Development of Customer-Based Outcome Measures for an Engineering Program[a]

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The Accreditation Board for Engineering and Technology (ABET) has proposed fundamental changes to their accreditation criteria that are performance based, rather than prescriptive. As a result, engineering schools must now consider developing methods and measures to evaluate their engineering programs. One approach to developing program outcomes is to utilize feedback from customers of the engineering education system, specifically alumni and practicing engineers. As part of a larger research effort, the Department of Industrial Engineering at the University of Pittsburgh used customer feedback to develop a set of outcome measures for its program. Responses from surveys sent to the 1987 engineering graduates were analyzed by focus groups consisting of industrial engineers from the Pittsburgh area. From this information, the participants developed affinity diagrams to represent the requirements of an industrial engineering degree. Results of the affinity diagrams were then consolidated to form a set of fifteen measures that could be used in an evaluation program. The outcome measures developed were found to be in concert with the EAC 2000 criteria, yet were specific to the needs of the industrial engineering discipline. This paper discusses the research results and how the methods employed can be transferred to other engineering disciplines.

Introduction

Changes in the work environment now require engineering graduates to be more than technically proficient. Engineering graduates must also demonstrate proficiencies and capabilities necessary to integrate and succeed in a continuously changing workplace, such as working in teams, communicating effectively, understanding social and economic concerns, etc.[1,2] Recognizing that the methods and criteria used to evaluate engineering institutions have constrained schools from addressing industry's needs and making improvements to the educational system, ABET has proposed changes to their criteria that are more performance based.[3] As a result, engineering schools must now develop their own methods and metrics to evaluate and improve the education they deliver to students. The Joint Task Force on Engineering Education Assessment[4] has further stressed this by making a call to the engineering education community to develop methods and assessment tools to assist in the evaluation efforts of engineering programs and quality of engineering students.

At the University of Pittsburgh Department of Industrial Engineering, a research effort was conducted to develop an approach to measuring the education delivered to students and to offer a model of the engineering education system that may be used to assess the educational

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processes.[5] By incorporating two Total Quality Management (TQM) concepts, that of focusing on customer requirements and feedback, as well as statistical data reduction techniques, a set of measures was developed for both the educational processes a student experiences and the outcomes he/she should possess at graduation. Eliciting customer requirements and feedback in engineering education is not new, as the literature indicates many such applications. (For example, see references[6,7,8,9,10,11,12].) However this research effort extends the customer's contribution by empirically modeling the relationships between the process measures and the outcome measures, thus creating a feedback mechanism that may be used in process monitoring and improvement.

In this paper we examine one portion of the larger project, that of creating a set of outcome measures for the program. This was accomplished by incorporating the use of feedback from alumni and structured brainstorming techniques from practicing engineers. The paper first discusses how results of an alumni survey were used to obtain a rich database of possible outcomes. Next, the methods used to consolidate the database into a set of outcome measures for the industrial engineering department is discussed. Finally, a comparison between the derived outcomes and the EAC 2000[13] criteria is given.

Responses from Alumni Survey

In the late summer of 1993, a baseline survey was sent to the entire engineering class of 1987, as part of another research effort by the School of Engineering at the University of Pittsburgh.[14] Alumni were asked questions about their perceptions of engineering knowledge, skills, and attitudes they obtained while attending the university. In addition, alumni were asked several open-ended questions about what should be the primary aim of an engineering education. Responses to the survey were analyzed to capture potential outcomes of an engineering education. From the open-ended portion of the survey, two questions were coded to determine what, from the customer's perspective, were the outcomes of an engineering education. The questions were:

1. "What is the primary aim of an undergraduate engineering education?"
2. "What factors do you look for when interviewing and hiring an engineering graduate?"

Alumni responses to these questions were coded according to the various "knowledge, skills, and attitudes" an individual should possess at graduation, as suggested by the engineering education literature.[15,16,17,18,19,20,21] The frequency of responses were also calculated. This coded list of survey responses provided a large database to develop possible outcomes for the engineering education system. Using this list, affinity diagrams were developed by practicing engineers that later became the outcomes for the evaluation model.

