step 2 can be completed in about one and one-half days, and an actual retreat setting away from phones and other distractions is recommended for this step. Two weeks should be adequate for teams assigned to fill information gaps to complete their studies. If many critical



decisions were deferred because of information gaps, then a second one-day retreat may be required for Step 4. If few or no deferred choices remain at the beginning of Step 4, then this step can be completed in one or a few one-hour meetings. The committee assigned Step 5 documentation responsibilities should be able to complete its tasks within two weeks. Completed documentation should be presented to the appropriate faculty/staff group(s) for formal approval(s).

### **Stage 3: Curriculum Renewal Objectives, Performance Measures, Goals and Milestones**

An ASEE report<sup>1</sup> entitled “Engineering Education for a Changing World” focused on the need for engineering curricula to keep pace with what faculty, students, parents, alumni, and employers will need in a quickly changing world. The report specified a number of critical action items. Among these was Action Item 2 which states:

Within the context of the overall institutional vision, every engineering educational program should be driven by a periodically reviewed planning process. This process should identify the program's objectives and lead to a specific plan, with milestones, for accomplishing them.

Use of a strategic planning process such as the one included as Stage 2 of the curriculum renewal process will develop a strategic plan for the engineering department in the form of a set of general strategic objectives and actions. Stage 3 identifies specific objectives for curriculum renewal and design parameters for curriculum change.

The starting point for Stage 3 is the department's general plan for strategic action. This input is integrated with stakeholder expectations (alumni, students, and employers of graduates) as documented by survey responses or other types of fact-gathering efforts. Based on these inputs, the CDT employs a group consensus process to develop a set of curriculum renewal objectives. Consensus processes are also used by the CDT to select the performance measures, goals, and milestones. Choices of measures, goals, and milestones are based on the selected curriculum renewal objectives and the knowledge and skills that are important to practice in the discipline(s) taught in the curriculum.

The steps that follow are based on an approach to selection of curriculum renewal objectives, performance measures, goals and milestones developed by Barnett<sup>2</sup>. With Barnett's approach, the CDT employs



both divergence and convergence steps. In the divergence steps, the group generates as many ideas as possible for some stated area of interest, while in the convergence steps, the group prioritizes or ranks ideas generated during the divergence steps<sup>9</sup>.

#### Selection of Objectives, Performance Measures, Goals, and Milestones

(1) Select curriculum renewal objectives: The CDT begins with the engineering department's general strategic plans [in the form of strategic objectives and short-term actions, if available] and/or stakeholder inputs.

##### a. Divergence.

(1) Private brainstorming is used by each member of the CDT to generate candidate curriculum renewal objectives.

(2) Public brainstorming is used to create a master list of individual member suggestions for renewal objectives, and to add to this list any suggestions that come from the group interaction.

##### b. Convergence.

(1) The CDT reviews the items on the master list with a discussion to insure that every CDT member understands each candidate curriculum renewal objective.

(2) The CDT considers possible combinations of candidate objectives that have essentially the same intent.

(3) The CDT considers possible deletions of candidate objectives that appear to be irrelevant to the strategic planning objectives and/or stakeholder inputs. [Note, consensus is considered to be the best guideline for a deletion action.]

(4) A member of the CDT may propose adding a candidate objective. The intent of any objective added at this point must be clear to every member of the CDT.

(5) The CDT considers rewording the candidate objectives. Any member of the CDT can make a suggestion to modify since the set of objectives are now considered to be "collectively owned"<sup>7</sup> by the CDT.





c. Voting.

- (1) Multivoting<sup>8</sup> is used to identify the most important curriculum renewal objectives. A choice of no more than one to three curriculum renewal objectives is strongly recommended for any given cycle of the curriculum renewal process.
- (2) If the multivoting did not finish the process of elimination to the CDT's satisfaction, the nominal group technique should be used to select the desired number of objectives on the basis of selecting those objectives with the highest total scores.

2. Select performance measures: After the CDT has identified curriculum renewal objectives, performance measures are selected for each objective. The knowledge and skill areas appropriate to the discipline(s) taught in the curriculum are an additional set of inputs for this step. All of the activities in this step are conducted for each selected curriculum renewal objective.

a. Divergence. Group brainstorming is used to create a master list of candidate performance measures for the curriculum renewal objective under consideration.

b. Convergence

- (1) The CDT reviews the items on the master list with a discussion to insure that each CDT member understands each candidate performance measure.
- (2) The CDT considers possible deletions of candidate performance measures that appear to be irrelevant to the curriculum renewal objective.
- (3) A member of the CDT may propose adding a candidate performance measure. The intent of any measure added at this point must be clear to every member of the CDT.

c. Voting. Nominal group technique is used to score each candidate performance measure. Group consensus is then used to select the desired number of performance measures for the curriculum objective. A selection of no more than five measures for any objective is strongly recommended.

It is important to note that once the CDT has selected a set of performance measures for each of the selected curriculum renewal objectives, the collection of performance measures can be used to graphically illustrate the capabilities of an existing curriculum and any candidate curriculum under consideration. Two types of graphical representation are useful at this point. Spider plots show the content of a curriculum in terms



of the selected performance measures. Each ray on the spider plot represents one of the selected performance measures, and the intersection of the line segments with the ray indicate the "amount" of the measure present in the curriculum. Barnett and Leonard<sup>3</sup> present an example of this representation for the undergraduate industrial engineering curriculum at Clemson University. A phase diagram can be used to show the time-phasing of subject materials in a curriculum. Figure 2 provides information concerning the time phasing of topic areas in the industrial engineering curriculum at Clemson.

