# Investigating Engineering Student Estimation Processes

**Heather Nachtmann, Justin R. Chimka, Alisha D. Youngblood**
**University of Arkansas**

## Abstract

Education-related engineering economy research focuses on solution methodology and lacks an emphasis on data modeling and estimation. Estimation of cash flows is a vital component of engineering economic analysis and should be effectively taught to undergraduate engineers. The first step in investigating estimation pedagogy is to study and document the estimation processes of engineering students. This paper describes ongoing research focused on collection and documentation of engineering student estimation processes, including description of data collection materials, methodology, and preliminary results. The long-term goal of this research is to develop educational materials to improve estimation pedagogy for undergraduate engineering students. This paper imparts a continuation of work presented to the Engineering Economy Division at the 2002 ASEE Conference.

## Introduction

This research was introduced at the *2002 American Society for Engineering Education Annual Conference & Exposition* (Nachtmann and Lehrman, 2002). This paper presents results from a pilot study investigating engineering student estimation processes. Engineers are frequently called upon to provide estimates in order to facilitate decision analysis. Formal estimation instruction, if any, that engineering students receive prior to entering the workforce takes place within the engineering economy classroom. The Accreditation Board of Engineering and Technology (ABET) for undergraduate engineering programs has defined a set of outcomes that these programs must demonstrate that their graduates have achieved. One of these outcomes (b) requires the ability to analyze and interpret data within the design and conduct of experiments, which frequently requires an awareness of and capability in estimation. This coupled with the importance of preparing students for the challenges of real world analysis (Bordogna, et al., 1993; ASEE, 1994; National Science Foundation, 1995; National Research Council, 1995), such as data collection and estimation, provide the motivation for this research. The fact that an effective estimation curriculum does not currently exist has been acknowledged (Moore, 1997; Goyal, et al. 1997) along with recognition of the challenge of developing effective estimation pedagogy (Goyal, et al, 1997). Until now, education-related engineering economy research has focused on solution methodology and lacks an emphasis on data modeling and estimation.

Our research goals are to understand engineering student estimation processes and develop educational materials to improve engineering estimation pedagogy. The research phases (as shown in Exhibit 1) include:

1) designing and conducting a pilot study to develop experimental materials and identify methods to analyze and describe engineering estimation processes and to evaluate a pre-prototype model to potentially improve estimation pedagogy (completed),

2) designing and conducting a proof-of-concept study to finalize and evaluate the experimental design and materials used to model engineering student estimation processes and to develop prototype materials for improving estimation education (ongoing), and

3) conduct a full development study to effectively describe student estimation processes and develop, evaluate, and distribute materials for improving engineering estimation education (future work).

