Preparing Students for ABET a – k

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Abstract – **The ABET EC2000 guidelines present specific behavioral outcomes for engineering graduates, commonly referred to as "a-k." While some of these criteria are standard in traditional engineering education – engineering problem solving, scientific knowledge – others, such as life-long learning, group effectiveness, and social awareness, are more abstract. To meet these criteria, we must actively promote student development in knowledge, skills and behavior in these areas and measure the effectiveness of our instruction. Measuring student behavior in these areas and showing positive change as a result of the time spent in the educational program creates a major challenge for educators. To address this, the authors have explored various psychological models used to describe student development: intellectual and ethical development, belief systems, emotional intelligence, and learning styles. In this paper, these models are used to describe the student growth required to promote development toward the professional engineer as defined by ABET, as well as instructional approaches that can promote the desired student growth.**

Keywords – ABET, intellectual development, curriculum design, assessment.

INTRODUCTION

It is clear from the guidelines provided by ABET that the criteria for accreditation in EC2000 expect engineering programs to actively promote *development* in all professional phases of a student's life. [1] Entering students are immature novices with limited knowledge of the physical world, mathematics, and the skills for applying them to practical problems. By graduation, the student should have "acquired the knowledge, skills and behavior required for effective professional practice". ABET looks for the process of assessment that we use to measure that growth and the performance of the graduating student in eleven categories, commonly referred to as "a-k." (These will be discussed in detail later in the paper.)

In order to promote maximum student development, even the most effective instructional programs need to work continually to improve their instructional and assessment methods. Hence, ABET also expects all engineering programs to have in place a process for evaluating program development. As a management philosophy, continual development has been adopted by industry to optimize their production efficiency and product quality. However, it is not a strategy commonly used in designing and managing undergraduate engineering, so effectively meeting the criteria, as specified by ABET, will require a cultural shift in many engineering departments

This problem exists, in part, because assessment and evaluation in higher education are primarily summative (certification), rather than formative (improvement). A continual improvement program uses both forms of assessment. Formative assessment is used to provide continual feedback on effectiveness and is normally private, while summative is used for a public measure of level of competence. [2] Summative assessment, without formative assessment, can appear to observers as being critical and raise defensive attitudes among those being assessed. An effective formative assessment process insures good progress toward program goals, so that, when summative evaluation is performed, the results are predictable and affirming rather than threatening.

While measurement of student performance on some of the a-k criteria is common and fairly straightforward, other categories, such as life-long learning, working in teams, and social awareness ("professional skills") [3], are much more difficult to judge. And yet, given the projections for the future of engineering in *The Engineer of 2020* [4], it is clear that these areas are just as important as those traditionally emphasized in engineering education.

In this paper a process for constructing a curriculum that incorporates these less traditionally emphasized areas is outlined. A model of student cognitive and emotional growth in terms of knowledge, skills and attitudes is used to frame the discussion of ABET outcomes criteria (a-k). Based on this model, curriculum and courses are established by faculty teams.

WHO ARE OUR STUDENTS?

Measuring improvement requires that we be able to determine the starting level of our students and to use available tools to promote their development. If we are to document growth in all a-k areas, we need to understand what motivates student behavior and how development occurs. Who are our students?

I. The Belief System

As a starting point in describing our students, Rokeach [5] states that we each have a Belief System, consisting of:
- **Beliefs** about the physical, social, and spiritual realm, and our place in these realms

- **Personal Values**, or priorities, such as family, wealth, power, security, which are not subject-specific, and
- **Attitudes**, such as political and religious affiliation and opinions on social issues, which are shaped by our beliefs and personal values. Action, or behavior, is based on our attitudes. Repeated behavior becomes a habit.

The role of the belief system is to maintain and enhance our self-esteem in two areas, *competence* and *morality*. An open belief system accepts new information and revises beliefs and attitudes as appropriate. A rigid, or closed, belief system is reluctant to accept new information unless it is consistent with established beliefs and values. As children, our belief system was based on the early influence of parents, teachers and friends. It contains both cognitive and emotional memory, some accessible and some that is subliminal. A major goal of education, then, is to promote the development of an open belief system, which will entertain challenges to unexamined assumptions about the world around us.

Historically, this has not been the explicit goal of engineering education. Traditionally, engineering education has defined our responsibility as instructors fairly narrowly, to provide the knowledge base and skills required to solve technical problems. The other aspects of the student's life have been included in the liberal education portion of the program.[6] ABET now holds us – the engineering educators – accountable for preparing the student in all aspects of her/his role as a citizen and scholar.

