# AC 2010-479: TEACHING DECISION-MAKING IN ENGINEERING: A REVIEW OF TEXTBOOKS AND TEACHING APPROACHES

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# Teaching Decision-Making in Engineering: A Review of Textbooks & Teaching Approaches

## Abstract

Despite the importance of decision-making in engineering, only a limited number of studies investigate how to teach and learn decision-making skills in engineering. We conducted an in-depth content analysis of 1) first-year engineering textbooks and 2) instructional decision-support tools published in ASEE proceedings in the last decade. We discussed our findings in the light of research and theoretical frameworks on decision making. The examination of fourteen books that are commonly used as a textbook in first-year engineering courses revealed that half of these books discussed decision making usually very briefly or as one step in the design process. Twenty-nine percent linked engineering decision making to social and ethical issues (e. g., examination of engineering disasters and historical decisions that led to failures). In addition, two books (14%) discussed decision-making in the context of teams. The review of instructional tools and methods presented by engineering educators at ASEE conferences indicated that decision making is taught and studied in three different approaches: during design projects, using simulations, and through case-based teaching approaches.

## Introduction

In everyday life and at work people make many decisions. Doctors diagnose illnesses and prescribe medicine, teachers identify student knowledge and skills and develop appropriate learning activities, and engineers identify needs and develop technological solutions. From a broad perspective, decision-making can be defined as the act of choosing one option out of many alternatives[6 and 21]. Dwarakanath and Wallace[2] (1995) identified two types of decisions: the first type starts by generating several alternatives and a comparison of these against each other. The second type of decision-making process involves an evaluation of an alternative against criteria as it is generated. Engineering decisions generally require an understanding of systems and involves the goal of design optimization.

## Review of Research on Decision-Making

Prior research in people's decision-making processes[3 and 16] has been conducted with diverse professionals such as doctors[7], nurses[10], teachers[5], and engineers[20]. However, while much research has been conducted with professionals, studies focusing on the development of students' decision-making processes are limited. Interestingly, researchers in both engineering design (conducting research on practitioners) and engineering education (focusing on research in student learning processes) call for more research in this area[20and 22]. The National Science Foundation and the National Academy of Engineering (2001) also address the need for more focus on decision-making in the context of design.

Although limited, there had been recent studies and efforts on engineering decision making. For example, the on-line workshop, Decision-based Design, aims to inform engineering and design educators and to promote a dialogue around essential questions about engineering decision-making. Another prevalent project that explicitly focus on engineering decision-making was developed by the Missouri recovery program[17]. This project included a workshop that utilized Structured Decision Making (SDM). The SDM approach focused on complex decisions and the importance of uncertainties.

There are, however, few researchers who examined students' use of data or decision support structures to make design decisions[14 and 19]. Studies with first-year engineering students show they rarely use structured decision-making tools and tend to overlook critical information during the decision-making process[9]. Novice engineering students make decisions based on limited data and evidence. In addition, when novice designers use a decision support tool such as QFD, they do not always use them correctly[9]. At the senior level, students tend to collect more data and use these data to make decisions[19].

Various decision simulations have been developed and used for instructional purposes. For example, Blandford and his colleagues[1] used a computer based tool, Weighted Objectives Methods By Arguing with the Tutor (WOMBAT), designed to teach engineering students effective design decision-making skills. In this simulation, students select an artifact among six different designs of cars or televisions. As students make decisions, they are guided and challenged by an embedded tutor. Similarly, Ryan and her colleagues[14] used an on-line problem-solving portal as an assessment tool in an engineering economy course. Participants in this study were asked to select a mortgage plan and the computer program recorded students information gathering processes such as the number of information visits and time spent when gathering information. These researchers also tracked student actions such as accessing resources, making assumptions, and making a decision.

Other researchers focused on steps and stages when making decisions. Several researchers defined engineering design as an iterative decision-making process[2]. Similarly, the steps of SDM used in the Missouri River recovery program represent the design cycle[17]: (1) Define the problem; (2) Describe the objectives; (3) List the possible actions; (4) Predict the consequences of those actions in terms of the objectives; (5) Examine the trade-offs among the objectives to select the best action. Rangel et al[11], on the other hand, classifies decision-making into five stages: (1) representation of internal and external states and potential courses of action, (2) valuation of the different courses of action, (3) selection of the action with the highest value, (4) outcome evaluation and (5) using the evaluation of the outcome to guide future learning. Researchers also investigated the group decision-making processes. Interesting finding include the importance of discourse and argumentation in relationship to quality decisions[15].

