An Integration Approach to Industrial Engineering Curriculum Design

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INTRODUCTION

Engineering curricula at most major research universities are driven, in part, by research and technology. Research directions are often defined by funding agencies and major corporations. Faculty learn, develop, and apply the technologies necessary to obtain external funding. This knowledge, combined with individual interests, eventually impacts the content and structure of the curricula. The advantages of this approach are that the technical components of the curriculum are continually updated, and, in many cases, additional instructional laboratory equipment is available following completion of research activity.

However, technical knowledge is only one of the factors to be considered when designing an engineering curriculum. First, the curriculum must satisfy university, college, ABET, and course sequence requirements. In addition, the curriculum must be designed such that graduates possess the knowledge and skills needed for success in the industrial sector, where the majority of graduates are employed.

The process of designing a curriculum is similar to engineering design with requirements that must be met, and objectives that must be optimized. From this came the idea for developing a linear, additive, multi-objective model that identifies the objectives that must be considered when designing a curriculum, and contains the mathematical relationships necessary to quantify the value of a specific curriculum. This paper presents the details of this curriculum evaluation model including the objectives, the mathematical equation for each objective, and the incorporation of these values into a computer program. The model can be used in the evaluation of various curricula alternatives, and to conduct sensitivity analysis to better understand their differences.

OBJECTIVES OF THE MULTI-OBJECTIVE MODEL

The first step in the process of developing a multi-objective model was the collection of data to determine the knowledge and skill set that Industrial and Manufacturing Engineering (IME) graduates need to possess. This was accomplished by the development and mailing of a twelve page questionnaire to a random sample of 225 alumni, and all of the members of two advisory boards[1]. The results from the survey form the basis for many of the objectives of the model.

Clearly, an engineering curriculum must be designed to provide students with a basic understanding of the topics in the discipline. In the questionnaire, respondents were asked to rate, using a one (low) to five (high) scale, the importance of nineteen industrial and manufacturing engineering topical areas. The extent to which the emphasis placed on each of the topics in a curriculum matches its importance as defined by the respondents is one component of the model.

An unfortunate consequence of focusing on the topical content of a curriculum is a tendency to minimize other curricula objectives. To determine the relative importance of these other objectives, the respondents were also asked to rate the importance of ten attributes of college graduates. The three highest rated attributes of communication, problem solving, and people skills have been incorporated into the model. These are skills that are gradually developed over a period of time by practice rather than the addition of another course to the curriculum.

Two components of the model relate to the organization of the curriculum. Tyler[2] has proposed that a curriculum should be integrated both vertically and horizontally. Vertical integration comes from the repetition of material previously learned, and the application of that material to increasingly complex situations. This is necessary to reinforce concepts and to achieve a higher level of understanding of the material. Horizontal integration refers to the use of material in different topical areas so that students can better understand the interrelationships that exist. A second component of curriculum organization is time. New knowledge and skills are soon forgotten if not used, so the time between learning and its application must be kept to a minimum.

MULTI-OBJECTIVE CURRICULUM MODEL

A linear, additive multi-objective model contains three parts; 1) a method to capture the objectives into a mathematical model, 2) scaling of the values from the model to a uniform range, and 3) assigning a weight to each of the objectives. Each of these parts is described below.

Curriculum Integration

To simplify the model, both vertical and horizontal integration were viewed as equally desirable. Likewise, only the integration of engineering related material has been included. The fundamental unit of measure is the fraction of time that material from one course is used in another course. Examples include the use of engineering statistics in a statistical process control course (vertical integration), and in a human factors course to analyze response time data (horizontal integration). Additional studies in statistics are included only if they draw on knowledge from earlier statistics courses.

A example of a From\To integration matrix for the courses in a curriculum is shown in Table 1. The three courses in the table are three quarter credit hours (shown as (3)). In this example, Engineering Statistics (a prerequisite course) is used approximately 50% of the time in the Statistical Process Control course, and 15% of the time in the Human Factors course.

Table 1. Curriculum From\To Integration Matrix

From(i)\To(j)	Engineering Statistics (3)	Statistical Process Control (3)	Human Factors (3)
Engineering Statistics	*	.50	.15
Statistical Process Control	.00	*	.05
Human Factors	.00	.00	*

The integration rating is obtained by summing the integration for each course, integ(i, j), weighted by the credit hours, ch(j), of the To course. A weighting function, w(i), has been included in order to place more value on the integration of topics rated higher in their importance to IME graduates. The formula used to determine the integration score is shown below.

$$\text{Integration Score} = \sum_{i=1}^{n} w(i) \sum_{j=1}^{n} integ(i,j)\ ch(j)$$

IME Topics

The survey data on the importance of each of the IME topics was used to develop a credit hour goal for each topic. The reasoning was that there is an optimal number (goal) of credit hours to be allocated to a specific topic which should be directly related to the mean score of the topic in the survey. Applying this relationship, the topics in the questionnaire were selected to represent approximately equal periods of classroom instruction necessary for a student to obtain the required level of knowledge. A linear function is used to establish a credit hour goal from the mean score of the topic in the survey. For example, the goal for statistics is nine quarter credit hours, which is based on its mean rating of 4.03.

