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ABSTRACT

Educational objectives were developed for an undergraduate electrical engineering curriculum. The courses studied were computer programming, electrical science, electrical networks, electronic engineering, and engineering communications. The courses were analyzed in terms of purpose, content, and objectives. Definitive problems for each course were decided upon by professors responsible for each course. These problems represented the most complex types of questions a student would be able to solve after completion of the course. Therefore, these problems became the educational objectives for electrical engineering students. Each course was then described in terms of these difinitive problems. The student was evaluated in terms of his own performance, independently of the performance of other students. It was concluded that specified educational objectives served as guidelines for teachers in the selection, revision, and presentation of course materials. These objectives also acted as guidelines for the students in the assessment of goals. The major objectives of this engineering education system have paved the way for treating curriculum design as a system engineering problem. (BRB)

SPECIFICATION OF EDUCATIONAL OBJECTIVES FOR SYSTEM EVALUATION

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SUMMARY

Educational systems may be rationally evaluated only if the system objectives are properly specified. However, educational goals are traditionally stated in terms of vague intangibles, such as "development of mental maturity," or "acquisition of knowledge." It is virtually impossible to decide, without much greater specification, when students have achieved such vaguely stated goals. (The assumption is implicit that the primary function of educational institutions is to induce some sort of change in the students.)

One solution is to state educational objectives in terms of observable student behavior. This approach was applied to the specification of course objectives in an undergraduate electrical engineering curriculum. A procedure was devised for developing a set of eventually specified objectives as a more precise restatement of course goals. The resulting objectives were stated clearly and concretely, so that their attainment could be objectively measured on a binary (go, no-go) scale, and the performance of individual students measured independently of the performance of other students.

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I. IMPROVEMENT OF EDUCATIONAL SYSTEMS

A critical demand today involves the development of an empirical demonstration of educational improvement [4]. However, the common practice and long-standing tradition of stating educational goals in vague, intangible terms makes it difficult to determine objectively whether any educational innovation actually is an improvement [7, p. 10]. A brief perusal of the catalogs of leading liberal arts colleges, as well as schools of medicine, law, and engineering, reveals that educational goals are consistently stated in terms of intangibles, such as [7, p. 2]:

> ...liberation of men from the meagerness of mere existence, development of mental maturity, development of wisdom and judgment, acquisition of knowledge, learning to understand and appreciate our democratic cultural heritage, development of intellectual curiosity, etc.

Because of this practice, it has been noted [11, p. 1] that statements of the goals of education, despite their wide availability, generally have much less impact on the curriculum or on what actually takes place in the classroom than they otherwise might. This is principally because such statements have little exact meaning for the prac-

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ticing classroom teacher or for any other educator. Only when the broad, general goals are given operational definition can they be expected to have much influence on what a student learns in school. When the goals are not stated clearly and precisely it is impossible to evaluate a course or program of study efficiently, and appropriate content, materials, and methods of instruction cannot be rationally selected [12, p. 3].

In 1967 Decker [7] reported how evental specification was used in developing a set of behavioral criteria for the training of medical technologists. This set of criteria was based on an analysis of the tasks technologists perform. In 1968 the writer applied this principle to the description of course objectives for an undergraduate electrical engineering curriculum.

II. STATEMENT OF THE PROBLEM

Currently, professional accrediting agencies (e.g., the Engineers' Council for Professional Development, ECPD) establish whether or not the vaguely stated goals of an engineering curriculum are equivalent to professional engineering practice. The investigation described here was undertaken to develop and test a procedure for establishing an equivalence between those goals and some set of eventally specified objectives. Ultimately, it would be desirable to establish the equivalence between professional practice and the eventally specified objectives directly.

As a first step, it appeared reasonable to examine what engineers actually do in professional practice. The ECPD has stated [13, p. 5] that

> ...engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.