Development of Focus Group Affinity Diagrams and Importance Weights

In the winter of 1995, focus groups of practicing industrial engineers were determine, from the factors found in the literature and survey, the outcomes of an engineering education. Focus groups, a method commonly used in marketing and in many TQM applications to acquire customer requirements, have the following advantages:

1. they are a research method that captures ‘real-life’ data in a social environment,
2. they are flexible - the dynamics of the group often allow issues to be explored that may not be possible with structured questions found on mail surveys,
3. they have high face validity, and when conducted properly, have high construct or convergent validity,[22,23]
4. when compared to other means of obtaining information about attitudes, focus groups produce rapid results, and
5. they are typically low in cost compared to other methods for capturing customer data (i.e. surveys, interviews, etc.).[24]

Participants in the focus groups were individuals active in the local Pittsburgh chapter of the Institute of Industrial Engineers (IIE). Participants were selected based on two criteria: (1) they obtained an undergraduate degree in industrial engineering, and (2) they received their degree prior to 1990. (A few of the participants were graduates of the undergraduate program at the University of Pittsburgh.) Two focus groups were held. The first consisted of primarily male IE’s; and the second consisted of all female IE’s.

To determine the product outcome variables for the model, focus group members were asked to conduct a structured brainstorming exercise called an affinity diagram.[25] An affinity diagram is a TQM problem solving tool ordinarily used to gather large amounts of data (ideas, issues, etc.), organize the data into groupings based on natural relationships between each data item, and give definition to the formed groups. It is a helpful tool when large amounts of information need to be classified functionally. To help facilitate the focus group, items from the database were written onto index cards (participants were also highly encouraged to contribute their own outcomes). Prior to the meeting, focus group members were sent information about the research project and an agenda. Once at the meeting, members were given specific instructions on how to develop affinity diagrams, as well as how to assign weights to the outcomes in relation to their importance in obtaining an engineering education.

The first focus group was comprised of eight male industrial engineers, and one female engineer. From an exit survey, all but one engineer were satisfied with the results of their focus group’s affinity diagram. The female engineer in the group felt the results of the focus group may have been gender biased. To determine if gender differences existed, a second focus group was conducted with all female participants. This second focus group consisted of five female industrial engineers. From the exit survey, all participants from the second focus group were satisfied with the results of their affinity diagram. Further, all participants from both groups thought the use of affinity diagrams and weighting techniques were effective methods for the intended goal. The affinity diagrams developed by the focus groups are shown in Figures 1 and 2 along with their attached weights (weight score and normalized percentage). Interestingly, both focus groups eliminated quantitative measures, such as ‘QPA’ and ‘graduating in four years,’ from their affinity diagrams. One focus group member indicated that he did not ‘trust’ anyone who was capable of completing their degree in four years.

The results of the focus groups were similar. Both focus groups formed affinity diagrams that consisted of comparable categories (or outcomes) having to do with: engineering knowledge, problem solving, communication skills, experience, professional traits, management-type abilities, and a well-rounded education. Many of these outcomes were even assigned the same ‘header’ cards. As indicated, focus group participants were also not timid about eliminating cards they thought were redundant or did not belong as outcomes.

Once the affinity diagram was completed, weights were attached to the categories in terms of their relative importance to obtaining an engineering education. Use of swing weights[26], a weighting and ranking technique, was selected over traditional numerical weighting methods because they allow for a range of magnitudes between most and least preferred outcome variables. Using this method, focus group members avoided selecting outcomes that may be ‘hot’ or current trends in engineering education or industry. It also allowed each group to focus on important outcomes that may be taken for granted or those that may be *expected* from the engineering education system (e.g. basic science knowledge).

