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Modeling Undergraduate Engineering Outcomes

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An outcome assessment objective is the ability to track students from the point that they enter their engineering program through graduation. By monitoring student progress, faculty can best assure that the desired outcomes are being met and, where they are not, introduce improvements—this is the core of ABET's performance-based criteria. To provide the structure for doing this, a representative model of the engineering education system was developed, evaluated, and validated at the University of Pittsburgh. This model provides insight into those factors and educational processes that influence outcome achievement. The model is based on the assumption that the educational processes a student experiences (i.e. curriculum, in-class instruction, work or research experience, etc.) are related to the graduate's obtainment of certain engineering knowledge, skills, and attitudes (i.e. EC 2000 outcomes), as supported by the engineering education literature. With input from working engineers, an alumni questionnaire was developed to measure various aspects of the model. The alumni responses along with archival data were used to evaluate and verify the overall model. Several promising models that yielded good predictive value were developed for individual outcomes. Differences were found between students who had pre-graduation work experiences and those students who did not. The model for students with pre-graduation work experiences generally showed a consistently high correlation between the predicted and actual outcomes; whereas, a similar model for students without pre-graduation work experience only yielded modest correlation. This paper discusses in detail the approach taken to model the engineering education system and demonstrates how these models have been used to improve the engineering environment at the University of Pittsburgh School of Engineering.

INTRODUCTION

THE ACCREDITATION BOARD for Engineering and Technology's (ABET) performance-based criteria, EC 2000, require that each engineering program's faculty implement and maintain a closed-loop, continuous improvement system [1]. As part of that system, faculty must demonstrate that the program's graduates have, in fact, acquired certain knowledge and skills including acquiring a minimum set of eleven outcomes. In addition, the system must be flexible enough to allow for continued improvement and reassessment. An ultimate objective would be the ability to monitor and track students from the point that they enter engineering through graduation. Intuitively, we as educators know that there is connectivity between what we are doing (i.e. the curriculum or in-class instruction) and what is being produced (i.e. the engineering graduate), but what is the extent of this connectivity? Further, how do the various processes relate to the different outcomes? Understanding the direct and indirect relationships among processes and outcomes is crucial because they provide the foundation for continuous improvement in engineering education and the key to the promise of the new ABET criteria.

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An important first step in defining these relationships is to model the engineering education system. The purpose for such a model is twofold. First, a representative model would enable faculty to better understand the system and hence better assess learning as students matriculate through the system. If developed properly, such a model could identify those students who might be 'outliers' (i.e. not achieving one or more outcomes; or have a high probability of leaving engineering even though they are academically successful). Second, by relating the various educational processes to the different outcomes, engineering educators would obtain a better understanding of the system within which they work. Hence, knowledge of these relationships would allow for more targeted interventions and improvements for both individual students and groups of students.

Empirical modeling is commonly used to draw correlated inferences and define relationships among different factors (i.e. process elements and outcomes of a system). Empirically derived models may also be used to predict system outputs given information about the inputs and processes. While a diverse number of systems have been successfully modeled, it is only recently that attention has turned to the engineering education system. To date, many of the empirical modeling applications in engineering education have focused on retention or performance [2–8]. Factors used in developing these models have included, but are not limited to: gender, race, geographical background, personality differences, and attitudes about engineering including self-assessed confidence and certain intellectual factors. At the University of Pittsburgh, we have developed logistic regression models to predict attrition and performance in our freshman engineering program using quantified measures of student attitudes [9]. Implementation of these models has allowed freshman advisors to better inform students of opportunities that engineering offers, devise programs of study that take advantage of students' varied interests, and set realistic retention goals. Further, our modeling of components of the engineering education system has helped us quantify, define, and evaluate relationships among student attributes, their educational experiences (in particular, innovative interventions), and now the educational outcomes.

For this research, we have developed, evaluated, and validated a pilot model of the engineering education system. While initially specific to industrial engineering at the University of Pittsburgh, we feel the model can be generalized to other engineering disciplines and settings. The model is based on the assumption that the educational processes that a student experiences (i.e. curriculum, in-class instruction, experience, etc.) are related to the graduate's engineering knowledge, skills, and attitudes. To do this, we hypothesized a conceptual model of the system using the engineering education literature in conjunction with input from working engineers obtained through focus groups. Using this conceptual model, an alumni questionnaire was developed to measure various aspects of the model. Alumni responses from the questionnaire then were used to evaluate and verify the conceptual model.