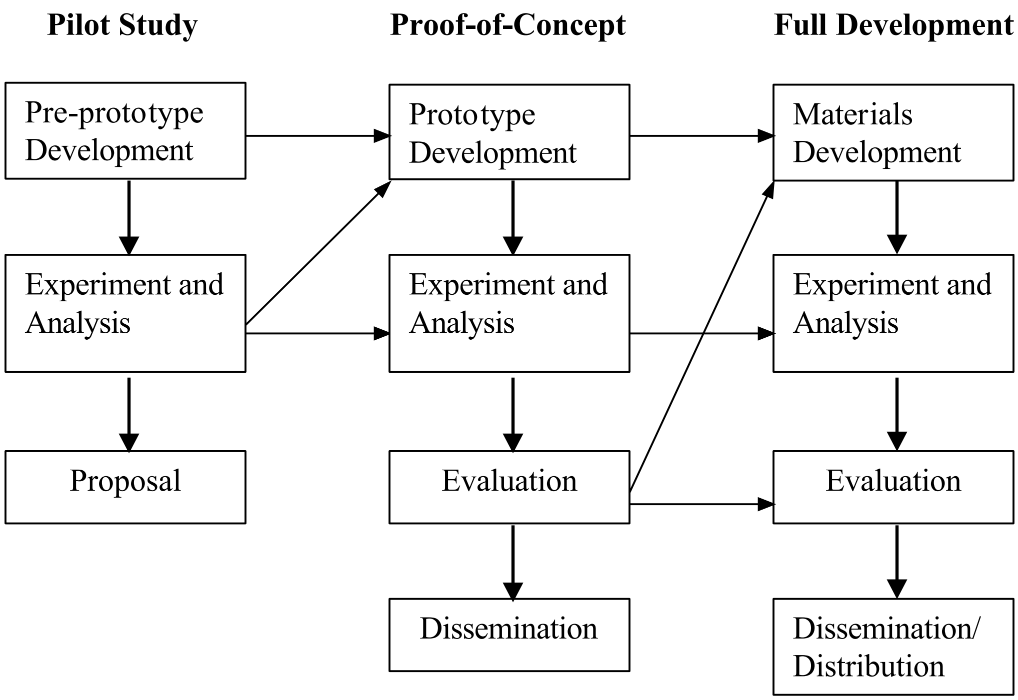


Exhibit 1. Project phases

Pilot Study

The pilot study has been conducted. In this section, some future analysis and experimental methods will be demonstrated, and an outline of prototypical teaching materials will be cross-validated with pilot study data. Experimental materials were designed and used to collect data from 58 volunteer industrial engineering students (41 reported male, and 15 reported female). The average age of the sample is 19.2 years with an average of 2.7 college semesters completed. The collected data were analyzed to evaluate a pre-prototype estimation process model, which was developed from reviewing multiple estimation resources (Canada and Sullivan, 1988; Canada, et al., 1995; Matthews, 1983; Newnan, et al., 2001; Ostwald, 1991; Stewart, et al., 1995).

The pre-prototype estimation process model is the first step towards developing materials to improve engineering estimation education and includes the following eight steps:

1. **Problem Definition:** Define the problem. What is to be estimated?
2. **Criticality Determination:** Determine the criticality of the estimate. How important is accuracy?
3. **Data Collection:** Gather available appropriate data, and eliminate any extraneous information. What information is given as a starting point?
4. **Model Selection:** Select the appropriate estimation model. Given supplied data and criticality, is there a standard technique to use?
5. **Estimate Generation:** Generate the estimate using the selected model or technique.
6. **Estimate Assessment:** Review the estimate for plausibility.
7. **Estimate Revision:** Adjust the estimate based upon experience or intuition.
8. **Final Estimation:** Report the final estimate.

Whether or not students considered these estimation process steps was included in linear regression as binary process variables for the purpose of describing their estimation processes.

An Estimation Exercise Tool was designed, tested, and revised prior to administration to the students. The tool consists of six independent estimation tasks covering the following topics:

1) Spring Break Trip Gas Money,
2) Building Size Comparison,
3) College Graduation Rate,
4) Federal Highway Funds,
5) Employee Staffing, and
6) Big Mac Calories.

The tasks are designed to cover a topic familiar to the general public, provide relevant but incomplete data, and require a unique, numerical final estimate. An example estimation task is provided next.

**Building Size Comparison Estimation Task:** What is the ratio of the volume of the Vehicle Assembly Building at Cape Canaveral to the volume of the Pentagon?

**Given Information:**

Vehicle Assembly Building:

Height: 525 feet

Pentagon:

Height: 77 feet, 3.5 inches
Length of one outer wall: 921 feet

For each estimation task, participants were required to write down the processes that they used to develop their estimates and to provide their levels of confidence that their final estimates were correct. In addition to providing basic demographic information, a series of questions were given to assess each student's risk profile to identify if they were risk seeking, neutral, or averse.

Preliminary statistical analysis was undertaken in the form of linear regression. A measure of estimation accuracy was first modeled as a function of estimation task (1, 2, 3, 4, 5, 6), student age, task confidence level, gender, semesters completed and time to finish estimation tool. The dependent variable (generated to be approximately normally distributed) is the zero-skewness log transform (Box and Cox, 1964) of task estimate absolute error. In this case, $R^2$ is 0.7289, and the results show that the estimation task (1, 2, 3, 4, 5, 6) variables are jointly significant, and task confidence level is significantly (though negatively) related to estimation accuracy. That is, the particular estimation task not surprisingly has a significant effect on estimation accuracy. Also, controlling for other independent variables, the more confident the student about an estimate, the less accurate that estimate tends to be. The risk profile data has not been fully analyzed in part due to concerns that the related questions were misinterpreted by many of the student participants.

The average participant completed the Estimation Exercise Tool in 44.4 minutes and reported an overall confidence level of 53%. The average ($\mu$), standard deviation ($\sigma$), and median of absolute percent error (APE) and confidence level (CL) by estimation task are reported in Exhibit 2. As indicated by the large APE $\mu$ and $\sigma$ values, outlier identification will be an important component of the proof-of-concept analysis. The overall average APE (n=339) is 463%. When sorted, the APEs of the first 336 of the data points range from 0% to 585%; the APEs of the remaining six data points range between 8307% and 51764%. Removal of these six outliers decreases the overall average APE to 63%. Exhibit 2 results include all data points.

