120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #5939

An Instrument for Assessing Upper-Division Engineering Students' Efficacy Beliefs about Mathematics

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An Instrument for Establishing Engineering Students' Efficacy Beliefs about Mathematics

Abstract

The factor validity of a pilot instrument to assess upper-division engineering students' *self-efficacy beliefs* (SE beliefs) about their lower-division mathematics was established. The instrument aimed at identifying how junior and senior engineering students relate their lower-division mathematics knowledge to the solution of upper-division engineering problems in two disciplines: Electrical & Computer Engineering and Mechanical Engineering. The pilot instrument was used to predict *a priori* the hypothesis that those students who believe that solving core, upper-division engineering problems is: (a) influenced by their effective use of lower-division mathematics (i.e., their *outcome expectancies* or OE beliefs); (b) who also have confidence in their own mathematical abilities (SE beliefs) should be more skilled at setting-up and solving these problems. The instrument was subjected to a confirmatory factor analysis using the structural modeling feature in SAS, v.9. Reliability analysis produced a Cronbach's α coefficient of 0.862 for the mathematics SE beliefs scale and a Cronbach's α coefficient of 0.797 for the OE scale ($n = 49$). The current standard is that $0.7 \leq \alpha < 0.8$ is good and that $0.8 \leq \alpha < 0.9$ is very good. These results provide evidence that the pilot instrument items measure an underlying (latent) construct. Confirmatory factor analysis indicates that these two scales are independent, thus adding to the construct validity of this instrument. The paper concludes with a discussion concerning how students' SE and OE beliefs are postulated to affect students' problem solving skills of upper-division electrical and mechanical engineering problems.

Introduction

Calculus, linear algebra, and differential equations are a foundational and distinguishing analytic course of study central to any four year engineering curriculum. Engineering students' *beliefs* in their ability to successfully apply the mathematical concepts from these courses to their upper-division course work (i.e., students' self-efficacy) was examined in two concentrations: (a) electrical (and computer) engineering; (b) mechanical engineering. Linked with this examination was the question: "Are engineering students' *expectations* of their performance in their upper-division courses associated with their proficiency in these mathematical topics?"

A pilot instrument was developed to find an answer to this question and simultaneously examine these students' self-efficacies. Specifically, this instrument was developed to assess junior and senior engineering students' *self-efficacy beliefs* (SE) and *outcome expectations* (or OE beliefs) about how their lower-division mathematics affects the course of their success in their upper-division engineering concentration.

The research literature reports on the influence of students' beliefs about their knowledge on their problem-solving skills. A substantial portion of this research is concentrated in mathematics and other sciences (e.g., physics). There are fewer studies that report on students' beliefs about their engineering course work and in particular, students' beliefs about lower-division mathematics as it applies to their upper-division course work.

Conceptual Framework

Beliefs are part of the foundation upon which behaviors are based. Bandura[1] (1981) demonstrated that beliefs correlate closely with human behavior. Bandura further[2] suggests that humans develop specific beliefs concerning their abilities to handle and cope with change. Bandura called this self-efficacy (1986). Bandura describes an individual's perceived self-efficacy as "one's judgment of their abilities to organize and execute given types of performances." Furthermore[3], Bandura suggests that self-efficacy beliefs depend on the situation relative to the task to be performed (1997). If Bandura's theory of self-efficacy is applied to the study of junior and senior engineering students, one might predict that students who have confidence in their foundational mathematics skills should be more adept at setting-up, and solving upper-division problems.

A question is: "Do engineering student' judgments of their mathematical abilities affect the elegance or the quality of their problem-solving approach?" According to Ormrod[4] (2006) one's sense of self-efficacy influences how one approaches challenges and goals. Furthermore, one's judgment of the likely consequence that their performance will produce is what Bandura calls an *outcome expectation* (Bandura, 1997). Bandura states "...the outcomes people anticipate depend largely on their judgments of how well they will be able to perform in given situations and the likely consequence that their performance will produce; performance is thus prior to outcomes" (p. 21). Thus, how one behaves largely determines the outcomes one experiences. If Bandura's theory if further applied to the study of engineering juniors and seniors, one might predict that students who believe that their mastery of upper-division concepts is influenced by adept mathematical skills should provide a rigorous, comprehensive approach to a problem with the expectation of producing a complete and a correct answer. Informed by Bandura and Ormrod a question is: "When engineering juniors or seniors are confronted with an upper-division problem, do they believe that their lower-division mathematical skills are central in enabling them to solve the problem? Furthermore, do they believe that they are adept in their use of the mathematics to succeed in solving the problem?" According to DiClemente[5] (1986) and Hofstetter[6], Sallis & Hovell (1990) a high sense of one's self-efficacy in one domain is not necessarily accompanied by a high sense of self-efficacy in another domain.

