Assessing and Developing Capabilities to Analyze Broader Contexts for Engineering Practice

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Abstract

Trends throughout the world require that future engineering solutions must address a broad range of opportunities and constraints. Many opportunities and constraints will emerge from non-technical facets of the contexts for the engineering solution: economic, environmental, social and global. Reflecting the importance of broader contexts for engineering solutions, ABET included the following outcome in its Engineering Criteria: "Graduates will have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." Despite the existence of the outcome for almost ten years, engineering programs have had difficulty in coming to grips with approaches both for assessing capabilities related to this outcome and for augmenting these capabilities in their graduates. The paper will offer potential learning objectives, assessment approaches, and instructional approaches related to the ABET outcome in the hopes that the suggestions will spark broader application and future research.

Introduction

Engineers perform their tasks within a broader socio-technical context. The importance of understanding the broader implications of engineering in social, global, environmental, and cultural contexts has long been recognized as engineering students take courses beyond engineering and science either before and/or during their undergraduate careers. However, the increasing rate of technological change and the increasing breadth and depth of the impact of technology on all areas of life and society have raised the importance of analyzing broader contexts of engineering solutions. For example, Oberst and Jones[1] document ten different factors increasingly connecting engineering practice with larger economic and social trends in the world. As a result, the Accreditation Board for Engineering and Technology (ABET) in the United States included outcome h in its list of program educational outcomes: "Graduates will have the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." Despite its existence in the set of program outcomes for almost ten years, engineering programs have had difficulty in coming to grips with approaches both for assessing capabilities related to this outcome and for augmenting these capabilities in their graduates.

Realizing the importance of assessment and instruction related to each of the ABET program outcomes, the Foundation Coalition (FC)[2,3], one of the Engineering Education Coalitions supported by the National Science Foundation (NSF), launched a project to assemble existing resources for assessment and instruction related to each of the eleven student outcomes. Resources included papers, instructional modules, and assessment instruments that engineering educators had written or developed. The project intended to synthesize the compendium of resources so that engineering educators might have easier access to resources that they might use in their classes to work on one or more of the program outcomes. Results of the project are being made available on the FC web site[4]. The proposed paper will examine results from the project and additional resources that are directly related to outcome h.

For outcome h, engineering programs must address the following questions:

- What observable student performances would demonstrate competence in this particular area, i.e., what must students be able to do in order to satisfy the outcome?
- How might evidence of student performance with respect to the outcome, while the student is still on campus[5], be acquired and analyzed in order to evaluate a program?
- How might student performance with respect to the outcome be improved? That is, what types of instruction are likely to result in improved student performance and what meaningful learning experience can contribute to the development of these outcomes in undergraduate students[5]?

The preceding questions may be addressed by presenting (1) learning objectives, (2) assessment approaches, and (3) instructional approaches. Brief descriptions of the three items are provided for readers who may not be familiar with the terminology used in this document.

Learning Objectives ABET student outcomes do not describe observable behaviors. Data can only be collected on observable behaviors; therefore, learning objectives[6,7] need to be formulated for outcome h in order to describe desired observable student performance related to each outcome. This paper offers sample objectives that might be associated with outcome h.

Assessment Approaches Moving from learning objectives to judgments regarding the degree to which the program is achieving its learning objectives requires relevant, appropriate, and informative data upon which judgments can be based. Prus and Johnson[8] described 15 different assessment methodologies, together with strengths and weaknesses for each methodology. There is no perfect assessment methodology, and evaluators often select multiple assessment methodologies to balance their strengths and weaknesses. Choice of the appropriate methodologies depends on many factors, including the goals and scope of the evaluation. For example, faculty members are usually interested in assessment of the courses that they are teaching as well as assessment of the program to meet the ABET accreditation criteria. Assessment approaches for course and program levels may differ, although there may be overlap. This paper offers resources that might be applicable to program assessment plans.