3. Select goals and milestones. At this point, a target goal will be established which sets a threshold defining an adequate level of understanding/level of coverage for each performance measure. An associated milestone will specify the point in time when the target goal must be reached. Later, once candidate curriculum revisions have been identified, the target goals and associated milestones will have been reviewed and possibly revised to reflect the capabilities of the candidate curriculum revisions under consideration. Experience has shown that the CDT tends to set target goals and milestones which are too optimistic. Again, all of the activities in this step are conducted for each selected performance measure.

a. Divergence. Group brainstorming is used to create a master list of candidate goals and associated milestones for the performance measure under consideration. Note that each candidate is specified as a set of two values; that is, each entry on the master list consists of both a goal and a milestone.

b. Voting. Consensus must be reached on each choice of both goal and milestone. Nominal group technique is used to determine the goal with highest total score. The group may find the milestone associated with this selected goal is a consensus value. If not, the CDT may choose to use an average of the milestone values for goals [on the master list] which are roughly equivalent to the selected goal.

#### **Stage 4: Curriculum Analysis**

Models that offer means of grasping the overall structure of the curriculum are needed as part of a comprehensive management process. Such a model would identify strengths and weaknesses in an existing curriculum or the definition of goals for an improved curriculum. A hierarchical process is desirable in which the "big picture" is first sketched in broad strokes and details filled in as the process proceeds. Such an



approach prevents the whole process from becoming mired in minutia as is likely if work begins at the course level. Two such models are described here: the knowledge/skills method and the augmented syllabus method.

### The Knowledge/Skills Method

The Knowledge/Skills method<sup>6</sup> is a technique employed to analyze an engineering department's existing curriculum and to aid in the design of a new curriculum. In the process of educating undergraduate students, two key ingredients of education are taught. The first one is knowledge, and the second one is skill. The Webster's New Collegiate Dictionary provides a definition for *knowledge* as "the sum of what is known: the body of truth, information, and principles acquired by mankind." Universities are a primary source of knowledge for students through different teaching techniques. The second ingredient to teach students during their engineering education is skill. *Skill* is defined in the Webster's New Collegiate Dictionary as "the ability to use one's knowledge effectively and readily in execution or performance." In other words, knowledge is what is learned and skill is the ability to use the learned information.

The following example illustrates the difference between knowledge and skill. Students in a differential equations course gain knowledge about the existence and uniqueness of solutions of differential equations, about superposition of solutions and about solution techniques such as separation of variables. Later this knowledge can be developed into skills involving differential equations such as modeling and solving fluid flow problems, heat conduction problems and electrical circuit problems. This example illustrates that knowledge is typically obtained during lecture sessions and book readings whereas skills are achieved by applying the lecture and book knowledge to homework exercises and laboratory experiences.

Thus, in understanding the engineering education process it is useful to categorize the curriculum into knowledge and skills. Although skills are derived from knowledge, it is most useful to first identify skills required by a practicing engineer and then establish the knowledge necessary to develop those skills. The following is an explanation of the Knowledge/Skills Method which includes examples of how it can be applied to an engineering curriculum.

### Establishing Knowledge Elements and Skills

The following steps define the process of developing an engineering department's knowledge elements and skills:

1. Form the distinction between an element of knowledge and a skill. During their education, engineers are taught a combination of knowledge and skills. Before these knowledge elements and skills that are taught can



be identified, the stakeholders involved in the process must have a clear understanding of what the definitions are for both knowledge and skill. Once the definitions are understood, then faculty and other stakeholders should be able to easily differentiate between these two elements. The following are helpful in identifying both the knowledge elements and skills.

- Knowledge is synonymous with "understanding that" while skill is parallel to "understanding how."
- A simple way of classifying a knowledge or a skill is by its part of speech. If an aspect of the curriculum is described with a noun then it is typically a knowledge element. If, however, it is most easily described with a verb then likely it is a skill. For instance, the theory of relativity is knowledge while taking a derivative is skill.

2. Agree on which skills are necessary for engineering graduates. The skills currently being taught are established so engineering faculty can see the effectiveness of their curriculum. With this information, the engineering faculty can see what skills their students are acquiring and what skills their students are lacking. Skills and their levels can be established through several different processes. Faculty can either meet as a group, fill out surveys on their own, or use ABET course descriptions in order to establish the skills currently taught or desirable. If the faculty chooses to meet, then the CDT will lead the meeting, employing brainstorming methods to develop skills at each level. If the faculty chooses to fill out surveys, then each faculty member will develop what he or she believes are the necessary skills, and the CDT will use the surveys as a guide in developing consensus. At any point in the process the faculty could make use of input from other internal stakeholders (e.g., students) or external stakeholders (e.g., employers). This can be accomplished by inviting additional stakeholders to the meetings or having them fill out the appropriate surveys. The following description can be helpful in establishing a hierarchical skill structure.