Since a vast majority of upper-division engineering courses require foundational and rigorous mathematics to describe natural phenomena, it is reasonable to conclude that one's sense of their mathematical self-efficacy would influence the degree to which one believes that their engineering problem-solving skills are affected by their mathematical adeptness. This is supported by Bandura (1997) and Pintrich[7] & Schunk (1996) where it is indicated that one's efficacy beliefs depend on the context relative to the task at hand to be performed. Too, this might suggest something about students' *acceptance* of mathematical rules and properties that cannot be easily comprehended using physical intuition alone. For instance, the Takagi function[8] $\tau(x)$ is an example of a function that is continuous everywhere and yet is nowhere differentiable. Based on students' foundational studies of differential calculus and calculus-based physics, the nature of $\tau(x)$ eludes intuition. Does this type of example therefore suggest that students may develop the competence to solve certain mathematical problems if they agree to abandon their intuition? Or does this suggest that the use of logic and induction assists a student in performing a mathematical analysis wherein competence may be lacking? Competence is defined here in the context of one's ability to complete a task without instructional support. This raises the question: If a student competently performs a computational analysis does this imply that they possess an understanding of the underlying mathematical concepts? In the last two decades research in mathematics, science and engineering education has shown that although students may possess the computational skills necessary to correctly solve homework problems they often possess a poor understanding of foundational concepts (Miller[9], 1990; Bransford[10], 1999; Bransford[11], 2000). Findings from this research suggest that many students are able to successfully perform computational exercises yet are unable to demonstrate competency of the underlying principles. This accentuates the need for understanding how students perceive of fundamental concepts and furthermore, how perceptions about such concepts get utilized to solve problems.

If this conceptual framework is applied to the study of junior and senior engineering students, one might predict the following: (a) students who believe that their ability to solve upper-division problems are affected by the skillful application of lower-division mathematics (OE beliefs); (b) who likewise have confidence in their own mathematical abilities (SE beliefs) should be more adept at solving upper-division problems than those students who have lower expectations concerning their ability to solve these problems.

Self-efficacy should not be confused with self-confidence in one's abilities (Maibach[12] and Murphy, 1995). Self-efficacy is related to very specific tasks. For instance, a junior in mechanical engineering might have confidence in their skill at applying vectors to the solution of dynamics problems. Yet they may admit they don't yet know how to apply Euler's identity to the writing of the kinematic equations of motion for a planar mechanism. Figure 1 illustrates the conditional relationship between self-efficacy beliefs and outcome expectancies in the context of the application of mathematics to the solution of upper-division engineering problems.