Outcome assessment is a method for determining whether students have learned, have retained, and can apply what they have been taught. Assessment plans have three components: a statement of educational goals, multiple measures of achievement of the goals, and use of the resulting information to improve the educational process. The results of outcomes assessment are part of a feedback loop in which faculty members are provided information that they can use to improve their teaching and student learning[9]. For example, after industry provides feedback on the co-op student or intern, faculty members and administrators can determine if their program and courses within the program are effectively teaching teaming skills and appropriately providing opportunities for students to practice teaming skills in class and on course projects. Designing a program-level assessment, collecting assessment data on an outcome, and analyzing the results may be complex and less objective than technical research; however, the goal is clear: to determine as reliably as possible if the objectives have been met and, if not, to what should be done to improve each student's educational experience[10].

Instructional Approaches The ABET a−k outcomes include technical and non-technical (or "soft") skills that faculty members are expected to teach and therefore measure. Improving performance with respect to skills, as opposed to transferring information, requires alternative approaches to instruction[11]. For example, research shows that students need to do more than take notes while listening in order to learn[12]. Woods et al.[13] showed that students do not develop problem-solving skills by (1) watching faculty members work problems, (2) watching other students work problems, or (3) working many problems (even open-ended problems) themselves. Instead, problem-solving skills are learned in a workshop environment. Seat and Lord[14] state that interaction skills (a subset of team skills) cannot be learned either by osmosis or simply working in groups. Interaction skills must be taught explicitly. Students need opportunities to develop and practice soft skills. Student-student interaction is an effective way to learn and is often neglected in the traditional lecture course[15].

Teaching critical knowledge, skills, and attitudes required for outcomes a−k must be student centered, where the teaching faculty members are viewed as coaches, facilitators, and guides in the learning process. Learning activities that reflect real-world situations must engage students in individual and collaborative problem solving, analysis, synthesis, critical thinking, and reasoning. New teaching and learning approaches that heighten practical learning and allow students to demonstrate the application of their studies to real-world situations must be put to use[16]. Hopefully, the paper will provide engineering educators with additional materials and resources for constructing assessment and instructional plans for improving the capabilities of their students to characterize the broader contexts in which they will be practicing.

Learning Objectives

Several projects have offered learning objectives. The most extensive project, Engineering Education: Assessment Methodologies and Curricula Innovation, was funded by NSF to create a set of assessment resources for engineering programs[17]. For each of the eleven program education outcomes the multidisciplinary, multi-institutional project team constructed a set of outcome elements. Then, they built learning objectives for all six levels of Bloom's taxonomy[18,19] for the outcome elements. For outcome h, the team identified on two outcome elements:

- Understand the impact of engineering solutions in a global context (where global is taken to mean to cross cultures and societies, example areas of impact include, but not limited to, environmental, political, and economic)
- Understand the impact of engineering solutions in a societal context (where societal is taken to mean issues associated with the groups of people and their beliefs, practices and needs)

Since the preceding project was completed before ABET extended outcome h from global and societal contexts to global, economic, environmental, and societal contexts, the project generated outcome elements associated only with global and societal contexts.

Notice the outcome elements do not encompass a second language. Many engineering programs in the United States have not required a second language as part of demonstrating that their students satisfy outcome h, Lohmann and Rollins[20] state that facility with a second language both orally and in writing is required for international competence. Questions about facility with a second language should be thoughtfully addressed in formulating a set of learning objectives for an engineering program.

Lucena offers the following learning objectives for a course entitled Engineering Cultures that

Downey (Virginia Tech) and he co-developed over a period of several years[21]. The course is being taught at both Virginia Tech (where it was first offered) and Colorado School of Mines.

- Understand and compare different models of culture and begin using a new model based on the concept of "dominant images" of what is an engineer? What counts as engineering knowledge? and Where are engineers expected to work?
- Describe and discuss engineering and its practitioners in the following cultural and historical contexts: 20th century United States, Japan, early 20th century Russia, Soviet Union, France, Britain, Germany, India, Mexico, Brazil, and Colombia.
- Define, discuss, and critically assess concepts related to engineering and culture, such as: economic competitiveness, corporate culture, dominant images, and technological tradition.
- Describe and provide examples of ways in which engineering, its artifacts and practices, can affect culture and how culture influences technological choices and practices.
- Understand and analyze elements of organizational culture such as categories of work, power, membership, ideology, rituals, emotional and cognitive role embracement and distancing.
- Understand how you can serve as a consultant to companies, governments, and peer engineers on facilitating cultural differences among engineers from different countries.
- Understand the contributions of studying the history of technology to your knowledge, social status, and the kind of work you might be doing after graduation.