At the highest level of the hierarchy are those skills which all engineers should possess. These skills are referred to as Level 1 skills or fundamental engineering skills. Most engineering faculty would agree that the set of Level 1 skills can be divided into Engineering Design Skills, Engineering Control Skills, Model Building and Problem Solving Skills, and Organizational Skills. However, this list of Level 1 skills can be modified to fit a particular department's teachings.

Next, each Level 1 skill is broken down into main engineering skills designated as Level 2 skills. Like Level 1, Level 2 skills are general enough to be used by all types of engineers. For example, Engineering Design Skills can be broken down into the following Level 2 skills: Process Design, Product Design and Facility Design. A proposed structure for Level 2 skills is shown below.

Level 2 Skills (Main Engineering Skills):



## 1. Engineering Design Skills

- 1.1 Product design
- 1.2 Process design
- 1.3 Facility design

## 2. Engineering Control Skills

- 2.1 Process control
- 2.2 Production control
- 2.3 Quality control
- 2.4 Cost control

## 3. Model Building and Problem Solving Skills

- 3.1 Analytical models
- 3.2 Computer models
- 3.3 Physical models
- 3.4 Data collection/analysis
- 3.5 Economic analysis

## 4. Organizational Skills

- 4.1 Management skills
- 4.2 Communication skills
- 4.3 Interpersonal skills
- 4.4 Leadership skills
- 4.5 Decision making skills

Level 2 skills are further separated into Level 3 skills which are referred to as basic engineering skills. While Level 1 and 2 skills apply to all engineering disciplines, Level 3 skills are specific to a particular engineering discipline. In other words, it is at Level 3 that different skill requirements define different engineering disciplines and point toward the curriculum appropriate for each.

3. After skills have been established, agree on the knowledge elements necessary for engineering graduates. Knowledge elements are established so stakeholders know what is currently contained in the lectures and book readings of the engineering department. The processes used for determining skills can again be applied to establish knowledge elements. Like skills, knowledge elements are broken down into different levels.

The first knowledge level incorporates fundamental engineering knowledge. Level 1 encompasses the engineering prerequisite subjects and engineering core subjects. Prerequisite knowledge elements would



typically include chemistry, physics, calculus, differential equations and technical writing. Level 1 core knowledge elements might be computer programming, engineering graphics, statics, dynamics, strength of materials, materials, thermodynamics, electrical circuits and probability and statistics. This list can be adapted for an individual engineering department by its faculty.

Level 2 knowledge, the main engineering knowledge group encompasses the knowledge elements which define a particular engineering discipline.

Level 3 knowledge elements, known as basic engineering knowledge, are a breakdown of Level 2 knowledge elements. Level 3 knowledge elements would be similar to chapters in a textbook or items in a course outline. For instance, the Level 2 knowledge Quality Control can be decomposed into the following Level 3 elements: Control Charts, Continuous Inspection, ABC-STD 105, Dodge-Romig System, Test of Hypothesis, Acceptance Sampling by Variables, Process Control, Life Testing and Reliability, QFD/House of Quality, Testing, Benchmarking, Just In Time, ISO 9000, Business Process Reengineering.

4. Next, knowledge elements and skills can be integrated. For each Level 3 skill, specify the set of Level 3 knowledge elements from which that skill is developed.

#### Creating a Knowledge/Skills Matrix

After the knowledge elements and skills contained in the curriculum have been agreed upon, the faculty will have an improved understanding of the existing curriculum and how its components interrelate. This understanding can be developed further by creating knowledge/skills matrices. Using these matrices, faculty can detect both the under- and over-emphasis of knowledge elements and skills in the current curriculum. Furthermore, the relationship between current courses and the knowledge elements and skills being taught in the curriculum is demonstrated through these matrices. The steps needed to create a knowledge or skill matrix are as follows:

1. Create a matrix whose rows correspond to courses in the department and columns correspond to knowledge or skill elements at any level.
2. Place a symbol in a cell of this matrix to indicate that the given course teaches the particular knowledge or skill. The symbol can either be a check mark to represent a yes/no relationship or set of symbols to represent the degree of the relationship.



The following is a piece of a Skills Matrix for skills at Level 1 and Level 2 for a select few courses which are part of an industrial engineering curriculum. Here the cells indicate the degree of relationship between the skill and the course. The complete matrix would show every level of skill in the columns along with every course offered.

COURSES	SKILLS			
	Product Design	Process Design	Facility Design	LEVEL 1 LEVEL 2
Computer Programming	O	!	O	
Financial Accounting	^	^	^	
Work Design		^	^	
Human Engineering	O	^	^	

^ : weak relationship  
 O: medium relationship  
 !: strong relationship

### Creating a Stakeholder Matrix

It is important to recognize which knowledge elements and skills external stakeholders (e.g., employers) want emphasized. For this purpose, matrices can be created in order to address and illustrate external stakeholder expectations. The entries of this matrix display the relationships between the stakeholders' expectations and the knowledge elements and skills.

The rows of a stakeholder matrix correspond to stakeholder expectations and the columns correspond to knowledge elements or skills at any level. Stakeholder expectations can be obtained through surveys, interviews and questionnaires. These expectations may be in the form of general attributes desirable in engineering graduate students or specific knowledge elements and skills .