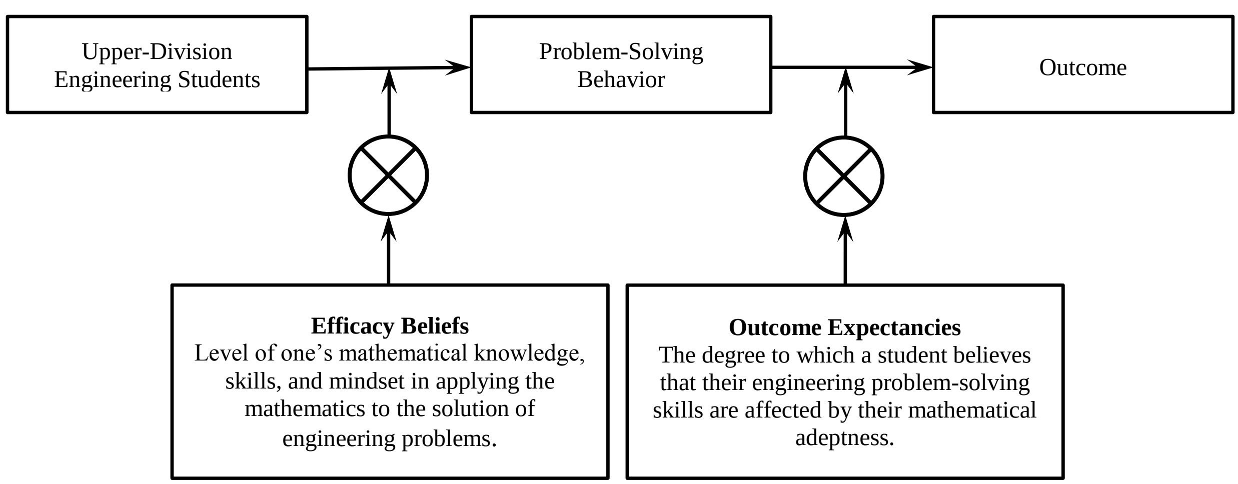

Figure 1. Conditional relationship between self-efficacy beliefs and outcome expectancies in the context of upper-division engineering students and their math problem-based solving behaviors.

In short, behavior is enacted when one not only expects a specific behavior to result in a desirable outcome (expectancy) but believes in their ability to perform the task (self-efficacy).

Hypothesis

Those students who believe that solving core, upper-division engineering problems is: (a) influenced by their effective use of lower-division mathematics (OE beliefs); (b) who also have confidence in their own mathematical abilities (SE beliefs) should be more skilled at setting-up and solving these problems. This is in comparison to those students' having lower expectations concerning their ability to apply their core mathematics to such problems.

Design/Method

The validity and reliability of a pilot m*athematics self-efficacy* (or MSE) instrument is being determined. A sample of upper-division engineering students was deemed the appropriate population for the study. Upper-division courses provide a common point where these students begin to rigorously apply lower-division mathematics to the setting-up and solution of generalized and inexact problems. The hypothesized factor structure associated with the MSE model is illustrated in Figure 2.

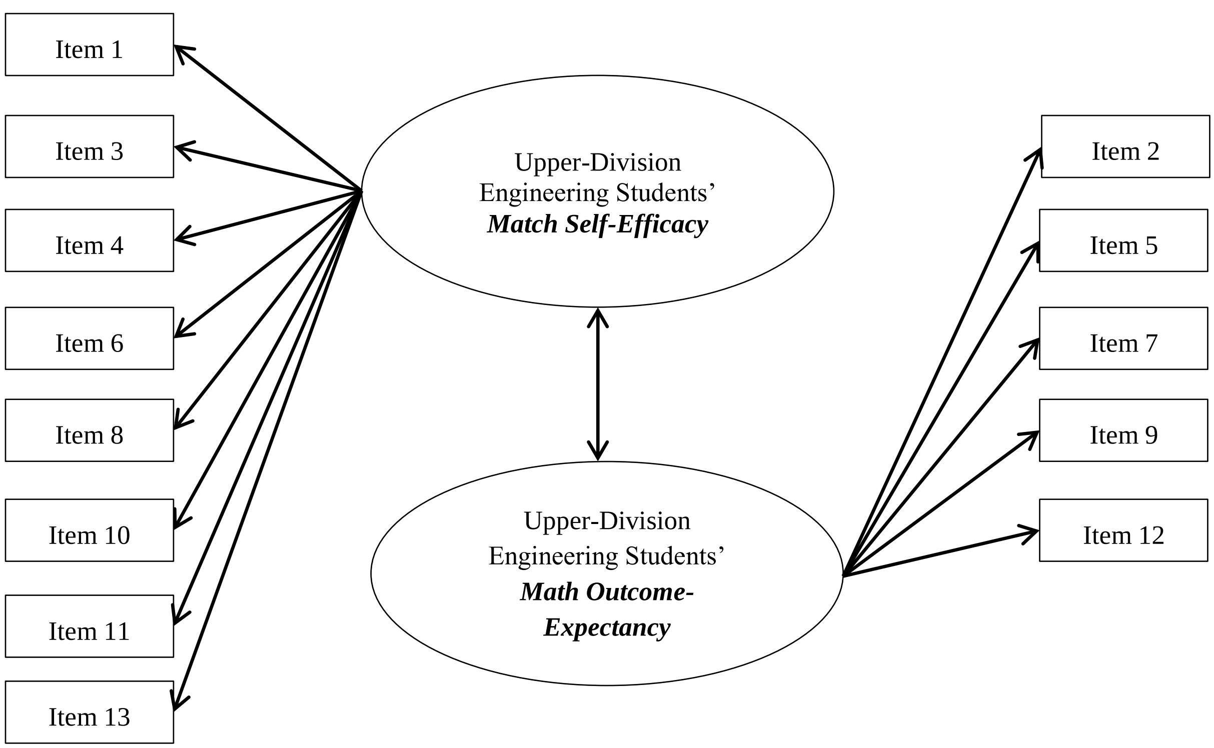

Figure 2. Hypothesized factor structure used in this study.

