Differences in Engineering Students' Beliefs About Knowledge Across Educational Levels

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Abstract

This cross-sectional study used Schommer's Epistemological Questionnaire (SEQ) to examine 518 engineering students from three different universities located in Tennessee to determine whether there were differences in their epistemological beliefs across educational levels (underclassmen, upperclassmen, and graduate). After examining these students, the results of this study indicated that Underclassmen (freshmen and sophomores) were significantly more likely than Upperclassmen (juniors and seniors) to have beliefs in Quick Learning.

This study contributes to engineering education research with conclusions that epistemological beliefs did indeed become more sophisticated as students progressed through college. In addition, it contributes to maintaining quality of engineering programs by providing an evaluation of student learning outcomes. In order to fully understand epistemological beliefs as related to engineering students' development and experience, further research is needed to longitudinally examine engineering students' epistemological beliefs.

Keywords: assessment, epistemological beliefs, higher education, learning outcomes, STEM.

Introduction

For the past three decades, there have been reports that address the concern that the United States is globally losing its competitive edge in the fields of Science, Technology, Engineering, and Mathematics (STEM) (Collea, 1990; National Science Foundation [NSF], 2010). The United States' competitive edge in STEM fields is important as science and technology perpetuate growth in the economy and in new markets. Furthermore, there is a concern that as American science and engineering workers approach retirement, the number of scientists and engineers to replace them will consistently decline (Committee on Science, Engineering, & Public Policy [COSEPUP], 2007; Southern Education Foundation [SEF], 2005). As engineering and science fields grow faster than jobs in other fields, opportunities in engineering will increase by 15% by the year 2012 (NSF, 2006). With this in mind, the engineering educators and researchers have outlined a course of action to reform engineering education in the United States ("The Research Agenda," 2006).

The National Academy of Engineering (2005) states that successful engineering education reform must consider each part of the engineering education system, so that "the teaching, learning, and assessment process will move a student from one state of knowledge and professional preparation to another state" (p. 18). The Accreditation Board for Engineering and Technology [ABET] (2009) also emphasizes the importance of knowledge by requiring engineering programs to assess their students' ability to apply the knowledge of engineering to the real world. Also emphasizing the importance of engineering knowledge, the Research Agenda (2006) for engineering education proposes that research is needed in the area of engineering epistemologies insofar as to understand "what constitutes engineering thinking and knowledge within social contexts now and into the future" (p. 259).

Engineering education researchers are interested in understanding the technical, social, and ethical aspects of engineering epistemologies ("The Research Agenda," 2006). This would assist engineering students in making a seamless and successful transition of applying theoretical skills acquired in college to the practical use of skills in an engineering career. Assessing the epistemological beliefs of engineering students is an initial attempt in understanding and examining engineering epistemologies. Epistemological beliefs can be quantitatively analyzed by examining engineering students' responses to questions that measure individuals' multidimensional beliefs about knowledge.

This cross-sectional, comparative analysis study investigated the effects of educational level on the epistemological beliefs of engineering students at three universities located in the southern United States. The following literature review will provide an overview of epistemology and of the Schommer (1990, 1998). epistemological belief development model.

LITERATURE REVIEW

Epistemology is a branch of philosophy that studies the origin, nature, methods, and limits of human knowledge. Educational psychologists study epistemological development and beliefs to determine how students come to know, what beliefs they have about knowledge, and how epistemological beliefs affect cognitive processes (Hofer & Pintrich, 1997). Three epistemological belief theories have influenced studies in educational psychology. Jean Piaget's (1932) genetic epistemology theory was the foundation for studying epistemological beliefs in educational psychology. Then, William Perry's (1970) intellectual and ethical development stage theory was a result of the first studies to examine the epistemological beliefs of college students. Perry's theory has served as a framework for other epistemological beliefs development studies (Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1986; Fedler & Brent, 2004; Hofer & Pintrich, 1997; King & Kitchener, 1994). Although these studies expanded on Perry's theory, some were initiated to challenge his work. For example, Belenky et al. (1986) challenged Perry's focus on males by specifically evaluating the epistemological beliefs of women. On the other hand, Baxter Magolda (1992), who was influenced by both Perry and by Belenky et al., examined gender influence on epistemological beliefs. King and Kitchener assessed how epistemological beliefs affected thinking and reasoning about ill-structured problems, whereas Schommer (1990) introduced dimensionality to epistemological beliefs.