Here we first describe our modeling approach and discuss how the resultant model can be used for quality improvement. Second, through validation, we describe a pertinent finding—individuals who had pre-graduation work experience showed a more consistent and higher correlation between predicted and actual outcomes compared to those students who did not have pre-graduation work experience. As a result of this promising preliminary research [10], we are now using a combination of different empirical modeling techniques (e.g. regression analysis, discriminant analysis, and neural networks) coupled with the combined databases from this research, to extend this work to other the engineering programs.

DEVELOPING A MODEL OF THE ENGINEERING EDUCATION SYSTEM

The modeling approach described and tested in this paper consists of four major phases.

- Describing the conceptual model of the system based on a priori relationships between educational processes and outcomes.
- Applying the conceptual model to a specific engineering program to refine the hypothesized relationships between educational processes and outcomes. This phase includes defining components of the processes and outcomes and developing corresponding metrics, along with developing a data collection method.
- Empirically based model development and evaluation. This includes redefining aspects of the conceptual model to better reflect the data acquired and subsequent correlations. In addition, the large set of potential component variables is reduced to a more manageable set of variables. Regression analysis is then employed to identify relationships that exist among the process variables and the educational outcomes.
- The final phase consists of model validation. Each of these phases is described in detail.

Development of the conceptual model

In a manner similar to how Astin created the input-environment-outcome model [11] for higher education, a conceptual model of the engineering education system was derived for empirical modeling purposes. Though simplistic in its organization, its development was arduous. The components of the model are separated into the outcomes and those processes that contribute to the outcomes.

Development of the outcomes. The EC 2000 outcomes provide a thematic basis for what engineering students should possess upon graduation. It is the responsibility of the engineering programs to determine how to incorporate these themes after considering input from key constituents (e.g. students, faculty, employers who hire students, other engineering schools that accept students into their graduate programs). There are several approaches to involve these constituents: focus groups with discipline specific practicing engineers [12], surveys of alumni, focused discussions among faculty members, input from a program's advisory board, etc.

As noted our pilot focused on industrial engineering. To determine the knowledge, skills, and attitudes specific to industrial engineering, focus groups of practicing engineers from the Pittsburgh area were assembled to develop and define outcomes through the use of affinity diagrams [13]. Fifteen outcomes resulted, as shown in Table 1. These outcomes were markedly similar to those proposed by the ABET, but were specific to the needs of industrial engineers. (It should be noted that this process was begun independent of ABET and before the first publications of the draft EC 2000 criteria. Hence the similarity between our results and ABET indicate the robustness of these outcomes.) There were also three additional outcomes beyond those conveyed by ABET: Creative Thinking, Experience, Management Skills, and Project Management Skills. The focus groups then weighted the outcomes in terms their importance to an engineering education.

Table 1. Comparisons between the product outcomes derived and the draft ABET 2000 criteria

Product outcome variable	Product outcome definition	Draft ABET 2000 Program outcomes
Basic Science and Math Knowledge	knowledge in basic science (physics, chemistry, etc.) and math (calculus, differential equations, etc.)	A. An ability to apply knowledge of mathematics, science and engineering appropriate to the discipline
Engineering Knowledge And Abilities	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
Discipline Specific (IE) Knowledge	knowledge and abilities in discipline-specific subjects	K. An ability to use 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	K. An ability to use the techniques and skills necessary for engineering practice
Problem Solving Abilities	knows how to identify, formulate, collect data, conduct 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	
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	
Management Skills	has management skills, understands organizational behavior, and has leadership abilities	
Project Management Skills	knows how to set priorities/goals, coordinate tasks/projects, budget resources, and has implementation skills	
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 J. A knowledge of contemporary issues
Knowledge of Latest Technologies	knowledge of latest technologies and state of the art	K. An ability to use 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

Development of 'processes' associated with obtaining an engineering education. A review of the literature resulted in multiple 'processes' of the engineering education system [14–16]. The processes and their elements were then grouped, as shown in Table 2.

An additional process was proposed, culture [17], which was defined as the opinions, traditions, and practices of a particular engineering program or school. Such a process might include the faculty's or students' perception of the institution's commitment to education, the level of respect faculty demonstrate towards students, and/or the support and helpfulness of staff and faculty towards students. Culture also includes the learning environment, e.g., the level of competitiveness (positive or negative); the extent that team or group work is encouraged; and/or the permissiveness towards academic integrity [18–19].