While some of the objectives specify observable behavior (define, describe, critically assess) some of the learning objectives specify internal mental states (understand). In order to apply these latter learning objectives, educators must construct learning objectives that specify observable behaviors.

Another learning objective might be formulated through analogy with the work of Shuman et al.[22] who in their research on outcome f (graduates will have an understanding of professional and ethical responsibility) offered the following learning objective: “the ability to resolve those moral problems that arise in engineering practice.” In this case Shuman et al. started with another outcome that specifies understanding and have constructed a learning objective that describes behavior that can be observed by thinking of how engineering graduates would address situations that would require understanding of ethical responsibility. In this case, they argue that engineering graduates must do more than understand, they must formulate and then resolve the moral problem(s) raised within the situation. Regarding outcome h that is likewise stated in terms of understanding, learning objectives might be constructed by envisioning situations faced by engineering graduates that might require understanding of global, economic, environmental, and societal contexts, and asking what would be desirable for engineering graduates to do in these situations. In these situations, it seems desirable that engineering graduates would formulate various elements of these contexts into opportunities for constructive action, constraints that would constrain such actions, and guidelines that would aid choices of constructive action among alternatives that might be generated. Then, these three desirable behaviors might be offered as learning objectives consistent with outcome h.

- Given a situation involving an engineering solution, graduates would be able to formulate societal, environmental, economic, and global issues into opportunities for constructive action.
- Given a situation involving an engineering solution, graduates would be able to formulate societal, environmental, economic, and global issues into constraints on alternatives for constructive action.

- Given a situation involving an engineering solution, graduates would be able to formulate societal, environmental, economic, and global issues into guidelines and/or criteria for selecting among alternatives for constructive action.

Another set of learning objectives can be drawn from the literature on intercultural sensitivity[23–25]. Hammer, Bennett, & Wiseman[26] use intercultural sensitivity "to refer to the ability to discriminate and experience relevant cultural differences" and "argue that greater intercultural sensitivity is associated with greater potential for exercising intercultural competence" which they define as "the ability to think and act in interculturally appropriate ways". Bennett[27,28] has offered a six-stage (Denial, Defense, Minimization, Acceptance, Adaptation, Integration) model for the development of intercultural sensitivity and intercultural competence called the Developmental Model of Intercultural Sensitivity (DMIS).

Assessment Approaches

The previous section provided a set of learning objectives that might provide a useful starting point for programs seeking to build an assessment and evaluation plan for outcome h. Once a program has constructed a set of learning objectives, the next step would be to identify assessment approaches that might be used to collect data. This section offers alternatives for assessment instruments and approaches that might be considered when formulating an assessment and evaluation plan. Alternatives are offered to reduce the effort a program might expend to find options to be reviewed before formulating a final plan.

Intercultural Development Inventory

The Intercultural Development Inventory (IDI) was developed to measure intercultural sensitivity using the theoretical framework of the DMIS. Results on the reliability and validity of the instrument are available[26]. The IDI is planned to be used as one of the outcome assessment instruments in the National Study of Liberal Arts Education[29].

Multicultural Experience Questionnaire

The Multicultural Experience Questionnaire (MEXQ) is an instrument, which is under development, intended to measure "multicultural experiences and openness to diverse groups"[30]. About 70 students have taken the MEXQ, the Defining Issues Test (DIT)[31], and the IDI and scores from the three instruments have been compared[32]. Analysis indicates some common factors among the three instruments. Comparisons of the IDI, MEXQ, and DIT with measures of intellectual growth[33–35] could be a direction for future research. Both the IDI and MEXQ offer normed instruments that could be used to complement surveys in which students self report their confidence and/or competency with respect to some outcome elements related to outcome h. More widespread application of either the IDI or MEXQ in assessment of engineering programs is another potential direction for future research.