Details of the math self-efficacy and math outcome expectation items are in listed in Table 1. All 13 items were written to reflect upper-division computer/electrical and mechanical engineering students' mathematical beliefs as the mathematics relates to their upper-division coursework.

All actively-enrolled juniors and seniors in computer, electrical, and mechanical engineering were invited to participate. Participants were recruited from a private university in NW Oregon. This site was chosen because of an already active collaboration between the engineering, mathematics, and education faculty.

The MSE instrument was administered within the first three weeks of the 2012 fall semester. The sample for this study consisted of n = 49 upper-division engineering students (30 junior males, 4 junior females, 13 senior males, and 2 senior females). This population is further categorized as follows: 16 juniors with a concentration in electrical & computer engineering; 18 juniors with a concentration in mechanical engineering; 5 seniors with a concentration in electrical & computer engineering; 10 seniors with a concentration in mechanical engineering.

Analysis

An item-total correlation test was performed to check if any items were inconsistent with the averaged behavior of the other items. That is, this analysis was performed to see if any of the items didn't have responses that vary in-line with those across the population and eliminating those items that were deemed as not measuring the factors representing the construct. Of the original 20 items, seven had total-item correlations under 0.30. These correlations were deemed less than exemplary (Robsin[13] and Shaver, 1991) and were dropped from subsequent analysis. The results of the item-total correlation analysis appear in Table 2. Reliability analysis produced a Cronbach's α coefficient of internal consistency of 0.862 for the mathematics SE belief scale and 0.797 for the OE scale. The current standard[14] is that $0.7 \le \alpha \le 0.8$ is acceptable/good and that $0.9 \le \alpha \le 0.9$ is good/very good.

Construct Validity: Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) was used to establish factor validity of the MSE instrument in addition to establishing the independency of the SE and OE scales. The structural modeling feature in SAS v.9 was used to perform the CFA.

CFA relies on a specific hypothetical structure and serves to confirm it existence in the data set. This method of analysis is more robust than exploratory factor analysis (EFA) in that EFA is concerned with the determination of the number of factors necessary to explain the relationships between a set of items and to estimate these relationships in terms of the factor loadings (Pedhazur[15] and Schmelkin, 1991). What's more, EFA does not assume a hypothesis regarding the structure of the instrument. CFA permits certain factors to correlate and items can be constrained not to load on certain factors if dictated by the validation structure. The MSE instrument was used to predict *a priori* the stated hypothesis (p. 4). Stated another way, CFA compares the empirical data with a hypothesized model to determine if the data may have reasonably resulted from the two-factor hypothesized model with the SE and OE items loading on two independent factors that were set free to covary.

Item	Description
SE Scale	
I1	Even if I make a concerted effort to succeed, I admit I just don't do as well in pure mathematics (e.g., Calculus III) as I do in my engineering coursework.
I3	I know how to successfully apply my freshman and sophomore mathematical concepts in an effective manner to the solution of engineering problems.
I4	I am not very effective when it comes to applying pure mathematical concepts (e.g., Calculus and Differential Equations) to the setting-up of engineering problems.
I6	When I apply pure mathematical concepts (for instance, concepts from Calculus) to the solution of an engineering problem, I find the link between the physical meaning of the solution and the mathematical concepts to be interesting.
I8	I understand my freshman and sophomore mathematical concepts well enough to be effective in my engineering coursework.
I10	I sometimes question if I have the necessary mathematical skills to learn engineering as effectively as I could.
I11	Given the choice, I would personally prefer to use as little math as possible when setting-up an engineering problem for a solution.
I13	Given the choice, I would personally prefer to use a little math as possible when solving an engineering problem.
OE Scale	
I2	My academic strength in my engineering courses is in large part due to my freshman and sophomore mathematics foundation; I expect that this foundation will have a bearing on my performance as a junior/senior in engineering.
I5	As a junior/senior in engineering, I believe that those in my ranks who are lack effective mathematical skills will most likely underachieve in engineering.
I7	I believe that those "C" students amongst my ranks progress through engineering in part due to the engineering professor placing extra emphasis on mathematical concepts.
I9	When one of our engineering professors places emphasis on complicated math concepts, I feel it helps me gain a clearer understanding of the underlying engineering/physical concepts.
I12	My academic achievement in engineering is directly related to my ability to understand and work-out problems in pure mathematics (like Calculus and Differential Equations).