Hypothesized relationships among outcomes and processes. As part of the EC 2000 implementation, programs must identify those strategies, activities, and processes that contribute to the learning outcomes. Because little literature exists that describes how educational processes are linked outcomes, a simple approach was taken to establish a priori relationships. Specifically, the hypothesized system processes were split into two categories: those that were considered to be *core* or *primary* to obtaining an engineering education, and those that were considered to either *enable* an individual to attend school and/or *enhanced* his/her engineering educational experience (designated here as enabler/enhancer). The resulting

Table 2. Educational processes associated with obtaining an engineering degree

Processes evaluated	Components or variables
Curriculum	Program development, course sequencing, course development, instructional capacity
In-Class Instruction	Teaching methods, materials, professor and teaching assistant training and qualifications
Learning Through Experience	Laboratory methods and materials, hands-on experiences, COOP, undergraduate research
Advising and Counseling	Job placement, student mentoring, career counseling, course counseling, honors programs, tutoring, instructional services
Management Support	Orientation, student assessment and admission, student financial aid, registration process and management, accreditation, administrative support
Student Growth Outside of Class	Engineering professional organizations (discipline specific, honorary, and special groups), study groups, student engineering contests, engineer's week, student growth outside engineering (athletics, clubs, student government)
Facilities and Equipment	Library, computer equipment and software, technical services (computer help, information systems like e-mail, technical writing and statistical help, etc.), bookstore

conceptual model [20] that describes these relationships is shown in Fig. 1. The core processes include the curriculum, culture, in-class instruction and experience. The student is integral to the core processes because he/she is 'who' the educational processes are directed at and contributes substantially towards achieving the outcomes. The curriculum and culture provide 'what' is delivered to the student, and the in-class instruction and experiences are 'how' or means by which the education is delivered. The enabler/enchancer processes include advising, student professional growth, engineering management support, program facilities, and university facilities. These processes support the core and the student, but do not directly contribute towards attaining the educational outcomes.

Program specification

Through the literature, we identified potential items or components for each educational process. Although the literature discussed a number of these components, further delineation was necessary for our application to industrial engineering. To illustrate, the process 'In-Class Instruction' included such components as teaching methods, materials, and instructor qualifications. The component 'Teaching Methods' was expanded to include classroom performance (i.e. organized and prepared, encouraged interaction, motivated students to learn) and attitudes of instructor (i.e. approachable, made oneself available to students); and the component 'Instructor Qualifications' was expanded to include not only competency in subject area,

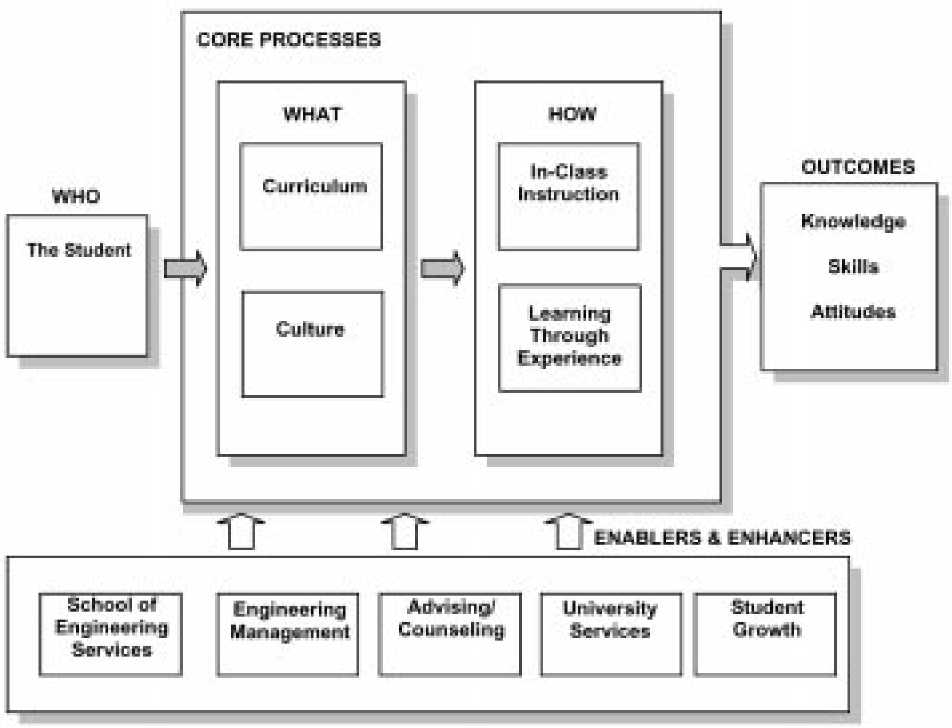

Fig. 1. Conceptual model of the engineering education system.

but also communication skills and understanding of the industrial environment.

