Teaching Engineers to Handle Uncertainty

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Abstract

One of the greatest challenges in engineering education is preparing students to handle the realities of their post-graduate workplace including challenges such as dealing with uncertainty and estimating data. This paper discusses the importance of educating engineering students to handle uncertainty and providing them with the appropriate tools to do so. Ongoing research is being conducted to develop educational materials to educate engineering students about the effects of uncertainty and how to handle uncertain data. The research plan is presented along with a literature review in this area.

Introduction

Several panel reports in the early 1990s claimed that undergraduate engineers lacked the ability to succeed in the real world (Bordogna, et al., 1993; ASEE, 1994; National Science Foundation, 1995; National Research Council, 1995). Around the same time, Condoor, et al. (1992) reported that students tended to primarily use subjective judgment in decision making as opposed to analytical techniques. The research project discussed in this paper addresses both of these concerns. The objectives of this research are twofold: 1) to assess the current state of engineering student abilities to estimate uncertain data parameters and 2) to educate undergraduate and graduate students in handling estimation uncertainty in the decision making process. These objectives will be met through pedagogical analysis, classroom instruction, and materials development. The primary researcher has experience in several prior engineering education research projects in the areas of design (Atman, et al., 1999), economy (Hartman, et al., 2001; Needy, et al., 2000b; Nachtmann, et al., 1999; Lavelle, et al., 1997), and management (Needy, et al., 2000a).

It has been recognized that one of the greatest challenges in education is to prepare students for the practical realities of their post graduation workplace (Shepard and Cosgriff, 1998). One specific challenge is to provide engineering students with the tools to handle uncertainty (Goyal, et al, 1997) and perform data estimation tasks that they will be faced with during their careers. Almost twenty-five years ago, it was recognized that the notion of risk and uncertainty inherent in real world business was not handled very effectively in education (Moore, 1997). In spite of this criticism, academia has failed to make tremendous strides in this area. Goyal, et al. (1997) believe that courses traditionally tasked with educating students in handling uncertainty do not provide students with sufficient tools for doing so. These courses, such as engineering economy, often present conditions that demand students accept input data as given so that solution methodology rather than data modeling is emphasized. Goyal, et al. (1997) argue that uncertainty and risk must be incorporated into engineering economy courses from the beginning in order to prepare students for real world situations that are fraught with both.

It is necessary that engineering students recognize and are able to handle: 1) the existence of the inherent uncertainty in all decisions, 2) how uncertainty affects the decision process, 3) the importance of valid data sources, 4) the lack of good data in real world decision making, and 5) the risk of not handling uncertainty during decision making. Engineering graduates are expected to not only be technically proficient but also skilled in real world issues (Raju and Sankar, 1999), such as decision making and handling uncertainty. Real world problems allow students to experience situations in the classroom that they may face in the future and help to bridge the gap between theory and practice (Bonwell and Eison, 1991). This research will contribute to the field of economic decision education by assessing student abilities to perform this type of analysis and by providing instructional materials for educators to use to better teach engineering students to perform uncertainty analysis and data estimation.

Pedagogical Analysis

This phase of the research will observe and document engineering students as they estimate uncertain data parameters. The participants will be freshman and senior level engineering students at the University of Arkansas. This will permit examination of student abilities as they progress through the engineering curriculum. Statistical and comparative analysis will be performed on the estimation performance results and self assessment, personality, and demographic information in order to compare student performance. The goal is to focus on students' higher order thinking abilities, such as estimation and decision making, through cognitive assessment including self assessment and personality testing (Merluzzi, et al., 1986).

Several research tools will be employed including: an Estimation Elicitation Tool, a Self Assessment Instrument, Personality and Risk Profile Exams, and a Demographic Questionnaire. These tools will be used to determine the effects of human characteristics and personality traits on estimation accuracy. Validation of all tools will be conducted through pilot administration and subsequent revision.

Estimation Elicitation Tool

The Estimation Elicitation Tool will be designed to elicit mathematical estimates from the engineering student participants. The tool will present several decision making scenarios and require subjects to independently estimate multiple data parameters with varying levels of familiarity and complexity.

Self Assessment Instrument

Students will complete the Self Assessment Instrument at the conclusion of the Estimation Elicitation Tool. Self assessment instruments allow students to critically judge the quality of their own work and their approaches to it (Andrade, 1999). It is important to design the self assessment instrument to encourage students to autonomously judge the success of their own performance (Haney, 1991). This will provide insight into the students' confidence in their estimation tasks.