II. Intellectual and Emotional Development

Cognitive Development: In his book, *Ethical and Intellectual Development in the College Years* [7], William Perry describes the personal developmental journey of the college student (as an "ideal-type") in three phases: (1) Starting as Dualistic thinking, in which everything is black or white and there is an Authority with all the right answers; through (2) Multiplicity, where there are several opinions but not an effective method for finding the best answer; to (3) a mature stage, where all "best" answers are Relative to the Context in which they are addressed, and the responsibility for finding the optimum solution resides with the individual. Authority, with a small "a", is a source of information and opinion.

Perry states that progress along the developmental journey is not just the result of growing older. There must be appropriate challenges to unexamined assumptions about critical issues. Those who meet the challenge and grow from the effort, look back later to see that their earlier simplistic opinions are no longer adequate. Based on Perry's model, the mature professional has the following characteristics:

- Has mastered a body of knowledge and corresponding skills central to a field of practice
- Exercises good judgment in making decisions
- Uses authority as a source of expertise
- Is willing to take risks and assumes responsibility for decisions

- Is capable of thinking critically, contextually, and complexly
- Uses reflective thinking and self-evaluation
- Has an effective and socially responsible value system

This list maps well onto the ABET a-k outcomes and the profile described in *The Engineer of 2020*.

In addition, according to Perry, growth occurs in major steps in response to challenges, followed by periods of stabilization. He found that students could not comprehend concepts that were more than one level above their functioning level on his nine-step scale. He also determined that a person cannot skip steps in development, but they can stagnate at a point where the challenge is too great.

The goal of liberal education is to structure those challenges so as to encourage student growth through the Multiplicity stage. By contrast, much of the instruction in technical programs is Dualistic in nature. The instructor is the Authority who knows the right answers, which can be found at the end of each chapter. There is little time for, or interest in, exploring alternative solutions or answers. Design, which is more open-ended, can be a real challenge for students and faculty. Design is the basis for most technical curricula that are structured to actively promote intellectual development through stages such as those described by Perry. [8]

Emotional Development: While Perry's scheme is based on cognitive development, the individual student's process of addressing the intellectual challenges is a very emotional experience. To better understand the emotional dimension of the student, Goleman [8] describes current brain research on the interdependence of emotions and cognition. His model of emotional intelligence, EQ, is being used by industry to evaluate employee performance and design professional training programs. The five dimensions of EQ are:

- Self-awareness (knowing your emotional state)
- Self-regulation (controlling personal behavior)
- Motivation (delaying gratification, persevering)
- Empathy (feeling other peoples emotional state)
- Social Skills (leading, responding, shaping relationships)

EQ has been shown to be twice as important as IQ in job performance and increases in importance as the individual progresses to higher levels of management. [10] Primal emotions and beliefs can trigger inappropriate responses unless the emotions are properly regulated by rational thought. In contrast to IQ, which is fully developed by the age of 10, EQ can be developed continuously throughout a lifetime. Studies of the U.S. youth culture have documented a decline in emotional competence since the 1970's, resulting in inappropriate social behavior and a lack of the discipline needed for effective scholarship. In response, schools are developing "self-science" programs to promote improved emotional competence. [11] Clearly, higher education should also promote development of emotional competence if its graduates are to succeed in the professional world

Goleman describes the optimum emotional state as "flow", in which all the mental energy is directed towards a task.

Athletes talk about being "in the groove". Research has shown that effective students are in a state of flow, which is described as akin to mild ecstasy, 40% of the time when doing their homework. Average students are in flow about 15% of the time. Helping students to learn how to move into flow to "engage" in their studies prepares them for effective performance in their professional careers. [12]

III. *Motivation to Change (Grow)*

Levels of motivation: If student growth beyond the simple acquisition of new knowledge is to occur, there must be a strong motivation to change. The typical entering freshman will put social acceptance and financial stability ahead of academic achievement. High school instruction prepares the freshman for learning through multiple-choice tests but not to deal with the complexities of college instruction. Our challenge is to create courses that engage the students in learning so that they move toward the mature professional upon graduation.

Galbraith [13] describes four levels of motivation:
- Coercion (prisoners, military boot camp)
- Remuneration (more pay, more work)
- Identification ("be a member of the team")
- Adaptation (change the system for improvement)

In the academic world, grades serve as a form of remuneration. Notice that the three lower levels involve extrinsic motivators. Only adaptation involves intrinsic motivation. When a student is totally engaged in his learning, when he is in "flow", true learning and change can occur. This is frequently referred to as deep learning, as opposed to surface learning, which is sufficient for passing the next test but has no long-term effect on the student's performance (behavior). The total engagement of deep learning can result in major steps in response to a challenge, an *educational marker*, where the major growth step Perry describes can occur.