In ranking the importance of the outcomes, both focus groups rated ‘technical background/engineering knowledge’ and ‘problem solving abilities’ as the two most important followed by ‘communication skills’ and ‘experience.’ Though the rest of the outcomes differed in their rankings, their relative positions were comparable between focus groups. For example, the outcome having to do with ‘management skills’ was ranked somewhere in the middle of the outcomes, where as the outcomes ‘professional traits’ and ‘having a well-rounded education’ were ranked with low importance. Because the results of the two focus groups were so similar, both in how the affinity diagrams were formed and in the rankings of the outcomes, additional focus groups were not conducted.

Synthesis of Affinity Diagrams

To arrive at a final set of outcome variables for the model, the two affinity diagrams and the literature-based survey coding were synthesized. First, the two affinity diagrams were consolidated by comparing the categories (and their corresponding cards). For most of the categories, the focus groups were in agreement (even to the naming of the header card). Where categories did not match directly, but there appeared to be a natural relationship between the two, a new category was formed. If no relationship was found between the categories and the associated cards, the literature-based survey coding was consulted to determine how the category (and corresponding cards) may be assigned. If no consistencies could be found between the affinity diagrams and the survey coding, a new category was formed. Three such categories were formed: discipline specific knowledge, creative thinking and engineering ethics. These final, synthesized categories became the outcome variables used in the larger research effort, as shown in Table 1. Definitions for the outcomes were based on the responses written on the individual cards that comprised each group.

Comparisons to ABET Criteria

Table 1 also show the many similarities between the customer derived outcomes and the "EAC 2000"[27] criteria. Criterion Three, Program Outcomes and Assessment, states that engineering programs must have an assessment process demonstrating that outcomes, important to that program, are being measured and monitored. According to the criteria, engineering programs must demonstrate that their graduates have the following abilities.

A. An ability to apply knowledge of mathematics, science, and engineering.
B. An ability to design and conduct experiments, as well as to analyze and interpret data.
C. An ability to design a system, component, or process to meet desired needs.
D. An ability to function on multi-disciplinary teams.
E. An ability to identify, formulate, and solve engineering problems.
F. An understanding of professional and ethical responsibility.
G. An ability to communicate effectively.
H. The broad education necessary to understand the impact of engineering solutions in a global/societal context.
I. A recognition of the need for and an ability to engage in life-long learning.
J. A knowledge of contemporary issues, and the techniques and skills necessary for engineering practice.

As indicated in Table 1, all the criteria appear to have been accounted for by the outcomes, as defined by the practicing engineers. In some cases, two criteria satisfied the same outcome. However, there were three outcomes that the practicing engineers felt were important, but did not appear to correspond to any of the EAC 2000 criteria: creative thinking, experience, and management skills. Experience, in particular, is an outcome that both focus groups considered to be critical in obtaining an engineering education. Whether this outcome and the other two are specific to the industrial engineering field or whether they are outcomes common to all discipline requires further research.

Conclusions

The methods employed here produced outcomes that are similar to those recommended by the accreditation board, yet specific to the needs of the industrial engineering program at the University of Pittsburgh. As a result, the use of focus groups and affinity diagrams may be considered credible methods for defining educational outcomes for a program and/or discipline. Further, these similarities also support the notion that the underlying engineering education system has strong attributes that allow various interested groups to arrive at similar solutions.

As mentioned previously, the outcomes and weights produced in this study were used in a larger research effort to develop a model of the engineering education system for use in process monitoring and improvement. The application of the methods described in this study contributed to the successful development, evaluation and validation of this model.