Despite these tools and research studies, specific tools and decision theories are rarely explicitly discussed in practice or in engineering textbooks. Engineering decision-making is taught implicitly using learning by "doing" approach, as part of introducing design and problem solving early in students academic career in college. Blandford, Cross, and Scanlon[1] argue that the model of learning decision-making skills by "doing design" is limited and that students should be taught how to use the most appropriate decision strategies. Other researchers also argue for the use of explicit decision support methods such as Quality Function Deployment (an application of multi-attribute utility theory for choosing among designs) or similar decision strategies, such as Pugh's chart[8 and 18].

Despite the importance of decision-making in engineering, a limited amount of studies investigated how current instructional materials address decision-making. By comparing the knowledge of decision-making which is used in the engineering program and provided in the textbook, this study was designed to answer this question: how first-year engineering textbooks address engineering decision-making?

## Content Analysis of First-Year Engineering Textbooks

### Research Questions

1. How do introductory engineering textbooks cover engineering decision-making?
2. What are various ways decision-making skills are taught by engineering educators?
3. What criteria help evaluate and compare instructional tools and strategies designed to teach decision-making?

### Method

Content analysis, a qualitative research method, was used in this project. Excel was also used to organize code and analyze the data.

#### Data source.

We analyzed fourteen first-year engineering textbooks which are currently commonly used in the first-year engineering courses. ASEE conference papers published in the last decade were reviewed. Twenty-two papers that focus on decision-making were selected for an in-depth analysis.

#### Textbook analysis.

The content analysis of the textbooks included seven steps: 1) index search, 2) content search, 3) coding, 4) grouping, 5) categorizing, 6) calculating, and 7) recapitulating. The analysis started by examining preset keywords in the index and then in the book. These keywords were determined based on relevant literature. For example, the researcher looked up the word "decision-making" through the index, went to the page according to the index and put a note which documents all keywords found in the certain page. Then the researcher recorded the keywords in the excel file and calculated the frequencies.

Next, the researchers begin the process of coding the textbooks, which involved identifying text segments, placing a bracket around them, and assigning a code word or phrasing that accurately summarized the meaning of the text segments. After coding the entire relevant text, we made a list of all code words in an Excel file. During the process, the number of codes increased. After coding and documenting, we grouped similar codes and looked for redundancies. The researchers took the new and expanded code words and repeated the whole process.

**Review of Instructional Decision-Support Tools**

Sixteen ASEE proceedings published in the last decade were selected and reviewed. The selection was based on the focus on decision-making, such as papers with decision-making as part of the title or keywords.

**A Framework to Support Curricular Decisions**

After an initial review of those papers, three categories were identified to compare the sixteen papers as shown in the Table 1.

Table 1. Decision Context and Support Tools

| | |
|---|---|
| **Decision Context** | ❑ Case-based<br>❑ Design-based<br>❑ Simulation-based |
| **Decision-Support Tools** | ❑ Software<br>❑ Case Study Discussion (CSD)<br>❑ Data & Evidence<br>❑ Decision Matrix<br>❑ Decision Trees |

**Results**

The analysis of textbooks revealed that seven out of fourteen books (50%) discussed decision-making (See Figure 4). These books generally referred to decision-making very briefly. Most of these books included decision-making as one step of the design process. While references to decision-making were brief in most books, two of them (14.28%) presented decision-making concepts relatively systematically. There were differences between books in how they discussed decision-making. For example, two books (14.28%) linked engineering decision making to social and ethical issues. These books discussed engineering errors which resulted from poor decisions as well as the consequences of these decisions. Two out of fourteen books (14.28%) discussed decision-making in the context of teams. One out of fourteen books (7.14%) introduced the utility theory. This theory is commonly used in decision-making research not only in engineering design but in other fields as well. Two books (14.28%) discussed decision-making in the context of cost analysis and economics.

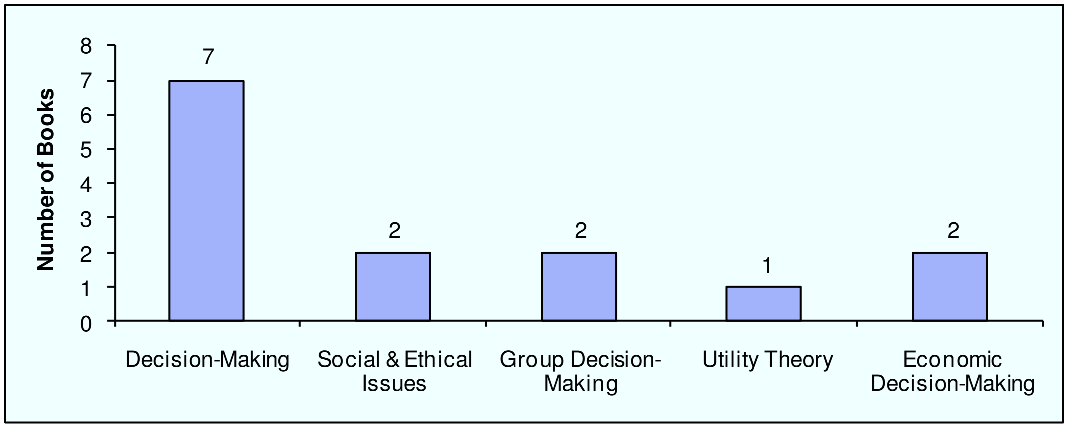

Figure 4. Categories Represented in Textbooks

These results indicate that current first-year engineering textbooks do not put a significant emphasis on engineering decision-making. This finding, however, does not mean that engineering decision-making skills are not taught to first-year engineering students.