Marker Events: In *Seasons of a Man's Life* [14], Levinson describes a marker event as one that "… has a notable impact on a person's life. …They change a man's life situation and he must cope with them in some way." We have found that most people have experienced educational markers that influenced their educational and personal development. [15] The marker could be an academic course, a special instructor, a project, or some other activity. Educational markers have the following characteristics:
- Stand out in the memory
- Provide insight and new meaning
- Can be positive or negative
- Are the basis for new growth
- Cannot be forced but can be programmed
- Involve a concrete experience and reflection

By designing educational activities for use in a course that have marker potential, we enhance the possibility of real personal growth and stronger retention of the class material. The marker potential is strengthened when there is preparation for and reflection on the key activity. Reflective thinking is a critical element of any growth experience. The instructor plays a key role as mentor in the reflective process.

Appropriate levels of challenge: Perry states that most effective learning occurs when the student is working in her "pleasure zone", between "panic" and "boredom". For flow to occur, the task must be challenging, but achievable. Outside the pleasure zone, the student is not likely to be engaged in the learning process. New information and skills can only be retained if they relate to prior knowledge and skill levels. Information learned out of context cannot be used as a base for acquiring new knowledge.

Preferred Learning Style: Each of us has a preferred method of learning. When this method of learning matches the method of instruction, we tend to learn more successfully. Helping the student learn how she learns and when she is most effective is useful in expanding her learning options. Instruments such as the MBTI and Silverman and Felder's LSI can be used to help the student understand a preferred mode of learning. [16] It can also help the student learn how to expand her learning modes to accommodate the instructor's approach to teaching. This increases the student's potential for academic success and motivation to learn.

IV. *Assessment in Student Development*

Formative assessment is a critical component of effective instruction and student learning. It is an integral component of moving into "flow". Continual feedback helps the student assess his performance and direct his energies in maintaining the effective effort. Graded homework or access to the answers allows a student to determine if he is on the right track. [17] A carefully graded term paper, with comments, promotes improvement. Rokeach describes the elements of feedback that help promote change and growth. [5] The feedback should:
- Appeal to the student's curiosity
- Be potentially useful in improving competence and morality
- Be unambiguous
- Be credible and logically correct
- Arouse self satisfaction by validation or dissatisfaction by raising doubts
- Be within the range of possible action, and
- Minimize ego defense

Our students have added "be timely" to this list.

Summative assessment is useful in establishing a final grade, but it does little to promote growth. It is the feedback on assignments during the term that influences the student's learning of the material and her development of the skills required to use it.

To summarize, each of us has a belief system. In an effective learning environment, the belief system of the student grows as it acquires new knowledge, new skills and

diverse attitudes toward the world. The mature, responsible professional will have a belief system such as described by Perry. Cognitive and emotional growth are critical to developing the mature belief system of an effective professional. A carefully designed educational system provides appropriate challenges and feedback to keep the student engaged in the developmental learning process.

TABLE 1
REORGANIZED ABET a-k CRITERIA

Outcome Criteria	Knowledge	Skills	Attitudes
a. Apply knowledge of math, science, engineering	**Applied science**	Comprehend technical literature	Value rigorous technical knowledge
e. Identify, formulate & solve engineering problems	Engineering approach	**Effective solution algorithms**	Desire to solve technical problems
k. Use techniques, skills & tools of engineering	Engineering tools	**Efficient, effective use of tools**	Need to assess limitations of tools
b. Design & conduct experiments, interpret data	Experimental method	**Laboratory techniques**	Empirical stance
c. Design a system, component or process	Design methodology	**Design process, creativity**	Open to risk and uncertainty
d. Function effectively on multidisciplinary teams	Team dynamics	Interpersonal communication	**Valuing others opinions**
i. Ability & desire to pursue life-long learning	Preferred learning style	Self-directed learning	**Self-improvement**
g. Communicate effectively	Forms of communication	**Writing, public speaking**	Clarity & understanding
f. Understand professional, ethical responsibility	Principles of ethics	Analyze situations responsibly	**Personal responsibility**
h. Broad education to understand social context	History & social science	**Use of multiple perspectives**	Social responsibility
j. Knowledge of contemporary issues	Political & social issues	Evaluating critical issues	**Objective analysis of issues**

STUDENT PERFORMANCE AND ABET a-k

I. The ABET Outcomes Criteria, a-k

The ABET criteria, a-k, are given in Table 1. They have been reorganized into groups that reflect different types of intellectual challenge. While the *knowledge* associated with each category is fairly well understood, there are *skills* and *attitudes* required that are not as well defined. A working set of these is listed in the table. What we see as the critical challenge for each of the criteria is in bold type.