Engineers engage in such activities as research, development, design, production and construction, operations, sales, management, testing, teaching, and consulting [5, p. 28ff]. Lichty [10, p. 283] and Brown [6, p. 332] assert that the particular distinguishing characteristic of an engineer is the ability to design. Hoover and Fish [8, p. 1] define an engineer as "a person qualified by aptitude and education to solve engineering problems and direct engineering activities." The ASEE Goals Committee [2, p. 16] states that "the engineer of the future--like the engineer of the past--must become a skillful problem solver." Beakley [5, p. 44] summarizes the functions of an engineer by stating

...in all cases he is a problem solver. Whether it be a mathematical abstraction that may have application to a nuclear process or a meeting with a bargaining group at a conference table, it is a problem that must be reduced to its essentials and the alternatives explored to reach a solution.

An engineer is therefore defined here as one who can solve specified types of problems. Given this definition, the primary educational objectives of an engineering curriculum can be specified as a set of definitive problems that a graduating student should be able to solve. A definitive problem in engineering is defined here as one that a qualified engineer can solve and that most laymen cannot solve.

Ideally, an engineer should be specified in terms of the types of problems he actually solves on the job. Considering the great variety of jobs engineers have, however, this appeared to be an impractically large task for an initial investigation. A reasonable first approximation of the ideal was to structure a set of problems that engineering educators believe engineering graduates should be able to solve. In this investigation, then, engineering professors determined the equivalence of eventally specified educational objectives (definitive problems) with vaguely stated course goals.

III. PROCEDURE AND RESULTS

The basic task was to develop a set of definitive problems reflecting professors' opinions about what an engineering graduate should know. Definitive problems were based upon an analysis of what is taught in various courses. (At this point, therefore, the procedure is descriptive rather than normative.) The problems were then discussed with professors to determine whether they really expressed the essence of what the professors expected of the students upon completion of the courses. Suggested revisions were made, and the problems again submitted to the professors. The general procedure was as follows:

1. A particular course was initially analyzed.

   a. Course purpose and objectives were discussed with the instructor.

   b. Course materials, primarily the syllabus and textbook were studied.

   c. Tests were studied as a primary source of data regarding what professors consider most important in the course.

2. Based on the preceding, the investigator specified his estimates of the most complex kinds of problems students should be able to solve upon completion of the course.

3. Professors responsible for the course reviewed the problems developed in Step 2.

4. The problems were revised as suggested by professors.

5. Steps 3 and 4 were repeated until the professors indicated that the problems represented the major course objectives. These are considered definitive problems.

It was implicitly assumed that there is no short-run temporal variation of course goals within any individual instructor. It was further assumed that there exists some group consensus among instructors about course goals. The problem of resolving inter-instructor goal differences was outside the scope of this investigation.

CURRICULUM DESCRIPTION

The curriculum investigated was a typical one for an undergraduate electrical engineering student majoring in electronic devices and circuits at Arizona State University. Because this was a feasibility study of a new approach to curriculum specification rather than an attempt to establish a complete curriculum in evental terms, only a few sample courses were considered. This particular sample was selected to demonstrate the applicability of the method over major subject matter areas--six courses representing seven areas of engineering studies.

The ASEE Goals Committee recommended the following subject matter areas as main ingredients for a basic engineering curriculum:

- Mathematics
- Computer Science
- Physical Science
- Synthesis, Analysis, Design of Systems and of Their Components
- Experimental Engineering
- Communications
- Engineering Ethics
- Humanities and Social Studies

All the above areas except the last two were represented in the six courses:

- ES 103, Computer Programming
- ES 231, Electrical Science
- ES 330, Electrical Networks
- ES 331, Electronic Engineering
- EE 332, Electronic Engineering
- ES 400, Engineering Communications

The relation of courses and subject matter areas is shown in Table 1.

Table 1

RELATION OF COURSES AND SUBJECT MATTER AREAS

Subject Matter Areas		Courses
Mathematics--	Computer Science	ES 103
	Physical Science	ES 231
	Engineering Science	ES 330
	Systems Analysis	ES 331
	Experimentation	EE 332
	Communications	ES 400

The mathematics area is represented in that three mathematics courses (MA 120, MA 121, MA 212) are pre- or co-requisite to five courses in the sample. Also, various mathematical techniques are required to solve problems in those five courses. The computer science area is represented by ES 103, Computer Programming. Physical science is represented by ES 231, Electrical Science. This is primarily a basic physics course with engineering applications. It is pre- or co-requisite to two physics courses in the curriculum. The areas of engineering science, systems synthesis and analysis, and experimental engineering are represented by ES 330, ES 331, and EE 332. This sequence of courses includes electric circuits and electronics, design of electronic systems, and laboratory experiments. The communications area is represented by ES 400, Engineering Communications.