Once each component was delineated in program specific terms, measures were developed. There are several ways in which a metric may be used to measure a particular component or process. Example metrics may include explicit scores (i.e. performance on the Fundamentals in Engineering, exams to assess an individual's mastery of engineering knowledge) or self-assessed attitudes (i.e. one's self-assessed ability to work in groups). The measure may also be more holistic, such as the assessment of a student's portfolio to evaluate an individual's communication skills. As faculty who are currently struggling with EC 2000 are well aware, choosing the best metric to describe a specific component is a difficult task. Often there is no one measure or set of measures that best describes a desired attribute. The preferred measure may not exist or may be too time intensive or expensive to obtain. Instead, substitute or surrogate measures must be sought in the interest of cost and time. We sought measures that: (1) would be consistent across all individuals, and (2) for which data could be collected for the desired processes and outcomes. To efficiently obtain data for the model, we chose to develop a closed-form questionnaire containing attitude measures that would highlight each of the desired components and outcomes. Although attitudes may not be the optimal measure for many processes and outcomes, they do provide an economical surrogate. (Part of our current research is directed at determining the extent that attitudinal measures can be used to assess learning outcomes.)

An attitudes instrument was developed during the spring and summer of 1995 and pilot tested using verbal protocols [21] followed by group discussion [22] with industrial engineering alumni from the University of Pittsburgh. The result was a concise, closed-form instrument with scaled responses that focused not only on asking individuals to provide their self-assessed competencies in their acquired engineering education outcomes, but also to reflect on their educational experiences as described by the processes and components. The alumni questionnaire is now available in a web-based version [23].

The instrument was mailed to over 1000 industrial engineering alumni from the University of Pittsburgh who graduated between 1970–1995. With one mailing, a 30% response rate of the entire population was obtained providing sufficient data to empirically build and validate the model [24]. The data were then split into two parts, one for model building and a separate portion for model validation and testing.

Because the questionnaire was sent to graduating classes as early as 1970, an analysis was conducted to determine if the response rate was consistent from year-to-year and between genders. The response rates were proportionally equal for both male and female alumni. However, the response rate for graduation years prior to 1985 was lower by thirty-five percent. This appeared to be reasonable as alumni graduating prior to 1985 may have not been able to reflect on their education to the extent that more recent graduates could.

Empirical model development

Two-part model evolvement and data reduction. By design, the model was to be described from the constituents' (i.e. the alumni who experienced the education) perspective. Since there were over 130 individual process-oriented statements in the survey, data reduction of these variables was necessary to feasibly apply regression analysis. Factor analysis was employed for the dual purpose of: (1) evolving the conceptual model to better reflect the alumni's perspective, and (2) reducing the number of process-oriented variables to a reasonable set for modeling. The objective of factor analysis is to reduce a set of inter-correlated variables to a smaller set of unobserved latent variables or 'factors,' whereby the variables within each factor are moderately to highly correlated [25]. Although the conceptual model may encompass the principal aspects of the education system, the particular processes and their components depicted in Fig. 1 and represented by the questionnaire statements may not characterize how alumni actually viewed the education system. Here, factor analysis was applied to the questionnaire responses to determine if there were other representations of the system from the 'customer's perspective.'

Because the process 'Experience' contained questionnaire statements that could only be answered by individuals that had some form of pre-graduation engineering experience (i.e. co-op, engineering internship, summer job, or undergraduate research), the data were split between alumni who had a pre-graduation work experience and those who did not. Since the enabler and enhancer processes were not specific to having pre-graduation experience, these processes were analyzed as a whole. BMDP Version 7.0 and its factor analysis routine 4M were utilized for this step. Variables were automatically assigned to a factor if the inter-correlation or factor loading was moderately strong ($\rho \geq 0.50$) [26]. Variables that had low inter-correlations ($\rho \leq 0.30$) or did not load to any one particular factor were eliminated from the study [27].