## The Augmented Syllabus Method

The augmented syllabus method<sup>4</sup> begins by establishing a coarse model of the curriculum based on four broad components: foundation material, defining elements, complementary elements and integrating experiences. The items comprising the model are concisely defined below.

**Foundation Material:** The component of the engineering curriculum that introduces the vocabulary of science and mathematics, develops a fundamental comprehension of the basic laws and principles that govern the physical world, and provides sufficient analytical ability to treat these basic laws and principles quantitatively.

Example:

- Newton's laws of motion
- Differential and integral calculus
- Conservation of energy

**Defining Elements of the Discipline:** Those elements that, either individually or in combination, constitute the essential and unique character and scope of the curriculum; a canon.

Example:

- Engineering mechanics of solids and fluids
- Static, kinematic, and dynamic analysis of structures and machines
- Work and energy, heating and cooling of objects and substances

**Complementary Elements:** Those elements that by complementing the defining elements broaden the scope of the curriculum as appropriate to insure readiness to enter the profession.

Examples:

- Numerical methods
- Instruments and measurements





- Electrical technology

**Integrating Experiences:** Those elements of the curriculum that involve students in the integration of disparate concepts, analytical processes, principles and practices, sometimes for the purpose of analysis, sometimes for synthesis, and often for both.

Examples :

- **Analysis**--Determining the braking capacity for a disk brake coupled to a rotating inertia, given the mechanical and thermal properties of the materials involved and the physical details of the device.
- **Synthesis**--Designing a means of arresting the motion of a large rotating mass, given a particular context from which the performance criteria and/or constraints can be derived.

The process can proceed in the following manner:

First, faculty agree on an appropriate model that identifies the essential larger elements of the curriculum without debating the relative importance of them or precisely what they include.

Next, through debate, discussion, and compromise, the appropriate details are filled in. For example, if it is agreed that there must be both foundation materials and integrating experiences, then the debate can shift to the question of what is contained in each. A temporal display (see Figure 2) can be helpful here, describing how the four broad components are distributed across the time span (e.g., four years) in which the curriculum is delivered. Such a display might have a concentration of basic elements early, followed by the defining elements as a diminishing fraction of each semester's work. Integrating experiences and complementary issues would become increasingly emphasized as time passes. After developing a display of an ideal curriculum, a similar figure representing the actual structure of an existing curriculum would afford a simple but powerful assessment tool, from which continuous improvement strategies naturally result.

Course-level debate, negotiation, and compromise are required to mold the curriculum to conform to the ideal. However, the relationships among courses and even among topics within courses is too complex to easily represent. One helpful tool is the augmented syllabus which can be used in accomplishing course-level aims described above. It provides the following information in explicit form:



- Detailed topical coverage.
- Level of accomplishment, by topic, expected on the part of the student, both entering and leaving the course.
- Prerequisite knowledge for each topic and, when appropriate, the specific course where this knowledge should have been provided.
- Anticipated subsequent use of a topic when appropriate.
- Analytical tools required for the intended treatment of each topic.
- Identification of themes, e.g., fundamental principles that should be traceable through a curriculum.

Definitions of terms and examples used to develop the augmented syllabus serve to clarify the items above. The format used for the augmented syllabus was developed to present these items so that the important topical relationships and course-to-course articulation are clearly indicated and can be maintained over time and as instructors come and go. A useful set of items helpful for this purpose is the following:

Topic -- A single, specific item of discussion or instruction.

Prerequisite Topic -- A specific item of existing knowledge needed to comprehend a given topic.

Subsequent Course Use -- Following courses in which the topic of discussion will be specifically applied where it will serve as a prerequisite topic.

Time Allocation (hours) -- Lecture time spent discussing a given topic.

Fundamental Principles Involved--For example, one or more of the following principles:

Conservation of Energy

Conservation of Momentum

Conservation of Mass

Second Law of Thermodynamics

Equilibrium

Newtonian Mechanics

Analytical Tools Needed--Mathematical or computational processes required in the development and/or application of the topic being discussed.



Conceptual or Mastery Scale--A scale to measure the level of understanding of a given topic by students (a) entering and (b) completing the course.

### **Stage 5: Design New Curriculum**

The development of a modern engineering curriculum requires the optimization of course offerings and other elements of the curriculum within the constraints imposed by ABET standards, industrial advisory board recommendations, number of faculty, diversity of faculty effort, number of students, available resources, etc.

A method is presented for the renewal of an existing engineering curriculum by means of a case study application of the method to mechanical engineering. This method is based on a scheme for innovation and continuous improvement and it employs the Augmented Syllabus method (briefly outlined in the previous section). The procedure was specifically intended to be useful in the context of engineering departments having busy faculty who are being subjected to numerous competing demands for time and energy. It also had to be applicable in academic units that are subject to the due process of faculty governance, to remain compatible with the ideals of academic freedom, and to be conceptually simple and convenient to implement, regardless of existing administrative structures. Further, to overcome the "not-invented-here" syndrome, any curriculum renewal process must not become an issue in its own right, and it must not threaten any of the particular interests that might exist within a faculty.