The definitive problems developed for the six courses represent the most complex types of problems a student should be able to solve after course completion. The problems are fairly broad for lower level courses, and more specialized and complex for higher level technical courses. The problems are believed to define specific differences between a layman and an engineer; i.e., a student completing a particular course should be

able to solve them; a layman who has not had the course or its equivalent would ordinarily find them unsolvable. The problems were not tested for actual discrimination.

THE RESULTS

Table 2 shows for ES 330 the catalog description, the course purpose, and the course objectives stated as definitive problems. Tables 3 and 4 contain similar information for two other courses in the sample. The rest are available from the writer.

The stated purpose for ES 330 emphasizes in intangible terms what the instructor is to do. He is to "develop the basic theory of circuits," and do this in such a manner as to "establish a sound foundation for the study of modern network and communication theory." The five-page course syllabus goes into much more detail, stating what paragraphs and chapters of the textbook will be covered in what weeks, and what the general topics will be; however, it does not specify exactly what the student must be able to do.

The problems developed here do describe observable student behavior. In fact, the eventally stated objectives for ES 330 specify what might be a comprehensive final examination for students taking that course. Professors of electrical engineering agree that these objectives represent what is significant within the course. To test whether a student has achieved the course objectives, it would only be necessary to give him a series of specific circuits with values of components, and ask him to produce the specified entities (e.g., characteristic equation, transfer function, complex power, power gain versus frequency). The examination is so specific that it could be administered on a pass-fail

Table 2

DESCRIPTION, PURPOSE, AND DEFINITIVE PROBLEMS FOR
ES 330, ELECTRICAL NETWORKS

Catalog description--Mathematical analysis of networks and linear systems.

Purpose--Develop the basic theory of circuits in such a manner as to establish a sound foundation for the study of modern network and communication theory.

Objectives stated as definitive problems--Given a circuit consisting of V, I, R, L, and C components of specified values, and no more than 4 nodes and 10 branches, the student shall be able to

1. Write the network differential equation.
2. Write the network characteristic equation.
3. Write the transfer function F(s).
4. Sketch F(s) versus s, showing poles, zeroes, and asymptotes.
5. Compute initial values of specified Vs and Is.
6. Write expressions for specified time-varying quantities.
7. Compute magnitude and phase angle of V and I, and magnitude of P at specified points in the circuit.
8. Specify an ideal transformer to maximize power transfer.
9. Specify X_L and R_L to maximize power transfer.
10. Find complex power, active power, reactive power, and power factor.
11. Determine and sketch circuit Z, Y, and voltage, current, or power gain versus frequency.

Table 3

DESCRIPTION, PURPOSE, AND DEFINITIVE PROBLEMS FOR ES 231, ELEC[illegible]IENCE

Catalog description--Basic concepts of electricity and magnetism. The development of fundamental laws and their engineering application.

Purpose--Introduce the engineering student to the basic concepts and fundamental laws of electricity and magnetism and their engineering application.

Objectives--Given knowledge of the effects of various specified interactions of material properties, properties and behavior of systems, and system geometry (with emphasis on electric and magnetic field interactions), the student shall be able to:

1. Predict the performance of a specified simple system.

2. Design a simple system to achieve a specified performance.

Material properties include: conductivity, magnetic permeability, dielectric constant, and certain semiconductor properties.

System properties and behavior (performance) include: electron charge and velocity; current, voltage, and power at various frequencies, and their generation by motion of a conductor in a magnetic field; temperature; resistance, inductance, and capacitance; magnetic and electric fields; force on a conductor carrying current in a magnetic field, thereby inducing rotation or translation; induction of voltage in a second circuit due to current in a first circuit.