From the factor analysis, we found that the alumni differed in several areas as to how they viewed the processes of their engineering education. For this reason, the model(s) was split into two sub-models: alumni with such experience and alumni without this experience. Table 3 provides an example for the factor formed, 'Curriculum/In-Class Instruction—Relating Education to Industry' for alumni with pre-graduation experience. The example provides the questionnaire statements

Table 3. Example factor 'Relating Education to Industry'

Factor: 'Relating Education to Industry'	Pre-determined core process	Inter-correlation
Was up-to-date with the practices in industry	Curriculum	.774
Competency in the subjects taught	In-class Faculty qualifications	.730
Was fitting with the needs of industry	Curriculum	.720
Provided an in-depth education of the areas within the industrial engineering discipline	Curriculum	.685
Excelled beyond industry practices	Curriculum	.683
Understanding of the business environment	In-class Faculty qualifications	.643
Provided a broad education of the areas within the industrial engineering discipline	Curriculum	.616
Used practical examples	In-class Faculty performance	.601
Taught how to apply knowledge and skills to new contexts	In-class Faculty performance	.562
Provided a foundation to want to learn more	Curriculum	.526
Showed organization/preparedness in the classroom	In-class Faculty performance	.517
Motivated students to learn	In-class Faculty performance	.510
Communication skills with students	In-class Faculty qualifications	.504
Provided a foundation for future learning	Curriculum	.499

and their inter-correlations to the particular factor formed.

A single statement was selected to best represent each factor. (The purpose for choosing a single statement to represent the entire factor was to minimize the number of variables used in the model, as well as reduce the number of statements on future questionnaires. An alternative approach is to construct factor scores. That is, the factor inter-correlations are used in combination with the questionnaire responses to create a normalized 'weighted' score. The resultant factor score measures are largely free of measurement error and other individual differences among the respondents. In comparing the two methods, measures formed using factor scores have less variability than single questionnaire statements. However, more questionnaire statements are needed to form the factor score than in selecting a single statement to represent a key measure of the factor.)

Regression analysis and the results of the factor analyses were used to select a single key statement to represent the formed educational processes. With few exceptions, the statement with the highest loading was selected to represent the factor. Including the enabler and enhancer processes, 19 variables were used for the models for alumni with pre-graduation experience; 20 process variables were used for alumni without pre-graduation experience.

Relating process variables to outcomes via regression modeling. Two sets of 15 separate regressions (one for each outcome) were used to establish relationships among the process variables and the product outcomes for the two categories of alumni—pre-graduation work experience and no pre-graduation work experience.

To determine the goodness of the relationships, several indicators were used to help select the best model: the coefficient of determination (R^2), the adjusted coefficient of determination (R^2_{adj}), and Mallows' C_p criterion [28]. The R^2_{adj} statistic adjusts for the number of parameters in the model and Mallows' C_p considers the impact of both overfitting and underfitting the data. A C_p value equal to or lower than the number of parameters in the model is desired.

Table 4. Two example resultant regression models for alumni with pre-graduation experience

Product outcome	Coeff	Engineering education process variables	N	R^2	R^2_{adj}	C_p
Basic science & math knowledge	.96	Intercept	69	.45	.39	2.76
	.16	Overall self rating as a student				
	−.14	Admin. Respect towards students				
	−.12	Senior proj. increased oral communication skills				
	.24	Work exp helped me to communic. w/ others				
	.22	Job/career placement services				
	.16	Advisor made concrete/directive suggests				
	.35	Classrooms—maintenance and care				
IE specific knowledge	2.17	Intercept	68	.58	.52	5.54
	.16	Curriculum was fitting w/ needs of industry				
	.24	Overall self rating as a student				
	.19	Maturity level as began school				
	.13	Faculty encouraged students to work together				
	−.37	TA's were committed to their assign				
	.21	Senior proj. applied my prob solv ability				
	.12	Computer facilities—availability				
	−.16	Professional activities—personal develop				

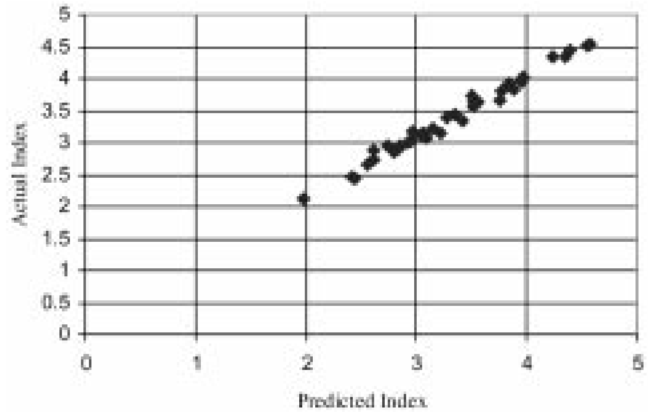

Fig. 2. Predicted versus actual indices for alumni *with* pre-graduation experience.