The method that resulted identifies key elements of the curriculum and helps integrate them through a four-year program. This integration is based on a rationally defined distribution of curriculum elements described earlier consisting of: (i) fundamentals (ii) defining elements, (iii) complementary elements, and (iv) integrating experiences. Each was defined based on faculty consensus. A distribution of credit hours among the elements was determined so as to yield a logical progression from the fundamentals to the defining elements and complementary elements, all coupled with integrating experiences in several different forms. Based on this credit-hour distribution, a series of possible courses was determined to form a concept curriculum. The topical coverage of these courses, at this point, is left for development. The concept curriculum courses are constrained by content of the curriculum elements and level of mastery for those elements. They must also satisfy any externally imposed constraints such as those emanating from ABET. The concept curriculum assists in planning for the flow and integration of key elements and in maintaining a proper balance of the various curriculum elements.

The final step in the curriculum development is the identification of specific courses and the topical



coverage of each. This is an iterative process that is best achieved using a coordinating committee and faculty subgroups reporting back to the faculty as a whole. The subgroups for individual courses develop topical coverage in detail. Subgroups discuss, with the faculty as a whole, course coverage, distribution of topics, and expected student mastery of topics. This procedure provides a method for incorporating continuous improvements as changing demands and constraints are imposed and new challenges to the educational mission are presented.

The procedures described here have provided a means of addressing curriculum improvement and management from the point of view of overall structure and composition. They constitute a systematic means of establishing, assessing and maintaining currency, balance, and focus of the entire curriculum and of the courses in the curriculum. The process establishes overall structure and composition of the curriculum, identifies fundamental principles and key concepts, and traces them throughout the curriculum. In addition, the methods help delineate topical content, define linkage, topic by topic, of courses with other courses in the curriculum. A mastery scale which fixes expectations and the level of emphasis on individual topics in individual courses is an integral part of the process.

These procedures and their philosophical basis have been briefly described in the previous section and more extensively elsewhere<sup>4</sup> and will not be elaborated in detail here. However, the previously published descriptions were based on anticipated outcomes and not on actual experience. Most of the salient ideas that are imbedded in the processes can be inferred from the case that is described here. Even though the example is restricted to a mechanical engineering curriculum, it is a general procedure applicable to a range of disciplines.

#### The Clemson Effort

At the Mechanical Engineering department at Clemson University, the overall process was coordinated by a four-member committee which led some initial discussions of the faculty as a whole and developed a loose consensus on some basic curriculum concepts. The coordinating committee then formulated a "straw man" to be submitted to the faculty for discussion and debate. To avoid turf battles, all discussion of individual courses, credits, prerequisites and the like were delayed until later in the process. All of the early discussion was restricted to curriculum-level issues. These issues were the determination of basic principles that should be traceable through the curriculum and an overall governing structure for the curriculum.



The “straw man” was very simple and took the form of Figure 3, without the lists of specific elements shown, which were identified later in the course of the early faculty discussions. As shown in the figure, the curriculum was seen as consisting of four principal components, viz., defining elements, complementary elements, foundation material, and integrating experiences as defined in the previous section.

Several candidate lists of items in each category were developed in small subgroup meetings of about five faculty each and compiled by the coordinating committee. The items which resulted are displayed in Figure 3.

A second “straw man” of sorts was developed by the committee showing a proposed credit distribution within the curriculum for each component. Also, to guide the ultimate decisions on credit-hour distribution and course definition, a measure of time and effort on the part of the students and faculty that was needed for each of the individual elements was prepared. In the case of the defining elements, Table 1 was the foundation for the process. Here, each of the defining elements is listed and the mastery level for each is identified by year (sophomore, junior, senior). Using the scale shown below the table, a measure of effort required to advance in level was estimated and used to provide a reasonable balance from year to year. Obviously, the sophomore and senior years are less burdened by the defining elements and thus are assigned greater portions of other components. The sophomore year is heavier in the fundamentals and the senior year emphasizes integrating experiences.

Using the information developed on levels of mastery and distribution throughout the curriculum the semester by semester distribution of all of the elements was generated in credit hour units. The result is shown in Table 2. From this model, a tentative identification of courses, shown in Table 3, was made and submitted to the faculty for discussion. In addition, the governing concept for each course was proposed using a skeletal syllabus. The whole process and the concept curriculum at any point in the process were treated as dynamic, with refinement and improvement an expected outcome at each step.

Through all of this, the discussion focused on what was needed in the curriculum. Typical arguments over the dropping or adding of courses were avoided scrupulously until the ultimate form of the curriculum began to emerge from the discussion. The result was an overall structure, the identification of material that is to be part of the curriculum, and the division of these materials into course-sized segments. All of this was accomplished in an unusually orderly fashion. This process was very successful in allowing significant integration of topical coverage throughout the curriculum to assure proper mastery of key identified topics.



## Stage 6: Implement New Curriculum

Presently, augmented syllabi (see Stage 4) are being developed for each course by faculty subgroups. These augmented syllabi will be used to build the curriculum that conforms to the general concepts that have been agreed upon. The curriculum is being implemented in a staged manner, with appropriate course substitutions allowing students who entered under the “old” curriculum to complete their degree with minimum impact.