Table 4

DESCRIPTION, PURPOSE AND DEFINITIVE PROBLEMS FOR

ES 331, ELECTRONIC ENGINEERING

Catalog description--Electronic circuits.

Purpose--Give the student a thorough development of linear and piecewise linear circuit models for tubes, diodes, and transistors. Analyze the behavior of these devices in the basic amplifier and configurations. Consider linear tube and transistor circuits. Provide the student with methods which are useful in treating a large class of active circuits without regard to the particular type of active device used.

Objectives--Given an active circuit element and its characteristics, the student shall be able to:

1. Determine the incremental parameters of the device or a combination of the devices, at a given operating point.

2. Design a circuit using the device which will exhibit specified operating characteristics.

Given a circuit with one or several active elements of specified characteristics, the student shall be able to:

3. Plot the load line and determine the Q point.

4. Determine power dissipation of the active elements.

5. Determine maximum and minimum values of specified Vs and Is.

6. Determine V or I amplification and power gain.

7. Sketch waveform of V and I.

8. Construct a piecewise linear model of the circuit.

9. Sketch a V-I plot.

Given a V-I plot of a black box, the student shall be able to:

10. Devise a piecewise linear model which will exhibit said characteristics.

basis. Thus, it is possible to state the previously intangible purpose of ES 330 in terms of eventally specified objectives as definitive problems the student must be able to solve.

A general, more complete form for definitive problems would also specify the conditions (available aids, references, etc.), and criteria for accepting or rejecting a solution. Because this was a feasibility study, and conditions and criteria are readily determined given the definitive problems, conditions and criteria were not explicitly stated.

VALIDITY OF COURSE OBJECTIVES FOR REAL-WORLD APPLICATION

To determine whether the definitive problems developed are similar to those that engineers are called upon to solve in actual practice, several professors and practicing engineers were asked to provide real-life examples of problems based on their experience in industry.* Table 5 shows definitive problems for ES 231 and ES 331 that are reasonable first approximations of real-life problems that engineers solve. Examples could also be devised for ES 103, EE 332, and ES 400.

One professor stated that there are no real-life problems corresponding to the objectives of ES 330 and the last objective of ES 331.

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*An interesting byproduct of this aspect of the investigation is that apparently there are only three general types of engineering problems:

1. Design a black box. (Here is a description of the desired result. How can it be obtained?)
2. Troubleshoot a malfunctioning black box. (Why isn't the desired result being obtained?)
3. Measure an unknown black box. (What are the characteristics of this device or system?)

This does not necessarily invalidate those definitive problems as course objectives, even though they might be invalid as curriculum objectives. If a course is thought of as a component of an engineering curriculum, it is the terminal objectives of the entire curriculum that should correspond most closely to real-life problems. In the beginning stages of his education the engineering student generally learns to solve simple idealistic problems as preparation for learning to solve more complex problems. It is not unreasonable, then, that there should be no real-life examples of the definitive problems describing basic course objectives. However, certain skills learned in a basic course may have direct application to solving real-life problems. This was shown when examples of real-life problems were devised that relate directly to types of problems students learn to solve in ES 231, a lower-division course.

Table 5

REAL-LIFE EXAMPLES OF SELECTED DEFINITIVE PROBLEMS

ES 231, Electrical Science

Objective 2

Design a non-inductive 500-ohm resistor capable of dissipating 20 kilowatts.

Design a 5 millihenry inductance coil for a low-pass filter capable of carrying one kilowatt of five megacycle r-f power.

Orient the components of a specified circuit in order to minimize magnetic field, electric field, and thermal interactions.

ES 331, Electronic Engineering

Objective 1

Measure the operating parameters of a given transistor to determine if it can be used in a specified application

Objective 6

Determine the theoretical gain of a specified amplifier above 100 kilocycles.

IV. APPLICATIONS

GENERAL USES

There appear to be four major areas in which the use of eventally specified objectives could improve educational systems. Two of these involve guidance of the educational process, and two involve its evaluation.