Table 4 provides two resultant model regressions, *basic science and math knowledge* and *IE-specific knowledge* (both for alumni with pre-graduation experience). As the table shows, for each outcome, the resultant process variables are given with their regression coefficient and their associated R^2, R^2_{adj} and Mallow's C_p. In general, the core process variables exhibited stronger correlations with the outcomes than did the enabler/enhancer processes, thus confirming our initial assumptions about the conceptual model.

MODEL VALIDATION RESULTS

Insights on the differences among those who had work experience versus those who did not

Validation is a critical final step in developing the models. Although many of the regression models explain a large portion of the variation around the outcome, they may not necessarily serve as good predictors of the outcome.

To validate the predictive performance of the derived models, the reserved data was used to obtain 'predicted' outcomes that could then be compared to 'actual' alumni responses. Rather than compare all 30 models, a weighting scheme developed by focus groups of practicing engineers was applied to both the predicted and actual outcomes to arrive at an overall predicted index and an actual index.

For alumni with pre-graduation experience, the predicted index was found to be an extremely strong indicator of the actual index (coefficient of determination equaled 0.99), as Fig. 2 demonstrates. In addition, no significant differences between the predicted and actual outcomes for each of the fifteen individual outcomes were found.

However, for alumni without pre-graduation experience, the relationship between the predicted index and the actual index was not as strong (coefficient of determination of 0.42), as Fig. 3 makes clear. Although the regression did not yield a strong correlation between the predicted and actual indices, results of statistical test indicate that the distributions of the fifteen individual predicted outcomes were not significantly different from the actual outcomes.

Because the individual predicted outcomes were not significantly different from the actual individual outcomes, the outcome models were taken as suitable to predict an individual's outcome competency based on information about specific processes or educational experiences.

As a whole, for the overall quality index the pre-graduation work experience model clearly shows a consistent, high correlation between the predicted and the actual outcomes. Not only do the results

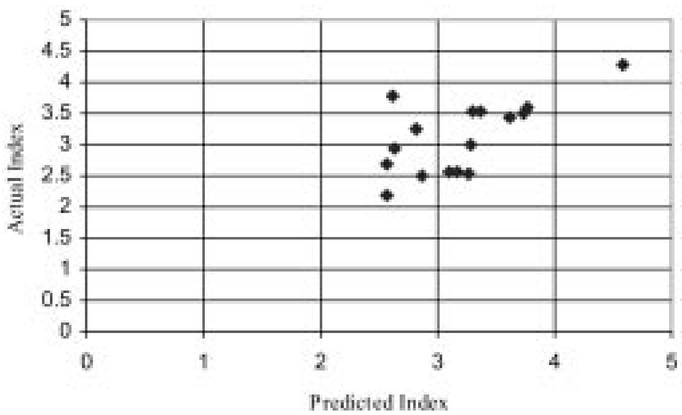

Fig. 3. Predicted versus actual indices for alumni *without* pre-graduation experience.

shed light on the validation of these models, they provide an insightful assessment. First, it is clear that alumni who had pre-graduation work experience (e.g. formal cooperative education experience, an engineering related internship or summer job, or an undergraduate research experience) have a more consistent view of their education compared to those students without such experience. Further, there is a considerable range in the quality index among these alumni with pre-graduation work experience as Fig. 3 shows; this confirms the robustness of the index. Knowing that the alumni with experience are less varied in how they rate their engineering education, allows faculty to focus more clearly on target areas for improvement, specifically those that the alumni rated low.

Second, the factor analysis conducted on the model found that alumni differed primarily on how they perceive the Curriculum and In-Class Instruction processes. Alumni with pre-graduation experience perceived curriculum and in-class instruction as one process, whereas engineers without pre-graduation experience saw these as separate entities. This finding suggests that alumni who had pre-graduation experience view their education in a much more holistic manner, rather than being simply a set of courses delivered by different instructors.