| **Task** | **Absolute % Error** | | | **Confidence Level** | | |
|---|---|---|---|---|---|---|
| | m | s | **median** | m | s | **Median** |
| 1 | 223% | 1361% | 27% | 58% | 24% | 68% |
| 2 | 1240% | 4264% | 70% | 36% | 26% | 33% |
| 3 | 77% | 67% | 63% | 31% | 26% | 20% |
| 4 | 187% | 1096% | 25% | 38% | 25% | 40% |
| 5 | 30% | 18% | 29% | 60% | 25% | 60% |
| 6 | 1006% | 6907% | 43% | 44% | 23% | 50% |

Exhibit 2. Absolute percent error and confidence level results

A coding scheme based on the pre-prototype model was developed to document and describe the estimation processes used by the students to complete each of the six estimation tasks. A coding scheme was developed to indicate whether or not a student considered each of the defined estimation steps during a particular task. Two analysts independently coded the estimation processes for each participant by task, compared their codes, and resolved all inconsistencies.

Added next to the main effects model previously described were the estimation process data.

Analysis of the binary process variables given in the estimation process model, while describing a negligible additional amount of variation in estimation accuracy, still is informative and shows promise for further development in the proof-of-concept phase. Criticality Determination was dropped from the model, because no student considered it while performing an estimation task: This concept will be important and new to students when they are exposed to it with prototype materials. Also dropped from the model was Estimate Generation; its correlation with Model Selection was 0.9932. These estimation steps might well be consolidated for prototype materials development. Less than one percent of the tasks included formal Problem Definition, another step important to estimation and the eventual proof-of-concept educational module. Less than eight percent included Estimate Revision. The variables Data Collection and Estimate Assessment (as well as Estimate Generation / Model Selection), while insignificant in their preliminary model, appear normally distributed according to Shapiro-Wilk *W* tests and have relatively large standard deviations. These concepts it may be said effectively distinguish between processes and so with more detailed measurement show potential for appreciable gains in variance explanation in proof-of-concept models. In general, the pilot study not only shows promise for linear regression in this phase but its results should do well to further inform future development towards the proof-of-concept.

Proof-of-Concept

The proof-of-concept phase of this research will expand upon the methodology and findings of the pilot study phase. The experimental materials utilized and evaluated in the pilot study will be revised based on the reported outcomes of the pilot. Any necessary adjustments to the Estimation Exercise Tool will be made including clarifying the risk profile assessment and additional demographic questioning. In addition, the pre-prototype estimation model will be expanded to a prototype educational module based on the pilot process analysis. The prototype module will introduce or reorient participants to the estimation process, present the revised estimation process model, and guide them through the model. Further refinement to the estimation process coding scheme will be made according to the revised estimation process model. A more comprehensive coding scheme will be developed and employed to track the number of times a participant utilizes a particular step in the estimation process and how they iteratively progress through the process. In addition to estimate confidence reporting, personality tests will be employed to further focus on the students' higher order thinking abilities through cognitive assessment (Merluzzi, 1986). The outcomes of the selected tests and their relationships to the student's estimation processes will be used to refine the prototype estimation module for the full development phase.

Full Development

Upon successful proof-of-concept, the last phase of the project will be conducted achieving the goals of understanding undergraduate engineering student estimation processes and developing educational materials to improve engineering estimation pedagogy.

Summary

This paper discussed the methodology and results of a pilot study conducted to begin investigation of engineering student estimation processes. This pilot study is the first of three research project phases intended to result in a thorough investigation of engineering student estimation processes, assessment of effective estimation pedagogy, and development of related educational materials. Ongoing research is currently being conducted in the proof-of-concept phase of the project.

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Heather Nachtmann
Heather Nachtmann is an Assistant Professor of Industrial Engineering at the University of Arkansas. She received her Ph.D. in Industrial Engineering from the University of Pittsburgh. Her research interests include economic decision analysis, engineering valuation, and engineering education. She is a member of AACE International, ASEE, ASEM, IIE, and INFORMS.

Justin R. Chimka
Justin Chimka is an adjunct assistant professor in the University of Arkansas' industrial engineering department. He received his PhD from the University of Pittsburgh. His research interests include probability and statistical models, and cognitive processes and problem solving. He is a member of ASA, ASEE, IIE and the Psychometric Society.

Alisha D. Youngblood
Alisha D. Youngblood is a Ph.D. Candidate and Instructor in the Industrial Engineering department at the University of Arkansas. She earned her B.S. and M.S degrees in Industrial Engineering from the University of Arkansas. Ms. Youngblood's research interests include engineering management, performance measurement, economic decision analysis, and logistics. She is an active member of IIE, ASEE, ASEM, SWE, and INFORMS.