The process for curriculum renewal has been implemented starting with overall view of the curriculum and the integration of key areas across courses and years. The curriculum structure is established by a faculty using cross-cutting elements; such elements are defined in the example structure as fundamental, defining, complementary, and integrating elements of the curriculum. With this structure as a basis for establishing a credit distribution, and the traditional constraints, such as ABET and university general education requirements, a yearly credit-hour distribution among the elements can be agreed upon by a faculty. From that base, courses can be proposed which fulfill the goals and satisfy the constraints. In the present case, faculty teams were formed to finalize course syllabi for consideration by the entire faculty.

The curriculum renewal process has successfully yielded a new mechanical engineering curriculum for consideration and further development by the faculty. The proposed curriculum has significantly fewer credit hours and is integrated to a greater extent than the existing curriculum across courses and years. Issues such as laboratories, communications and computing, among others, are being structured to provide a coherent development through the curriculum.

The procedures illustrated in this case study have the potential to be adapted for any engineering discipline. Furthermore, the curriculum review and integration process provides the foundation for continuous improvement of a curriculum once in place.



## Continuous Improvement

Once the new curriculum is in place, it should be subjected to continuous assessment and improvement. For the curriculum as a whole, this is institutionalized by repeating Stages 2 through 6 in a planned, periodic fashion. The continuous improvement of the curriculum is not intended to revamp or renew the curriculum, but rather to identify opportunities for smaller improvements. If the renewal process described above has resulted in a “reengineering” or radical change of the curriculum, the continuous improvement activities focus on “kaizen” or incremental improvement until such time that a major change is again deemed appropriate.

Continuous improvement can also be applied to each course. There are two purposes: one, to improve the course conduct, or how the course is delivered, and the second to improve the course content, the specific topics covered and their levels of emphasis. These are accomplished by formal techniques for securing input from students and feeding it back to the course instructor.

## Conclusion

Curriculum innovation and renewal has been presented as an integrated structured approach. The care and feeding of an engineering curriculum is a never-ending duty that must be undertaken by engineering administrators and faculty alike. The curriculum innovation and renewal process is dedicated to the purpose of helping engineering faculty carry out that responsibility. A manual containing a complete description of the curriculum innovation and renewal methodology and supporting case studies is under preparation.



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Eugene H. Bishop and Cecil O. Huey, Clemson University

Osama Eyada, Virginia Technological University

John F. Mahoney and Suleyman Tufekci, University of Florida

Bala Ram, North Carolina A&T University

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## APPENDIX

### APPLICATION OF THE "QUICK" APPROACH TO CONDUCTING STRATEGIC PLANNING IN THE DEPARTMENT OF INDUSTRIAL ENGINEERING AT CLEMSON UNIVERSITY

This appendix provides a listing of key milestones in application of the "quick" approach to conducting strategic planning in the Department of Industrial Engineering at Clemson University. Commitments of time associated with these accomplishing these milestones are also indicated. The key milestones and time commitments are as follows:

March 1992      Mission Statement Adopted [after discussion at two faculty meetings]

May 1992      "Quick" Approach to Strategic Planning Initiated [all faculty participated in the planning process -- eight faculty members were assigned to four two-person teams to complete Step 1, which took two weeks]

June 1992      Retreat Conducted [a one and one-half day session was held off campus; Step 3 was completed at this time]

June 1992      Statement of Strategic Objectives and Major Improvement Commitments Formulated [Step 4 was completed immediately following Step 3 at the same one and one-half day retreat, because no critical choice had to be postponed as a consequence of a knowledge gap]

July 1992      Strategic Objectives and Major Improvement Commitments Adopted [after discussion at a faculty meeting]

August 1993      Revised Major Improvement Commitments Adopted [at a half-day faculty retreat, new commitments were made including the drafting of a vision statement, fundamental values and guiding principles, and a formal strategic plan for the department]



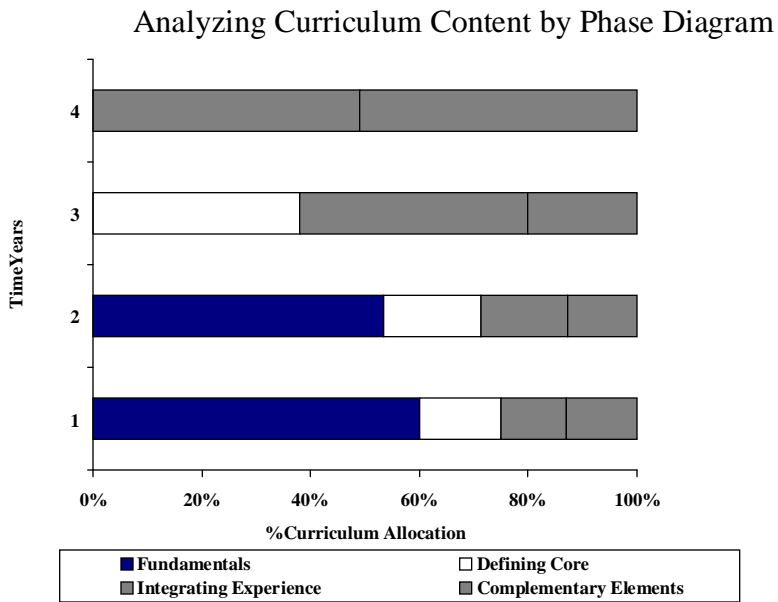
September 1993 Vision Statement Adopted [after discussion at two faculty meetings]