Table 1. Hypothesized MSE factor structure used in this study.

Measure	Item	Positive/Negative Wording	Item Total Correlations
SE Scale	I1	N	0.577
	I3	Y	0.428
	I4	N	0.561
	I6	Y	0.394
	I8	Y	0.434
	I10	N	0.506
	I11	N	0.344
	I13	N	0.529
Total SE Scale α	**0.862**		
OE Scale	I2	Y	0.514
	I5	Y	0.441
	I7	Y	0.448
	I9	Y	0.382
	I12	Y	0.489
Total OE Scale α	**0.797**		

Table 2. Item analysis results of the hypothesized SE factor structure ($n = 49$). The scores for the SE scale range between 8 and 40. The OE scale scores range between 5 and 25.

How well the gathered data fits the specified model depends on the simultaneous consideration of several criteria. Five important and competitive measures of model fit were examined and are considered to be among the currently accepted standards for indicating how well a model/factor structure fits the data. These five indices are: (1) the Goodness of Fit Index (GFI, Tabachnick[16] and Fidell, 2007); (2) the Adjusted Goodness of Fit Index (AGFI); (3) the Bentler-Bonett[17] Normed-Fit Index (NFI, 1980); (4) the Comparative Fit Index (CFI, Bentler[18], 1990; Kline[19], 2005); (5) the Root-Mean-Square Error of Approximation (RMSEA, Steiger[20], 1990).
The model fit statistics associated with this factor structure suggest that this model is an adequate fit to the data[18, 21, 22] (GFI = 0.897; AGFI = 0.88; NFI = 0.864; CFI = 0.882; RMSEA = 0.068).

Fit statistics very close to 0.90 for the GFI, AGFI, NFI, and CFI and lower than 0.07 for the RMSEA are commonly accepted values in concluding that a proposed factor structure fits the data. Hence, the above results suggest that the hypothesized factor structure is an adequate fit to the data for the population tested.

Conclusions

The factor structure tested in this study hypothesized a two-factor model with the SE and OE scales loading on two independent factors which were set free to covary. Model fit statistics from correlated item-total scale correlations and factor loadings, as well as a confirmatory factor analysis were deemed sufficient to support the *a prior* hypothesis. The hypothesis, which is that students who believe that solving core, upper-division engineering problems are: (a) influenced by their effective use of lower-division mathematics (OE beliefs); (b) who also have confidence in their own mathematical abilities (SE beliefs) are more adept at setting-up and solving these problems. This was established via the factorial validity of the mathematics efficacy beliefs instrument presented. Given the relatively small population and the focus on a single NW private university, subsequent utilization of the MSE instrument will require ongoing vigilance in terms of study-specific assessment of reliability as well as cross and predictive validations.

The intellectual merit of this study indicates promise in advancing both EE and ME educator's understanding of upper-division students' mathematical and thinking practices as the latter embark on solving problems in their respective courses of study. The outcome of this study suggests an original concept in the sense that a single psychological theory (Bandura[1,2]) was used to predict that students who believe that their mastery of upper-division concepts is influenced by their mathematical skills and their beliefs about their mastery of these skills.

The broader impact is this work bridges cognitive science and engineering education as a means to advance student learning in the areas of calculus, differential equations, linear algebra, and junior and senior level course work at the upper-division level as universally typical to a traditional Electrical & Computer Engineering and Mechanical Engineering curriculum.

The subsequent research ambitions of the author are to gain a more concise understanding of how upper-division engineering students connect and understand their lower-division mathematical concepts with their junior and senior course work. Given the initial findings of this pilot study, the engineering community might wish to consider: (a) the methods by which we teach mathematics concepts to lower-division engineering students; (b) the methods by which we knowingly and consistently associate these mathematical concepts with upper-division course work. That said, the author envisions a future research plan where the MSE instrument gets used as an "awareness tool" for considering how we might choose to structure teaching in a manner of this sort. Being that the author is focused on the development of cognitive learning instruments (psychometrics) in the field of engineering education, the latter is deemed "detail work" that subsequent teaching researchers will hopefully find useful.

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