Technical Background (f)
100/.19

knowledge of and can apply fundamentals
has basic principles
knowledge of engineering basics
has basic skills
provides tools

knowledge in basic science
knowledge o physics
knowledge of chemistry
knowledge of math/calculus
knowledge of statistics
knowledge of experimental verification

knowledge of engineering science
fluids
thermodynamics
process control

has knowledge of economics
knowledge of engineering design
has manufacturing skills
has an engineering thought process

Has Experience
75/0.14

knows what the real world is like
has practical experience
have hands-on experience
is confident

Personal/Professional Traits
(that can be influenced) (f)
30/0.06

has social awareness
is sensitive to culture, race, etc..

has the desire to continue education
has technical creativity
knows how to think independently
knows how to think logically
knows why a concept needs to be learned

has a professional image
is organized
knows how to manage time
can budget resources
goal oriented
has positive work ethics
is responsible

Abilities for Problem Solving
100/.19

can solve complex problems
can solve real/industry problems
can apply theory
apply the scientific method
has problem solving skills

have a basis for an engineering career
productivity and quality engineering management

knows how to identify a problem
be able to formulate problems
know how to analyze a process
    think analytically
    think critically
data collection
have analysis skills
have engineering skills
be able to conduct design
have decision making abilities

Information Systems/
Information Technology (f)
50/0.10

have computer skills
know how to use software packages
know how to program
can use computers for modeling

can use the computer as a communication devise
information systems analysis and design (MIS) (f)

knows how to look/obtain information
has the background to be creative

Keep Up to Date
15/0.03

should have an up-to-date education
knowledge in changing & latest technologies

prepared for the workforce

knowledge in discipline specific subjects
has advancement in specific areas or has a concentration

Have Communication Skills
85/0.16

have oral communication skills
be able to communicate socially
knows how to reason

have business writing skills (f)
have written communication skills
knows how to communicate through graphical methods

be able to work with people
have teamwork abilities
be able to work in groups

Organization and Management Skills
85/0.16

management (f)
    personnel/human resources
    leadership
    coaching
    management theory
have management skills

has leadership skills

have project management abilities

knows how to set priorities/goals
knows how to coordinate tasks/projects
has implementation skills

organizational behavior and development (f)
knows organizational behavior
has social awareness, politically
has knowledge of psychology
has background in engineering ethics
has an understanding of the work environment
knowledge of training and development (f)

sales skills (f)
awareness of marketing issues (f)
knows accounting
has knowledge of business/contract law (f)

Have a Well Rounded Education
10/0.02

has knowledge in
    philosophy
    humanities
    English literature
    social sciences
    sociology
    history
    foreign languages
    international affairs

Figure 1. Affinity Diagram Developed by the Focus Group Consisting Primarily of Male Participants

Engineering Knowledge
100/0.11

- have engineering skills
  - knowledge of engineering design
  - know engineering basics
  - knowledge of discipline-specific subjects
  - background in engineering ethics
  - be able to conduct design
  - provide tools
  - know fundamentals
  - have basic principles
  - have basic skills
  - know process control
  - know a particular area of concentration
- knowledge in basic science
  - knowledge in:
    - experimental verification
    - statistics
    - math
    - calculus
    - chemistry
    - physics
    - engineering science
      - thermodynamics
      - fluids
- has manufacturing skills
- have computer skills
  - computer as a communication devise
  - know how to program
  - use computer for modeling
  - know how to use software packages

Solving Abilities
99/0.11

- have problem solving abilities and skills
  - knows how to identify a problem
  - be able to formulate problems
  - knows how to analyze a process
  - knows how to set priorities/goals
  - can solve complex problems
  - have analysis skills
  - thinks analytically
  - thinks logically
  - knows how to reason
  - knows how to think critically
  - have decision making abilities
- know how to think creatively
  - have technical creativity
  - knows how to adapt

Have Communication Skills
95/0.10

- written
- oral
- knows how to communicate through graphical methods
- be able to communicate socially

Have Management Skills
85/0.091

- has ability to budget resources
- have project management abilities
- knows how to coordinate tasks
- knows how to coordinate projects

Know What Real World is Like
87.5/0.095

- has experience
- have practical experience
- prepared for the work force
- have hands-on experience
- has an understanding of the work environment
- can solve industry problems
- can solve real problems
- knows how to look/obtain information
- becomes productive, quickly