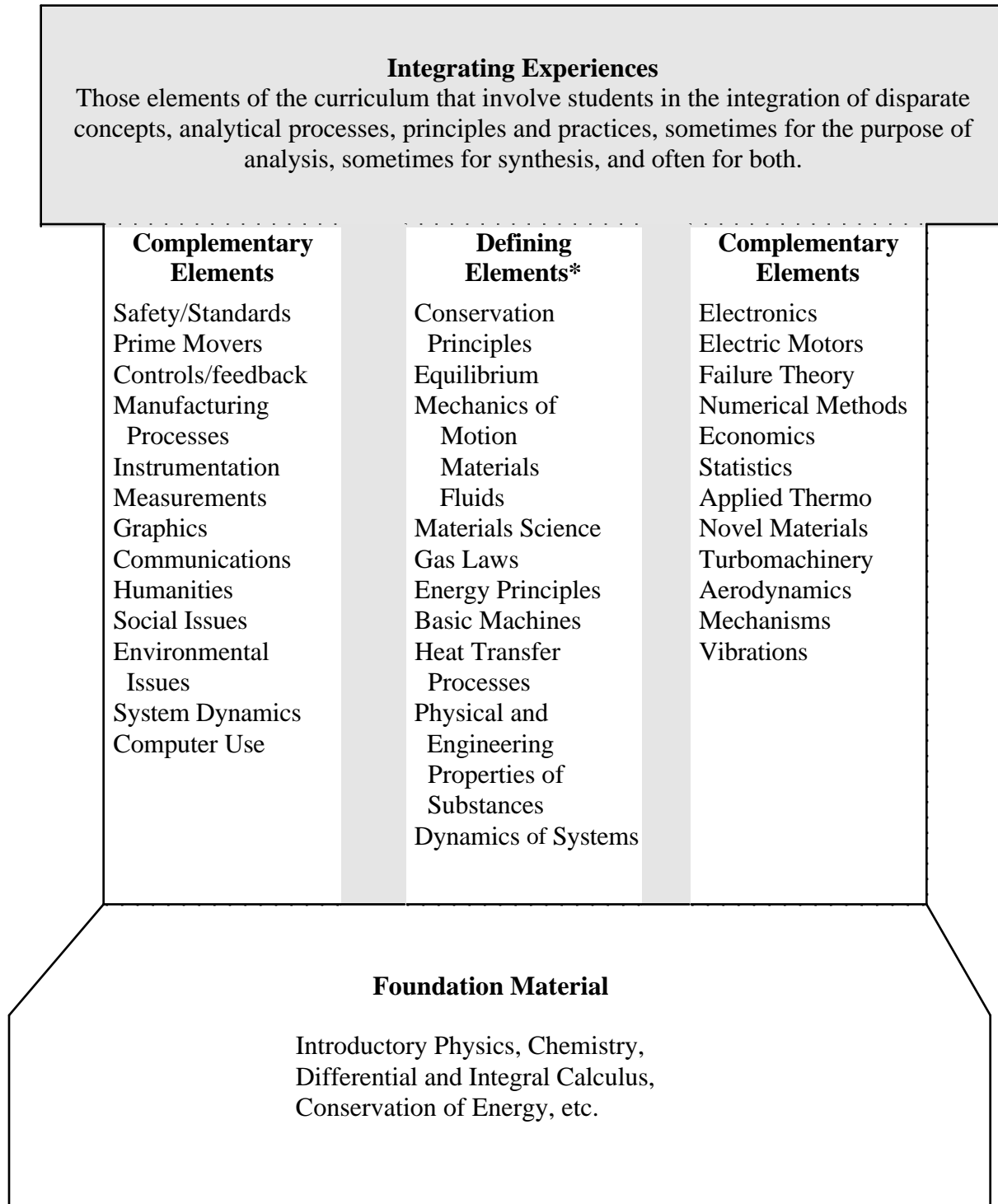
October 1993 Strategic Plan Adopted [at a faculty meeting after a committee worked for two months to formulate the plan from the Statement of Strategic Objectives and the Vision Statement]

November 1993 Fundamental Values and Guiding Principles Adopted [following discussion at three faculty meetings]



FIGURE 2: Temporal Distribution of Curriculum Elements





\* As Presented in the Context of Engineering--as Distinguished from the Presentation in Science Courses

Figure 3: Curriculum Structure

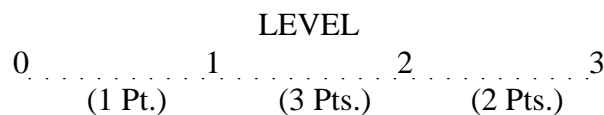


Defining Element	Freshmen	Sophomore	Junior	Senior
Terms		Establish Foundation	Foster Development	Provide Depth and Breadth
Conservation Principles		1 → 2	2 → 3	3 → 3
Equilibrium		1 → 2	2 → 3	3 → 3
Mechanics of				
a. motion		1 → 2	2 → 3	3 → 3
b. materials		0 → 1	1 → 3	3 → 3
c. fluids		0 → 1	1 → 2	2 → 3
Materials Science		0 → 1	1 → 2	2 → 3
Energy Conservation Processes		0 → 1	1 → 2	2 → 3
Basic Machines		1 → 2	2 → 2	2 → 3
Heat Transfer Processes		0 → 0	0 → 2	2 → 3
Physical and Engineering Properties of Substances		1 → 2	2 → 2	2 → 3
Systems		0 → 1	1 → 2	2 → 3
<b>Total Effort</b>		<b>20</b>	<b>29</b>	<b>19</b>

Mastery Level Key:

- 0--No Previous Exposure
- 1--Qualitative Exposure to Concepts
- 2--Quantitative Skills/Homework Problems
- 3--Use in Design/Synthesis/Analysis -- Can use to explain basic processes

Effort Required for Mastery Level Advancement



Level 1 → 1 (1 pt.), Level 2 → 2 (1 Pt.), Level 3 → 3 (1 Pt.)