Currently approximately 86% of the undergraduate industrial engineering students participate in the formal accredited CO-OP program at Pitt, 25% have participated in an undergraduate research experiences, and 31% have had an engineering internship or summer job. (Roughly 38% of the IE students have participated in two or more of the mentioned work experiences according to our *University of Pittsburgh Senior Exit Survey* of students graduating between 1998 and 1999, thus accounting for the greater than 100% figure of pre-graduation experiences.) By encouraging undergraduate engineering students to obtain significant work experience as part of their education, Pitt students receive a more complete educational experience that is consistent with their competencies. Although it is a volunteer program, approximately half of the engineering graduates earn the Cooperative Education Certificate.

USE OF THE MODELS FOR EC 2000 EVALUATION

In addition to the insights gained from the differences between those individuals who had work experience and those that did not, models such as the ones developed here can be used to predict how well individuals or cohorts of students should achieve individual outcomes. Also, through an overall index, the quality of an engineering program can be assessed given the unique strengths and weaknesses of individual students. Each of these uses is discussed below.

Determining the predictability of the model and its use in EC 2000

For many of the resultant outcome models as much as 40% to 60% of the variation could be accounted for by the process variables. Hence, many of the identified relationships also can be considered to provide reasonable predictive models for the engineering education system. Considering that both the engineering education system and the alumni population surveyed are fraught with large inherent variation, accounting for this amount of variation is noteworthy.

The outcomes that produced notable model relationships for alumni with pre-graduation engineering experience were:

- *IE specific knowledge* (outcome k)
- *Problem solving abilities* (outcomes b and e)
- *Creative thinking, Teamwork skills* (outcome d)
- *Professional traits* (outcomes f and i).

For alumni without pre-graduation experience, reasonable regression models were created for:

- *Knowledge of latest technologies* (outcome k)
- *Problem solving abilities* (outcomes b and e)
- *Engineering* ethics (outcome f).

Using the regression outcomes, one can then predict how well each student might achieve each outcome. Consider an individual, who had pre-graduation experience but who did not score 'high' on a particular outcome, say *IE Specific Knowledge*, as shown in Table 4. For the model *IE Specific Knowledge*, we can predict which of the independent or process variables potentially contributed to the poor resultant outcome rating. For this example, the above Table 4 indicates that the following processes influence *IE Specific Knowledge* outcome:

- How the curriculum fits the needs of industry.
- One's overall self-rating as a student.
- One's maturity level as he/she began school.
- How much the faculty encouraged students to work together.
- How much the teaching assistants were committed to their assigned duties.
- How much senior design project helped students apply their problem solving abilities.
- The availability of the computer facilities.
- Personal development from being involved in professional activities.

In analyzing the individual's ratings for the process variables, exceptionally low ratings for 'Overall self-rating as a student' may contribute to a low rating for *IE Specific Knowledge*, as well as a low rating of 'How the curriculum fits with the needs of industry.' If such processes are found to be receiving low ratings, then educational interventions can be introduced—thus providing a conduit for continuous improvement.

A quality index: weighting of the outcomes

In addition to predicting specific outcomes, the individual models can be combined to produce an index, or overall measure of a student's achievement of the outcomes. Such an index may serve as a measure of overall quality of education with respect to the 15 individual outcomes. In developing such an index it is important to realize that not all outcomes are equally important, and hence should be weighted appropriately. Using swing weights [29], the same focus groups that developed the initial outcomes were asked to weigh the outcomes based on their relative importance to receiving an engineering education. The constituents considered several outcomes primary to obtaining an engineering education and were all weighted highly and equally important (weights are shown in parentheses):

- Basic Science and Math Knowledge (9%)
- Basic Engineering Knowledge (9%)
- IE Specific Knowledge (9%)
- Problem Solving Abilities (9%).

Also highly emphasized by the focus group members were:

- Communication (8%)
- Teamwork (7%)
- Experience (7%).

The index provides a valuable measure in examining a student's overall achievement with respect to the EC 2000 outcomes. Each student who pursues and obtains an engineering degree is unique in his or her knowledge, abilities, and attitudes. A particular student may excel in their problem-solving abilities and in their basic and specific discipline knowledge, but have had marginal engineering experiences. Another student may be an excellent communicator, have strong experience and IE specific knowledge, but may be lacking in their basic science and math knowledge. Averaging a student's overall outcome achievement by weighting the outcomes allows for differences in students' abilities while still identifying those students who may excel in the majority of outcomes as well as those students who may be doing poorly with regards to achieving particular outcomes.