Schommer's (1990) epistemological beliefs theory was the first to suggest that epistemological beliefs are multidimensional and independent. In other words, she proposed that one can develop sophisticated or advanced beliefs in one dimension, while having naïve beliefs in another dimension. Schommer (1990) states that Perry's (1970) model influenced the first two dimensions of her model: structure of knowledge and certainty of knowledge. The structure of knowledge was either simple or complex. Simple refers to the belief that knowledge consisted of isolated pieces of information that were clearly understood. Complex knowledge consisted of pieces of information that were related and dependent on the other. Certainty of knowledge had the two extremes of either being absolute and not changing or continuously evolving. The next dimension, which was the control of knowledge, was influenced by the work of Dweck and Leggett (1988). The control of knowledge was set and unchanging at the naïve level of belief. At the sophisticated level, control of knowledge had several layers or increments that allowed knowledge to increase and improve. Finally, Schommer defined the speed of knowledge dimension based on the work of Schoenfield (1983, 1985). Knowledge was believed to be quickly obtained by an individual with naïve beliefs. In contrast, one with more advanced beliefs perceived the speed of knowledge as a gradual process.

In addition to her theory that epistemological beliefs were independent and multidimensional, Schommer created a method to quantitatively assess epistemological beliefs through a 63-item epistemological questionnaire with a Likert five-point rating scale (Hofer & Pintrich, 1997; Schommer 1990). Due to the questionnaire's time efficient evaluation method, Schommer's (1990) theory is a framework for several epistemological studies (Hofer, 2000; Jehng, Johnson, & Anderson, 1993; Kardash & Howell, 2000; Paulsen & Wells, 1998; Qian & Alvermann, 1995; Schommer, 1993; Schommer, Crouse, & Rhodes, 1992; Schommer-Aikins, Duell, & Barker, 2002; Trautwein & Ludtke, 2007).

Epistemological beliefs are critical to engineering education as that they impact how students learn, think, and solve problems (Schommer-Aikins, 2004). For example, research shows that students who believe that knowledge is certain are more likely to draw absolute conclusions from information that may change (Schommer, 1990). Students who believe that knowledge is fixed were less likely to value school (Schommer & Walker, 1997); students who believed that knowledge is quickly acquired are more likely to comprehend information poorly (Schommer, 1990). Students who believe that knowledge is simple are more likely to settle for a memorization study strategy rather than using higher-level cognitive processes such as elaboration (Hofer & Pintrich, 1997).

Students' beliefs may influence how instructors design engineering curriculum. For example, engineering instructors can use information about students' beliefs to change curriculum in order to move less sophisticated thinkers to higher levels of thinking. In addition, the instructors will be able to adjust the curriculum to enhance the intellectual development of students who are sophisticated thinkers (Marra, Palmer, & Litzinger, 2000; Marra & Palmer, 2004; Pavelich & Moore, 1996; Wise, Lee, Litzinger, Marra, & Palmer, 2004). Researchers examined engineering students' epistemological beliefs in the context of studying other students using both qualitative and quantitative methods. Except for Trautwein and Ludktke's study (2007), all demonstrated that epistemological beliefs do indeed become more sophisticated as students progress in educational levels (freshman through graduate level) (Jehng et al., 1993; King & Magun-Jackson, 2009; Marra & Palmer, 2004; Marra et al., 2000; Palmer & Marra, 2004; Paulsen & Wells, 1998; Pavelich & Moore, 1996; Schommer, 1993; Wise et al., 2004). Also, some of these studies reported that engineering students had less sophisticated epistemological beliefs than students in other majors (Jehng et al., 1993; Paulsen & Wells, 1998; Schommer, 1993; Trautwein & Ludtke, 2007).

Epistemological beliefs of college students have been examined by both qualitative and quantitative research methods. Both kinds of studies used these methods to provide support that epistemological beliefs become more sophisticated as students' educational levels advance (Jehng et al., 1993; Paulsen & Wells, 1998; Pavelich & Moore, 1996; Schommer, 1993; Wise et al., 2004). In these studies, younger students have shown naïve (not sophisticated) beliefs in that they believed knowledge was certain, simply structured, quickly acquired, and from an authority figure. Although qualitative research methods have been used to examine engineering students, the King and Magun-Jackson (2009) study is the only quantitative study that examined the relationship between epistemological beliefs (in each of the four dimensions) and educational level of a sample of all engineering students. Hence, the purpose of this cross-sectional study was to replicate and extend the research of King and Magun-Jackson (2009) by increasing the sample size of engineering students and examining the overall epistemological beliefs of engineering students across educational levels. To this end, the current study aimed to answer the research question, *Do epistemological belief dimensions (certainty, structure, control, and speed) of engineering students differ across educational levels (underclassmen, upperclassmen, graduate)?*

METHODOLOGY

Participants

The main inclusion criterion for this study was that the voluntary participants were enrolled in an engineering program. In the fall 2009 semester, data was collected from engineering students at two universities located in west Tennessee. One university was a large public institution and the other was small private institution. Then, in the spring 2010 semester, data was collected from engineering students at a medium-sized public university located in middle Tennessee. These universities were selected to participate in this study because of their similarities. For example, each university was located in Tennessee and accredited by the Southern Association of Colleges and Schools (SACS). In addition, all three universities had engineering programs that were accredited by the Accreditation Board for Engineering and Technology (ABET).