ABET is understandably vague in defining the specific knowledge, skills and behaviors it has in mind for the above criteria. At the same time, it is clear that the ABET study which led to EC2000, as well as the large number of other studies of engineering education, concluded that there is a core knowledge base that is unique to the engineering profession, as well as a set of skills needed to utilize it. And there are values that are fundamental to proper practice in the engineering profession. It is up to each engineering program to define them in terms of its program goals and develop measurable objectives for each course in order to accomplish the desired outcomes by graduation.

II. Orthobjectives and Perobjectives

Feisel [18] created two terms, "orthobjectives" and "perobjectives", to describe the relation between the knowledge, skill and attitudinal objectives. Orthobjectives are the orthogonal, but complementary, objectives resulting from knowledge, skill and attitudinal outcomes in a course or segment of a program. A well-designed course should have publicly stated attitudinal and skill objectives as well as knowledge objectives so that the student understands the purpose of the course. Perobjectives are overarching, reaching from the entering freshman to the graduating engineer. They help the faculty, as well as students, to look at the whole program and see where they are going.

To achieve the ABET outcomes requires a program with integrated objectives. Because our focus tends to be on subject acquisition in individual courses, we tend to overlook the interrelation needed to reach the skill and attitudinal objectives. Frequently, skill objectives are not well coordinated with the program design. For instance, at one time, we were instructed to have students perform some computer programming in every course, since building skill in programming is an important objective. Programming clearly made more sense in some courses than in others, but because we were not building the total program, we were redundant in this particular area and ignored others. In response to the overloaded curriculum, we tend to throw up our hands and say that there is not time to meet all these requirements. Simplistically, we assume we need one course for each objective. We understand that knowledge acquisition is sequential. We must lay a base of information upon which can be built more advanced information and concepts. The same is true for skills and attitudes. Competence in these areas must grow progressively and intentionally over the four years of the program. This results in a three-dimensional structure of objectives that progressively increases in challenge over the four years. Once the framework is developed, it is possible to determine in which course(s) and at what time each objective is to be addressed in the program.

Once a complete description of the program is compiled, with orthobjectives defining the interrelation between knowledge acquisition, skill and attitude development and perobjectives defining the rate of progress toward the desired outcomes, a plan can be designed for implementing the curriculum. The level of effort and time spent on a given objective depends upon its importance to the professional. In some cases, such as criteria **j,** knowledge of contemporary issues, practice in using the knowledge to solve specific problems may not be required. Conversely, the ability to

define, lay out, solve and evaluate the analytical solution to a technical problem (criteria **e**) is critical to the practicing engineer, so a considerable amount of time is spent on developing analytical skills.

Many of the skills and behavioral competencies required of the graduate can be built into existing courses, if appropriate activities and challenges are provided. For example, consider the concept of entropy. Compared with energy, entropy is an abstract concept that is difficult for students to understand. All engineers should at least understand the concept and be able to use it to explain irreversibility, direction of heat flow, etc. For those involved in designing heat engines or reaction kinetics, entropy must be a working concept that can be used in solving advanced problems. The special skills needed to solve those problems must also be acquired through practice at increasing levels of complexity. At the same time, entropy can be used to understand social and economic structures, environmental degradation, and the consequences of war. [19] Expanding the discussion to include the social impact of entropy can stretch the student's belief system. If this is an important objective for the academic program, then time for research and discussion on the social significance of entropy can be built into thermodynamics, or another appropriate course. In terms of preparing the engineer to deal with future professional challenges, this may be more important than studying all the power cycles.

III. Liberal Arts Courses

While such efforts can help students understand the social significance of engineering practice, it is in the liberal arts courses that criteria **f, h,** and **j** are addressed directly. Unfortunately, these courses are typically selected by the students on the basis of:
1. fitting within the available time slots
2. meeting general education requirements
3. not requiring too much reading or writing
4. individual personal interest
5. whether one's classmates are taking the course
6. importance for professional development

For this reason, neither the students nor engineering faculty treat these blocks in the curriculum with the respect they deserve. However, with a carefully designed set of behavioral objectives, it is sometimes possible to get liberal arts faculty to work with the engineering school to provide courses that further the goals of the total academic program. This is more likely to occur at institutions that are primarily engineering colleges, where most of the students taught by the liberal arts faculty are engineers, than at large universities.