DISCUSSION AND FUTURE WORK

As discussed, the purpose of this paper is twofold: to demonstrate an approach for modeling the engineering education system and describe how the resultant model(s) can be used for EC 2000 assessment and quality improvement. Although the conceptual model and the resulting empirical models presented provide one approach to modeling engineering student outcomes, their value is multifaceted. First, the overall model allows faculty to view the system from the perspective of the engineering graduates. Although many programs ask their alumni to provide feedback about various aspects of their education, rarely are alumni asked to review their education from a system's perspective.

Second, the models provide educators with knowledge of the relationships among those processes that comprise the system and the student learning outcomes. The modeling approach used here examined engineering education as a system where each outcome was a function of the hypothesized processes.

Third, from the validation of the overall index, we start to demonstrate the predictive nature of the models for quality improvement. Through both the factor analysis and the validation, differences between alumni with and without pre-graduation experience exist. The factor analysis results suggest that students with experience have an advantage in understanding how the curriculum and the instruction are connected. Students who do not separate these processes may view the instructor as an expert or a conduit to the knowledge and thus gain more out the course. Whereas, students that separate the curriculum from the instructor may not fully gain knowledge and skills from the classroom. In addition, even though the variables in both sets of models only explained a portion of the variation, the predictive capability for the model index produced for alumni who had experience was much higher than the model index for alumni without experience. This suggests that alumni who had experience were more consistent in how they viewed their competencies and educational experiences. Further, though not significant, alumni with experience tended to rate their knowledge and skill competencies higher than did alumni without experience.

The information that has been learned about these relationships and about the types of students who obtain an engineering degree allows us to target specific processes that will, in turn, have the greatest impact on improving outcome measures. For those outcome measures that did not yield significant relationships, it is possible that they are influenced by variables exogenous to what is being measured. More investigation is necessary about the processes that affect an individual engineering education.

The modeling approach and resultant models presented in this paper are still in their early stages. Much work is needed before these models can be fully implemented as part of an overall evaluation system. We are working towards developing additional models to predict engineering student quality. Such models include intermittent measures, e.g. attrition and probation [30–31], and the EC 2000 outcomes, similar to those described in this paper. However, several issues must be tackled before mature models can be used with confidence. Foremost, more complete data is needed about the system. The data used here was collected from one engineering department. In 1998, the alumni questionnaire was adapted to all engineering programs at the University of

Pittsburgh and was subsequently sent to the 1988–1997 graduating classes. The models presented here are being re-analyzed and modified given data from six engineering departments. A follow-up survey will be conducted in the summer of 2001.

Although the outcomes of the model were developed in part by practicing engineers, the processes of the model were taken primarily from the engineering educational literature. To make the conceptual model more representative, input on the processes and their components is needed from both practicing engineers and engineering faculty.

To achieve more effective real-time models requires collecting data at each stage of a student's undergraduate career and for different student cohorts, including those who drop or transfer out of engineering. We are currently collecting such data and are building models to consider and incorporate the longitudinal considerations [32]. We have developed and implemented companion instruments that track students throughout their undergraduate studies. These questionnaires are administered on a yearly basis and consider different aspects of a student's experience in a format complementary to the conceptual model.

Though we employed rigorous methods to develop, administer, and analyze the questionnaires, several issues arise with the use of closed-form questionnaires. First, the viability of self-assessments as metrics has been question by a few people [33]. Further, some research indicates that using self-reports (student and/or alumni) to evaluate programs may be questionable [34–36]. There are a number of evolving methodologies and instruments for measuring various student outcomes, such as authentic assessment [37–39], concept mapping [40–42], and portfolios [43–45] to name a few. Yet, most of these 'assessment' methods had not been fully evaluated, and many have yet to be implemented. As the models are further developed, other methods to obtain metrics need to be explored.

Although it is costly and requires careful (and at times tedious) development, modeling as an assessment methodology can play a significant role in an overall evaluation system. At several recent engineering education focused conferences [46–48], a number of methodologies and instruments for assessing various student outcomes were proposed. As the use of these evolving methodologies and instruments matures, a next step is to tie the information together into a system of models for engineering educators to make decisions in a more real-time or predictive manner. With the advent of EC 2000, it is only a matter of time before the use of modeling becomes of age.

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