Students were solicited from seven different engineering disciplines: architectural, civil, electrical, mechanical, chemical, biomedical, and engineering management. They were classified at various educational levels (freshman, sophomore, junior, senior, and graduate). Overall, there were 518 engineering students who completed questionnaires: 267 were enrolled at the public university in west Tennessee, 103 were enrolled at the private university in west Tennessee, and 148 students were enrolled at the public university in middle Tennessee. Table 1 gives details of the descriptive characteristics of the students' educational levels, gender, and ethnicity. For each university, the first column displays the percentage of the sample that each characteristic represents, and the second column displays the percentage of the institution's population that the characteristic represents.

TABLE 1: INDIVIDUAL CHARACTERISTICS AS A PERCENTAGE OF INSTITUTION POPULATION AND ENGINEERING PROGRAM SAMPLE.

Characteristic	Public Univ - West TN		Private Univ - West TN		Public Univ - Middle TN	
	% Sample (*n* = 267)	% Population (*N* = 21,007)	% Sample (*n* = 103)	% Population (*N* = 1,507)	% Sample (*n* = 148)	% Population (*N* = 8,545)
Educational Level						
Freshman	20.9%	19.4%	44.7%	23.1%	18.9%	22.5%
Sophomore	20.6%	15.5%	24.3%	23.6%	12.2%	14.0%
Junior	25.8%	16.2%	4.8%	14.3%	20.2%	13.9%
Senior	27.7%	22.5%	18.4%	14.5%	38.5%	23.9%
Master	3.8%	15.9%	6.8%	24.5%	8.1%	15.7%
Doctoral*	.8%	4.5%	0%	0%	2.0%	4.2%
Gender						
Male	83.2%	38.0%	79.6%	48.0%	79.0%	37.7%
Female	16.1%	62.0%	18.4%	52.0%	19.6%	66.8%
Ethnicity						
African American	16.1%	36.1%	12.6%	19.0%	60.8%	74.1%
Alaskan Pacific	.8%	.005%	0%	0%	0%	0%
Asian American	4.5%	2.1%	7.8%	4.6%	4.0%	1.8%
Euro American	67.0%	52.7%	67.9%	42.5%	19.6%	21.8%
Hispanic	1.9%	1.4%	2.9%	2.1%	2.0%	.97%
Native American	.4%	.3%	.9%	.20%	0%	.13%
Multi Ethnic**	1.9%	--	1.9%	--	2.7%	--
Other**	6.4%	--	3.9%	--	9.5%	--

Note. TN = Tennessee.
Univ = University.
**The private university in west Tennessee did not have a doctoral program at the time of data collection.*
***Multi-Ethnic and Other Ethnicity data were not available for the universities.*

Instruments

The Schommer Epistemological Questionnaire (Schommer, 1990) assessed the students' epistemological beliefs within four dimensions: certainty (i.e., certainty that knowledge was either absolute and unchanging, or it was continuously evolving); structure (i.e., structure of knowledge was either knowledge consisted of isolated pieces of information that were clearly understood, or it consisted of pieces of information that were related and dependent on the other); control (i.e., control of knowledge acquisition was either innate, or it could be gradually increased and improved as it was acquired); and speed (i.e., speed of knowledge acquisition was either quickly obtained, or it was obtained gradually). Participants were presented 63 statements about knowledge and were asked to rate the statements (e.g., "The only thing that is certain is uncertainty itself.") using a Likert scale which ranged from 1= strongly disagree to 5 = strongly agree. These numbers were summed to form 12 subscales that yielded four factor scores (certain knowledge, simple knowledge, fixed ability, and quick learning) for each individual. Investigating the internal structure of the instrument, Schommer (1993) determined that the alpha coefficients ranged from .63 to .85. The students were also surveyed to determine their personal and pre-college characteristics using Barker's (1998) background information form. As a result, the students self-reported their gender, ethnicity, native language, high school grade point average, college grade point average, educational level, engineering discipline, and the number of engineering courses completed.

Procedure

After receiving approval from the three Deans of Engineering and the Institutional Review Boards, engineering instructors at each of the universities were contacted and asked to participate in the current study. Based on the preference of the instructors, the researcher, or data collection assistant, visited and administered the questionnaires to some of the classes. The remaining instructors administered the questionnaires without the researcher being present. The students were given a consent form that explained that the objective of the study was to gather data on engineering students' beliefs and views toward various topics. The students were also told that participation in the study was voluntary, confidential, and would not affect their status with the university or with their instructors. The epistemological questionnaire and background information questionnaire were given to groups of students who agreed to participate in this study in their classrooms during their regularly scheduled class time.