INSTRUCTION THAT PROMOTES STUDENT DEVELOPMENT

The type of instruction used can have a profound impact on the way students use the information provided and how it supports their growth. Traditional lecture/recitation is an efficient manner for disseminating large amounts of information. The instructor can model the analytical techniques used to solve problems and the students copy the solutions into their notebooks. However, this puts the student in a dependent mode that does not encourage responsibility or independent thought. By contrast, the active environment created by cooperative learning promotes student responsibility, team building, and communication skills, while improving retention of concepts because the student becomes quickly engaged in learning the material. While there may be a reduction in the amount of material covered, at the end of the term, more is retained. Furthermore, the discussion within a cooperative group can bring up alternative approaches and solutions and allow the students to challenge the material presented by the instructor or text. [20] Structured controversy can be used with cooperative learning to challenge the students' primitive beliefs and build their problem solving skills. Cooperative learning more closely parallels the way engineers work in practice, so that it is valuable preparation for professional work. In the class, the instructor can move from being the "Authority" to a coach, helping students discover their own solutions. This type of instruction is especially beneficial in "design courses" that emphasize criteria **b** and also experimental courses where criteria **c** is emphasized.

Cooperative learning also supports the development of life-long learning skills. Orthobjectives, as developed by Feisel, illustrate how activities to promote self-directed learning (SDL) could be built into a course. Recently, we have studied the importance of SDL as a prerequisite skill for undergraduate student success in distance learning programs.[21] For life-long learning to occur, the individual must have the motivation to continue learning and the ability to manage one's own learning. SDL itself must be learned. It is critical in preparing our students for their professional careers.

The challenge to an instructor who is considering moving from lecture to cooperative learning is significant. Few engineering faculty have participated in a course taught this way. Standard textbooks are not written with this mode of instruction in mind. And it requires more effort to develop new course material when using cooperative learning for the first time.

There are numerous other instructional methods and tools which are common to the educational community but that are seldom used by engineering faculty. Problem based learning, social simulations, field trips, debates, design projects, etc. each have their special advantages in meeting desired instructional objectives. The optimum technique depends upon the goals of the instructor – and the entire curriculum. Doing this alone is daunting. With the help of colleagues, it is more feasible.

Instructional Development Teams

Building an effective instructional program requires significant up-front group planning. [21] The independent subcontractor model of instruction, where each instructor is

given a unit of instruction, a classroom and a group of students will not achieve the benefits ABET is seeking.

Using ABET a-k as a starting point, a faculty group should identify their program outcome goals. These can then be built into a matrix that provides steady development of knowledge, skills and professional values. Special courses and activities can be identified to meet specific objectives. While this is being done, the methods for assessing student performance, as well as program effectiveness, should be developed, so that assessment is an integral part of the program, not a necessary add-on at a later time.

Once the program is laid out, instructional teams should be assigned responsibility for various parts of the curriculum. For example, in a mechanical engineering program, one group might develop the instructional sequence on solid mechanics, another on thermofluids and a third on materials and design. Each team would consist of several instructors and would be headed by a senior member of the faculty. Each team would be responsible for developing the syllabus of each required course, selecting effective teaching methods and working together to build a series of courses to provide a smooth progression in the requisite knowledge and skills. Coordinated with the other teams, skill and attitudinal objectives are then built into the total curriculum so that, in a given semester, the students are given practice on the critical skills (writing, programming, analytical problem solving, etc.) and presented appropriate challenges to build the beliefs and values needed for effective practice. [22]

Once the curricular structure is in place, each team works for continual development of their respective course sequence using their own assessment plan. New teaching innovations are built in over a period of years with groups assuming responsibility for the new material and methods. This reduces the work and spreads the responsibility. With a formal team structure, cooperation and assessment can occur more naturally and effectively. And it is more fun.

There have been several attempts to create highly integrated curricula [23] in order to address the complex interaction between different disciplines, such as math and science, as well as skill and attitude development. In some cases this works well, but it has certain limitations. The more the integration, the more rigid the curriculum becomes. With a fully integrated syllabus, it is difficult to accommodate nontraditional students who are not on a regular academic schedule, and it creates problems for students transferring to other institutions to receive academic credit when the course syllabus does not fit common structures. However, it is possible to improve the effectiveness of any program by having instructors work together to coordinate schedules and work toward common behavioral objectives within the standard course structure.

SUMMARY

There is now adequate research data and program support for any institution to develop an effective engineering educational program that works toward meeting the ABET outcomes. The keys to success are:

1. understand your students, how they best learn, how they change as they grow, and what motivates them,

2. be willing to undertake a comprehensive redesign of the curriculum, based on behavioral objectives, and

3. incorporate a comprehensive assessment program to evaluate both student growth and program effectiveness.

The results of the effort will not only satisfy ABET: they will provide long-term satisfaction for both faculty and students.

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