To identify how engineering educators teach decision-making skills, we examined the papers published in the ASEE proceedings in the past ten years. This analysis showed that three different strategies are used to teach decision-making skills. The most common method of teaching decision-making was by emphasizing decision-making skills in the context of a design project (See Figure 5). Next, educators used case studies that involve ethical or economical decisions. Two studies used simulations (computer-based or board games) to teach decision-making skills and processes. Various decision support tools are used as part of the instructional materials. These include the use of data and evidence in supporting decisions, case study discussions, use of software, as well as decision trees and matrices (See Figure 6).

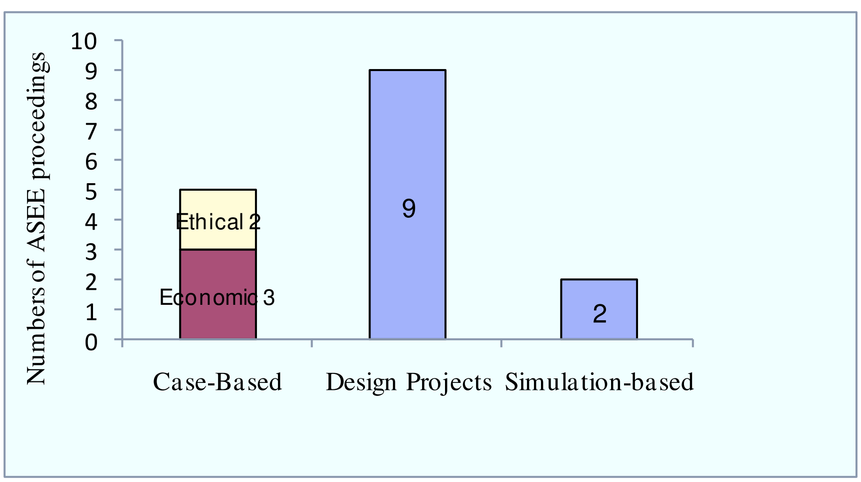

Figure 5. Categories Represented in the ASEE Proceedings

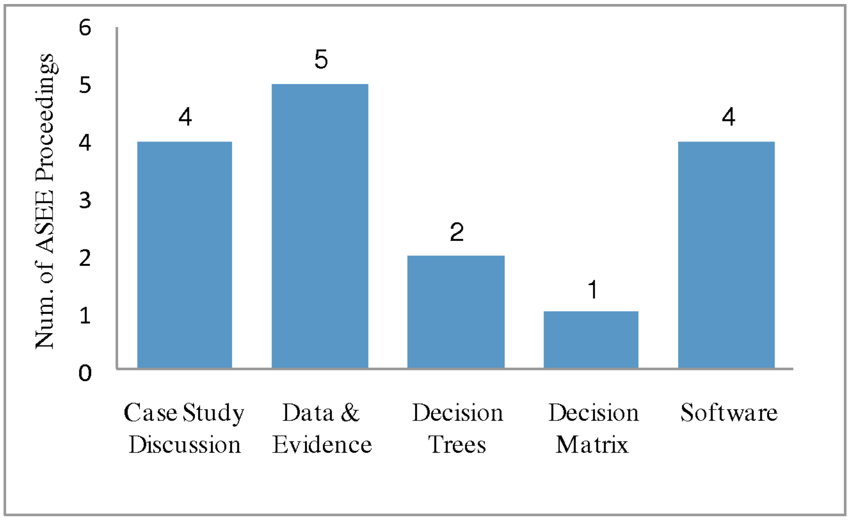


Figure 6. Decision-Support Tools Used in ASEE Proceedings

## Discussion

This paper is a first step of a series of future studies on learning and teaching engineering decision-making. As a starting point, we examined how engineering decision-making is addressed in engineering textbooks and engineering education studies. This analysis as well as the literature review showed there is more work to be done on decision-making so that effective curriculum materials can be developed for engineering students especially at the early stages of their education.

While the finding from this study does not mean that decision-making skills are not taught to first-year engineering students, it highlights gaps in current curriculum materials. Future research should further investigate the types of decisions engineers make and how students make these decisions. We suggest the use of decision-making theories such as the multi-attribute utility theory when studying engineering decision-making. In the light of such studies, effective tools and strategies can be developed to teach engineering decision-making skills.

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