Professional Traits (f)
85/0.091

- know how to learn
- has a professional image
- is organized
- knows how to manage their time
- is self motivated
- has leadership skills
- be goal oriented
- knows how to be discipline
- knows how to think independently
- has interests in the area of work

Have Teamwork Abilities
85/0.091

- be able to work in groups
- be able to work with people

Has Implementation Skills
85/0.091

- be able to apply theory
- be able to apply fundamentals
- be able to apply the scientific method to problems

Knows State of the Art (f)
80/0.086

- should have an up-to-date education
- knows latest technologies

Have a well rounded Education
75/0.081

- has knowledge in international affairs
- has knowledge in foreign languages
- has knowledge in social sciences
- has knowledge in:
  - psychology
  - sociology
  - philosophy
- has knowledge in English literature
- has knowledge in history
- has knowledge in humanities
- has knowledge of contract law
- has knowledge of economics
- knows accounting
- knows organizational behavior

Social Awareness (f)
50/0.054

- have social awareness
  - culturally
  - politically
- sensitive to culture, race, etc.
- has diversity in social life

Figure 2. Affinity Diagram of the Focus Group Consisting of Female Participants

Product Outcome Variable	Product Outcome Definition	Draft ABET 2000 Program Outcomes
Basic Science and Math Knowledge	knowledge and abilities in basic science (physics, chemistry, etc.) and math	A. An ability to apply knowledge of mathematics, science and engineering appropriate to the discipline
Basic Engineering Knowledge	knowledge and abilities in engineering science and engineering design	A. An ability to apply knowledge of mathematics, science and engineering appropriate to the discipline C. An ability to design a system, component, or process to meet desired needs
I.E. Discipline Specific Knowledge	knowledge and abilities in industrial engineering subjects	J. A knowledge of contemporary issues, and the techniques and skills necessary for engineering practice
Computer Skills	knowledge and abilities in computer programming, modeling and system development, use of software packages, and in how a computer can be used as a communication devise	J. A knowledge of contemporary issues, and the techniques and skills necessary for engineering practice
Problem Solving Abilities	knows how to identify, formulate, collect data, conduct analysis (to include statistical analysis) and design (to include critical, logical, and analytical thinking), make decisions, and implement them	B. An ability to design and conduct experiments, analyze and interpret data E. An ability to identify, formulate and solve engineering problems
Creative Thinking	knows how to think creatively and how to adapt	No Direct Match to ABET Criteria
Communication Skills	has written (text & graphics) and oral (formal and social) skills	G. An ability to communicate effectively
Teamwork Abilities	has the ability to work with people and in groups	D. The interpersonal and social skills necessary to function on a multi-disciplinary team
Experience	has practical, hands-on engineering experience	No Direct Match to ABET Criteria
Management Skills	has abilities to set priorities/goals, coordinate tasks/projects, budget resources, and implement tasks; as well as have an understanding of organizational behavior and leadership concepts	No Direct Match to ABET Criteria
Engineering Ethics	has a background in engineering ethics	F. An understanding of professional and ethical responsibility
Professional Traits	has a professional image, knows how to learn and think independently, has a desire to continue education, is goal oriented, is organized and can manage time, is self-motivated, and has positive work ethics	F. An understanding of professional and ethical responsibility I. A recognition of the need for an ability to engage in life-long learning
Social Awareness	has social awareness: culturally, race, gender, etc.	H. The broad education necessary to understand the impact of engineering solutions in a societal context
Knowledge of Latest Technologies	knowledge of latest technologies and state of the art	J. A knowledge of contemporary issues, and the techniques and skills necessary for engineering practice
Have a Well Rounded Education	knowledge of humanities, social sciences, and international affairs	H. The broad education necessary to understand the impact of engineering solutions in a societal context

Table 1. Comparisons Between the Product Outcomes Derived and the "EAC 2000" Criteria

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