TABLE 1: Distribution of Curriculum Elements



<b>Freshman</b>				
<b>Semester One</b>		<b>Semester Two</b>		<b>Total Years</b>
Fundamentals	11	Fundamentals	14	25
Defining	0	Defining	0	0
Complementary	2	Complementary	2	4
Integrating	0	Integrating	0	0
Elective	3	Elective	0	3
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>	<b>32</b>

<b>Sophomore</b>				
<b>Semester One</b>		<b>Semester Two</b>		<b>Total Years</b>
Fundamentals	4	Fundamentals	7	11
Defining	7	Defining	5	12
Complementary	4	Complementary	0	4
Integrating	1	Integrating	1	2
		Elective	3	3
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>	<b>32</b>

<b>Junior</b>				
<b>Semester One</b>		<b>Semester Two</b>		<b>Total Years</b>
Fundamentals	0	Fundamentals	0	0
Defining	11	Defining	5	16
Complementary	1	Complementary	4	5
Integrating	1	Integrating	3	4
Elective	3	Elective	3	6
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>15</b>	<b>31</b>

<b>Senior</b>				
<b>Semester One</b>		<b>Semester Two</b>		<b>Total Year/Major</b>
Fundamentals	0	Fundamentals	0	0/36
Defining	1	Defining	2	3/31
Complementary	3	Complementary	6	9/22
Integrating	3	Integrating	2	5/11
Elective	9	Elective	6	15/27
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>	<b>32/127</b>

TABLE 2: Concept Curriculum: Component



<b>Freshman</b>			
<b>Semester One</b>		<b>Semester Two</b>	
English	3	English	3
Chemistry	4	Chemistry	4
Math	4	Math	4
Engineering	2	Engineering	2
Elective, H/S	3	Physics	3
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>

<b>Sophomore</b>			
<b>Semester One</b>		<b>Semester Two</b>	
Statics	3	Solid Dynamics	3
Intro, Structures and Motion	3	Intro, Energy	3
Math	4	Math	4
Matl. Science	3	Physics	3
Computer Based Analysis	1	Elective H/S	3
Graphics	2		
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>

<b>Junior</b>			
<b>Semester One</b>		<b>Semester Two</b>	
Mechanics of Matls & Lab	4	Instru. & Meas. & Lab	3
Fluid Mech	3	ECE	3
Adv Dyn/Systems	3	Machine Elements	3
Thermo	3	Heat Transfer	3
Literature	3	Elective, H/S	3
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>15</b>

<b>Senior</b>			
<b>Semester One</b>		<b>Semester Two</b>	
MMS Lab	1	TFS Lab	1
Senior Design	3	Capstone Design	3
Elective, Science	3	Speech	3
Elective, Tech.	3	Elective, Tech	3
Elective, H/S	3	Elective, Tech	3
Elective, Free	3	Elective, Free	3
<b>Total</b>	<b>16</b>	<b>Total</b>	<b>16</b>

TABLE 3: Concept Curriculum: Courses





## Biographical Information

Donald E. Beasley received his BS and MS degrees from Clemson University and his Ph. D. from the University of Michigan in the area of Thermal-Fluid Sciences. He has been on the faculty of the Department of Mechanical Engineering at Clemson University since 1983. Dr. Beasley received an ASEE New Engineering Educator Excellence Award in 1988 and was named South Carolina Young Engineer of the Year in 1991. He is co-author of a text in measurements and is currently working on curriculum renewal and multimedia through the NSF SUCCEED Coalition.

D. Jack Elzinga earned the BS degree in Chemical Engineering at the University of Washington and the MS and Ph. D. in Chemical Engineering from Northwestern University. Currently, he is Professor and Chairman of the Department of Industrial and Systems Engineering at the University of Florida. Prior to coming to the University of Florida, he was on the faculty of the Johns Hopkins University. Dr. Elzinga has served on the IIE Research Advisory Council and as President of the Association of Chairs of Operations Research Departments.

Michael S. Leonard was graduated from the University of Florida with BIE, MSIE and Ph. D. degrees. He currently is Professor of Industrial Engineering at Clemson University. Previously, he served as Chairman of the Department of Industrial Engineering at the University of Missouri-Columbia and Head of the Department of Industrial Engineering at Clemson University. Dr. Leonard is Vice President-Academic Affairs for IIE. He has also served as President of the Society for Health Systems, as Director of IIE Health Systems and as Chairman of the ORSA Health Applications Section. Dr. Leonard is a registered professional engineer in the states of Missouri and South Carolina.