Personality and Risk Profile Exams

Multiple tests will be used to examine the personality traits and assess the risk profile of each subject. Two personality tests that may be administered are the Myers-Briggs Type Indicator and the California Psychological Inventory. The Myers-Briggs Type Indicator reports on an individual's placement on each of four scales: 1) Extraversion-Introversion, 2) Sensing-Intuition, 3) Thinking-Feeling, and 4) Judging-Perceiving. The California Psychological Inventory places subjects in four categories: 1) social expertise and interpersonal style, 2) maturity, normative orientation, and values, 3) achievement orientation, and 4) personal interest styles. Both tests are widely used in practice and based on normative data. In conjunction with development of the Estimation Elicitation Tool, appropriate personality tests will be identified and purchased during the first year. Another tool, a Risk Profile Exam, will be designed to provide the risk profile of each subject and identify if they are risk-seeking, risk-neutral, or risk-adverse. The goal here is study the effects of personality type and risk profiles on the estimation process.

Demographic Questionnaire

A brief Demographic Questionnaire will be designed to collect descriptive information including demographics and scholastic achievement. Information such as gender, age, and grade point average will be collected and used to control for demographic differences among the students.

Classroom Instruction

The primary researcher currently teaches multiple courses in the areas of estimation and uncertainty including two graduate courses, *Cost Estimation Models* and *Decision Models*, and two undergraduate courses, *Advanced Engineering Economy* and *Industrial Cost Analysis*. The relevant content of these courses is discussed next.

Topics

The first step to educating engineers about uncertainty and estimation is to include relevant topics in the content of appropriate courses such as engineering economy. Example topics are as follows:

- Risk and uncertainty,
- Decision making,
- Forecasting,
- Parametric estimation methods,
- Sensitivity analysis,
- Monte Carlo simulation, and
- Fuzzy set theory.

Projects

Each course includes an open-ended term project on a course-related topic of their choice. The projects are completed individually or in small groups. Students are asked to select a project that focuses on a real problem in their work, research, or personal life. Each project consists of a written report describing the problem area, analysis, results, and recommendations. Literature reviews primarily consisting of refereed publications are undertaken. Projects are presented orally to the class.

The goal of the project is provide students with the experience of conducting real world analysis. This experience provides them with the opportunity to estimate data and handle uncertain data. In a survey of engineering economy educators (Needy, et al, 2000b), only 58% of respondents included projects in their coursework. Engineering economy educators should be encouraged to include projects in their courses to avoid conventional textbook education in these areas.

Case Studies
Case studies are used to complement traditional homework assignments. The importance of the case study approach to engineering education has been recognized as a method to overcome the use of over-simplified examples within the classroom (Chinowsky and Robinson, 1994). Introducing students to reality-based case studies allows them to appreciate real world applications of the course content. Case studies can be used to exemplify the importance of accurate data estimation and handling uncertainty.

Article reviews
Students are required to review and present a peer-reviewed article in a related course topic. In addition to providing a thorough overview of the article, the students are asked to address the following questions:

- What research was done,
- How was it presented,
- Did the results support the premise of the article,
- Was the argument convincing, or did more or better work need to be done, and
- How much of a contribution to the field it made.

These article reviews provide students with the opportunity to review and critique scholarly research in areas of estimation and uncertainty. In addition, insight into current research in these areas is obtained.

Other Courses
Modules from the above courses can be used in other courses within the curriculum. The concept of decision making under uncertainty is important and should be incorporated throughout the curriculum. Modules focused on uncertainty analysis and data estimation can be used in courses such as *Introduction to Industrial Engineering*, *Engineering Management*, and *Senior Design*.

Educational Materials Development

A long term goal of this research is to develop materials to enhance engineering student development in the areas of handling uncertainty and estimation. These materials include a textbook, casebook, and resource bank.

Textbook
Based on deficiencies of the existing textbooks in this area, it is a long term goal of the primary researcher to write a textbook in this area. It is expected that ongoing research and education activities will provide materials and a framework for the text.

Casebook

Multiple real world cases of handling uncertainty in decision making from ongoing research will be compiled into a casebook to accompany the aforementioned textbook. Chinowsky and Robinson (1994) discuss the importance of the case study approach to engineering education. These authors state that an important contrast between engineering education and the engineering profession is the use of over-simplified examples within the classroom. Increasing the use of case studies may lessen the gap between the education and profession of engineering economy.

Resource Bank Development

In a related project, the primary researcher is working in conjunction with the University of Pittsburgh, Pennsylvania State University, and Lehigh University to assemble an online resource bank for engineering economy related topics (Hartman, et al, 2001). Several topics including cost estimation, risk and uncertainty, and sensitivity analysis are directly related to this field. An online resource bank in these topics is planned for educators and researchers to use and will contain listings of books, articles, cases, and people in relevant areas.

Summary

The research plan for an ongoing project is discussed along with a review of the literature in this area. The objectives of this research are to assess engineering student abilities to estimate uncertain data parameters and to develop educational materials to improve engineering education in the areas of uncertainty and estimation. The goals of this research are to: 1) obtain knowledge of the current state of student estimation abilities, 2) improve education in handling uncertainty in the decision process and data estimation, and 3) develop materials in this area including a text book, casebook, and resource bank.

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