Eventally specified objectives could serve as fairly specific guides to teachers in the selection, revision, and presentation of course materials, without actually specifying the particular materials to be used. Current procedure is most often to specify (if anything) the means (teaching materials), and let the individual teacher adapt them to whatever ends he has in mind. It seems more reasonable to specify the ends, and let the instructor develop the means for achieving those ends. This method would not necessarily deny the instructor a voice in determining course objectives; and it would give him a better framework for determining how to best organize and present the course material.

Students too would profit by the evental specification of course objectives. When goals are defined and identified only casually, the student is often misdirected rather than helped in his learning efforts [15, p. 78]. Tyler has noted [14, p. 22] that "In a considerable portion of the courses and classes students are not clear about what it is they are trying to learn." Much experimental evidence indicates that deliberate learning in response to explicit instructions is more effective than unintentional or implicitly guided learning [1, p. 235]. It appears that learning effort is enhanced and the efficiency of the

educational process improved by deliberate intention on the part of the student. Deliberate intention might be enhanced by the precise statements of educational objectives afforded by the use of rigorously evental terms. Mager even goes so far as to say [12, p. 53], "If you give each learner a copy of your eventally specified objectives, you may not have to do much else."

Experimental evaluation of a system implies specification of various experimental outcomes or events. Obviously, there are many possible kinds of events that could be specified with regard to the educational process. It seems sensible, however, if alternative procedures are being evaluated with respect to how well they achieve the objectives of some educational system, that the specified events relate in some manner to those objectives. This can probably be done most readily if the objectives themselves are specified in terms of events. Thus, evental specification of educational objectives permits a more precise evaluation of alternative means of achieving those objectives than is possible when the objectives are vaguely stated.

This evaluation of pedagogical procedures is, of course, based on the performance of students. A student can thus be evaluated on an absolute standard, independently of the performance of other students; either he can perform the specified tasks within specified limits of time and accuracy or he cannot. If he cannot, it would be desirable to give him remedial instruction in areas of the objectives he did not achieve. He could then take the test again. The procedure could be repeated until the student can perform all the specified tasks. This seems preferable to certifying a student as highly (A), fairly well (B), adequately (C), poorly (D), or not (F) competent in a vaguely de-

fined area of engineering, particularly since the standards are usually relative to the performance of a small and not necessarily representative number of students.

ENGINEERING AN EDUCATIONAL SYSTEM

The development of a system generally follows the sequence of: specification of system objectives and performance criteria; synthesis of several alternative systems; analysis of the systems; selection of one of the systems for implementation; implementation; modification of the system based on implementation experience. It does not seem unreasonable that a similar procedure could be used in developing an engineering curriculum, which can be considered, at least in part, as a sort of manufacturing or processing system [9, p. 387]. Such an approach does not preclude consideration of the subjective, humanistic goals of education. Indeed, it might even facilitate them by explicitly separating them from those parts of education that can be treated in a highly objective fashion.

The development of an educational system would thus start with the specification of the educational objectives as discussed in the preceding sections of this paper. Such a set of problems would be a realistic reflection of what a graduate might be expected to do when he starts to work. (Any particular student, of course, would have as his particular objectives only a small subset of the total set of curriculum objectives.) The fact that engineering professors with industrial experience could provide, with apparently little effort, examples of real-life problems young engineers are called upon to solve, suggests that assembling enough such problems to define realistic objectives for

an entire engineering curriculum may now be practical. The set of objectives, or definitive problems, would, of course, be periodically reviewed and changed to reflect changes in engineering practice and new scientific knowledge.

Given the set of objectives, the faculty would then devise the most efficient teaching procedures for the attainment of those objectives. Such procedures would be based on the outcomes of actual experiments with alternative teaching procedures, rather than being an extension of traditional teaching methods. After all, one of the big advantages of eventally specified educational objectives is the fact that their method of attainment is subject to experimentation. Such experimentation can be part of a continuous process of improvement of the educational system, based on hard experimental evidence.

In any system design, the specification of system performance objectives and evaluation criteria is of prime importance. This paper has developed and demonstrated a method for specifying in precise, evental terms major objectives of an engineering education system, and thus paved the way for treating curriculum design as a system engineering problem.

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