Capstone Design Project

The major design requirement in the ABET Engineering Criteria represents a tremendous opportunity to collect data related to student performance with respect to a number of the program educational outcomes. Once the initial direction a student project has been determined, the instructor might request an analysis of several elements of the economic, global, societal, and environmental context for the project. Students could be encouraged to integrate knowledge and skills from all of their previous courses, including courses in social sciences and humanities, as they prepare the analysis. To assist students in understanding how the analysis will be evaluated, the instructor might design a rubric to guide a systematic evaluation of the analysis. The rubric could be used both for peer evaluations of drafts of the analyses and for final grading of the analysis. Systematic collection and analysis of the data collected via the rubric across multiple major design projects could be used for program evaluation with respect to outcome h.

Summary – Assessment Approaches

Moore, Cupp, and Fortenberry[36] have conducted a wide-ranging survey of assessment approaches related to student outcomes. In their research, they have identified several assessment approaches that might be adapted for use with outcome h. These include self-report data from student surveys and interviews, student portfolios, and concept maps. However, from study of the available literature over the last two years, the author has concluded that there is a lack of published papers reporting assessment approaches related to outcome h. Additional work in this area would be a promising contribution.

Instructional Approaches

Unlike the situation with assessment approaches, innovative faculty members have developed a broad range of approaches that provide students many opportunities to increase their competence with respect to the learning objectives described in the previous approaches as well as learning objectives that have yet to be articulated. Felder and Brent[37] offer suggestions for general instructional approaches, problem-based approaches, and cooperative learning approaches for addressing each of the eleven student outcomes listed in the Engineering Criteria. In a survey of instructional and assessment approaches relevant to the "professional skills" outcomes, Shuman, Besterfield-Sacre, and McGourty[38] offer many innovative approaches to improving student learning with respect to learning objectives described in a previous section. Many of the innovative programs are combinations of language instruction, international experiences, and various types of projects. International experiences can include study abroad programs or internships in locations outside the student's home country. Projects have taken many different forms. Some projects are major design experiences with an in-depth analysis of the broader contexts for the project. Other projects involve teams in which team members are from two or more countries and much of the intra-team communication occurs through electronic channels. In other projects, student teams have untaken the challenge of addressing a challenge in a developing country using technology appropriate for the culture and context. Amadei[39] underscores the importance of these projects for addressing important needs and demonstrating the relevance of engineering practice for improving the quality of life for people in developing countries. Projects for developing countries have already launched programs at some institutions to support these types of projects and the trend may continue. Case studies that demonstrate the importance of addressing one or more aspects of the broader contexts of engineering solutions are another instructional vehicle for helping students explain the importance of envisioning the entire context. Acosta et al.[40] provide a case study where an American company purchased a manufacturing facility in Mexico. The first change initiative failed because of lack of communication with the workers in the plant, but management responded and the second attempt was more successful. Details, in this case details related to global, societal, and environmental contexts, that separate failed change initiatives from successful ones can provide valuable insights for students about the importance of broader perspectives.

Despite the obvious face value of the many of these projects, assessment of these projects has not often demonstrated improvement of the capabilities of the students who participated in the projects with respect to learning objectives that are related to outcome h. One reason for the absence of assessment for these projects is the lack of assessment tools with which growth in student performance might be assessed. So examples of instructional approaches also illustrate the value of future research in developing assessment approaches for student learning with respect to broader contextual issues.

Conclusions

Study of the available resources to support assessment and improvement of student performance with respect to outcome h of the program educational outcomes in the ABET Engineering Criteria has revealed an abundance of innovative instruction approaches and significant holes in published assessment approaches. Assessment of student understanding to evaluate the impact of engineering solutions in economic, societal, environmental, and global contexts is hampered by the lack of broad consensus on descriptions of the desired capabilities. One method of provide a description of the desired capabilities would be a list of learning objectives related to outcome h. Several alternative learning objectives have been offered to provide a starting point for programs looking to construct a set of learning objectives. While some resources for assessment approaches were provided, the paper suggested that broader application of existing resources and development of new instruments and approaches might be future research directions.

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