The model for the IME Topics (shown below) contains two parts, one for too little coverage and one for too much. The rational is that it is best to be at the goal and not above or below. The lower the deviation from the goal results in a better score. In meeting the goal, g(i), for a specific topic, the horizontal integration of that topic into a course in a different topical area was viewed as a bonus, that is, additional coverage at little or no cost. The term t(i) represents the sum of the credit hours in the curriculum for topic i, and t*l*(i) represents the equivalent number of credit hours that topic i is used in courses in other topical areas (horizontal integration). The two parts of the model (for too little and too much) are summed for all of the topical areas (numTopics).

$$\text{IME Topics Score} = \sum_{i\ 1}^{numTopics} \begin{cases} 0 & \text{if } t(i) \quad t\ (i) > g(i) \\ g(i) \quad t(i) \quad t\ (i) & \text{if } t(i) \quad t\ (i) \quad g(i) \end{cases}$$

$$\sum_{i\ 1}^{numTopics} \begin{cases} 0 & \text{if } t(i) < g(i) \\ t(i) \quad g(i) & \text{if } t(i) \quad g(i) \end{cases}$$

Communication

To simplify the model, written and verbal communication were valued equally. The rating, c(i), assigned to each course is based on an estimate of the fraction of the course grade that depends on communication. The communication score calculation is shown below, ch(i) is the number of credit hours of course i, and n is the number of courses in the curriculum.

$$\text{Communication Score} = \sum_{i\ 1}^{n} c(i) \quad ch(i)$$

Problem Solving

The taxonomy of problem solving developed by Plants, e.l.[3] was used to incorporate this skill into the model. The taxonomy starts at level one, Routines, that require the use of standard routines to solve a problem, and advances to level five, Generation, where the problem solver must develop new methods to solve a problem. The taxonomy was used as a basis to develop a one low to five high scale in order to assign a problem solving score, ps(i), to each course (i). Courses requiring the students to solve higher level problems are valued higher.

$$\text{Problem Solving Score} = \sum_{i\ 1}^{n} ps(i) \quad ch(i)$$

People Skills

A zero to one rating scale for people skills, p(i), is based on the fraction of course time that students are working with other people, either in or out of class. The formula is

$$\text{People Skill Score} = \sum_{i\ 1}^{n} p(i) \quad ch(i)$$

Time Between a Course and its Prerequisite

The time between course i and its prerequisite(s), j, was used to determine a score, tb(i, j) for this objective. Shorter time is valued higher. For practical purposes, a time spacing of one year or less was determined to be the minimum possible time between courses.

$$\text{Time Between Score} = \sum_{i=1}^{n} \sum_{j=1}^{numPreq} \begin{cases} 0 & \text{if } tb(i,j) \le 1 \\ tb(i,j) & \text{if } tb(i,j) > 1 \end{cases}$$

Scaling

For a given curriculum, the rating of each factor in the multi-criteria model must be scaled to a common range before being added together. This requires knowledge of what represents a "best" and "worst" rating for each factor, with the best rating assigned a value of ten, and the lowest a value of zero. Linear scaling is applied to assign an actual rating within these limits.

Objective Weight

A paired comparison approach[4] was used to develop a weight for the six objectives in the model. Applying this method, each objective is compared to every other objective in terms of importance. The results are analyzed to produce a normalized weigh for each objective. The results of this work are shown in Table 2.

IMPLEMENTATION

In order to facilitate future work in evaluating alternative curricula designs, the multi-objective model has been incorporated into a computer program. The program produces an analysis for a specified curriculum that shows which requirements are or are not met. It also calculates a score for each of the objectives in the model, scales it to produce a value, and then adds the individual values times the weight to produce a rating for the curriculum. An example printout is shown in Table 2.

Table 2. Computer Output for Test Data

Objective	Score	Value	Weight	Rating
Topics	52.8	5.0	.250	1.25
Integration	56.8	5.7	.250	1.43
Communication	14.7	3.9	.125	0.49
Problem Solving	333.0	2.6	.125	0.33
People Skills	11.8	2.7	.125	0.34
Time Between Courses	4.0	6.0	.125	0.75

			Total	4.59

The program uses test data for courses incorporated in a spreadsheet file that models catalog information. For each course, this "catalog" contains the information that is needed to determine if all of the university, college, department, ABET, and sequence requirements are satisfied. The data needed for the multi-objective model are also included. This includes the IME topical area, the communication, problem solving, and people skill rating for each course, and the From\To integration matrix.

FUTURE WORK

The next step in this research is to further refine the model such that it can be employed to evaluate alternate curricula. Sensitivity analysis will be conducted to determine the extent that the values for objective weights and course parameters can vary from the original estimates before a preference is changed. Following that, the feasibility of incorporating the model into a linear program to select an optimum curriculum will be explored.

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