Design and Data Analysis

This study used a cross-sectional study design in which two sets of comparison groups were statistically equated on pre-college and other variables. Per Schommer's instructions, 27 items were reverse coded before conducting any analyses. Next, preliminary analyses, which included inter-item reliability analysis, were conducted to establish the validity of using the SEQ to measure the epistemological beliefs of engineering students. Using this reliability procedure to create new scales also increased the internal consistency of the instrument used to predict the epistemological beliefs of the engineering students in the present study.

Inter-item reliability analysis was calculated for each of the four epistemological belief dimensions instead of calculating reliability for each of the 12 subscales. This procedure for calculating reliability scores was also done in other studies (Hofer, 2000; Qian & Alvermann, 1995; Schommer-Aikins et al., 2002). Multiple iterations of removing questionnaire items and conducting the reliability analysis were repeated until the Cronbach's alpha reached .60 (Cole et al., 2000). Using the items that remained, mean scores were calculated for each epistemological belief dimension. These mean scores were then used to conduct the analyses to answer the present study's research question as was done in the Hofer (2000) and Qian and Alvermann (1995) studies. Next, to address the research question, *Do epistemological belief dimensions (certainty, structure, control, and speed) of engineering students differ across educational levels,* one-way analysis of variance (ANOVA) was used. Participants were divided into three different groups according to their classification (Underclassmen: freshmen and sophomores; Upperclassmen: juniors and seniors; Graduate: masters and doctoral). Missing values were handled by selecting the option to exclude cases list-wise in SPSS.

FINDINGS

Reliability Analysis

After conducting the reliability analysis, sixteen questionnaire items were associated with the Fixed Ability belief dimension. It had an appropriate Cronbach's alpha value of .65 after the first iteration of analysis. This scale included such items as "Some people are born good learners, others are just stuck with limited ability."

Twenty-eight questionnaire items were associated with the Simple Knowledge belief dimension. Two items were removed before the Cronbach's alpha value reached .61. This scale included such items as "I try my best to combine information across chapters or even across classes."

Thirteen questionnaire items were associated with the Quick Knowledge belief dimension. It had an appropriate Cronbach's alpha value of .64 after the first iteration of analysis. This scale included such items as "If a person can't understand something in a short amount of time, they should keep on trying."

Six questionnaire items were associated with this Certain Knowledge belief dimension. After 4 items were removed, the Cronbach's alpha value reached .59. This is the closest to .60 that the reliability score would reach. This scale included such items as, "Scientists can ultimately get to the truth."

Epistemological Beliefs Across Educational Levels

As a result of the one-way ANOVA, only one of the four epistemological belief factors demonstrated a statistically significant difference. The speed dimension, or the belief that learning is quickly acquired, was statistically significant, F (2, 513) = 9.98, $p < .001$. Despite reaching statistical significance, the actual difference in mean scores among the educational levels was small. The effect size, calculated using eta squared, was .02. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Underclassmen (M = 2.42, SD = .48) was significantly different from Upperclassmen (M = 2.23, SD = .45). Graduate students did not differ significantly from either Underclassmen or Upperclassmen. Table 2 shows a summary of the ANOVA results.

TABLE 2: ANALYSIS OF VARIANCE COMPARING ENGINEERING STUDENTS' EPISTEMOLOGICAL BELIEFS ACROSS EDUCATIONAL LEVELS

Belief Dimension	*df*	*F*	η^2	*p*
Fixed Ability	2	1.88	.007	.15
Simple Knowledge	2	.75	.003	.47
Quick Learning	2	9.98*	.02	.00
Certain Knowledge	2	2.75	.01	.065

*$p < .001$.

SUMMARY

The purpose of this study was to cross-sectionally assess the epistemological beliefs of engineering students at three universities located in Tennessee. The study aimed to answer whether epistemological belief dimensions (certainty, structure, control, and speed) of engineering students would differ across educational levels (underclassmen, upperclassmen, graduate). This study supported several epistemological studies in that it found that engineering students' epistemological beliefs became more sophisticated as they progressed through college (Jehng et al., 1993, King & Magun-Jackson, 2009; Paulsen & Wells, 1998; Pavelich & Moore, 1996; Schommer, 1993; Wise et al., 2004). However, this study's findings only showed significant differences in engineering students' beliefs in the speed dimension, or beliefs in Quick Learning. In other words, Quick Learning was the naïve belief that knowledge is acquired quickly as opposed to the sophisticated belief that knowledge is acquired gradually. More specifically, in this study, the beliefs in Quick Learning became more sophisticated as students progressed from Underclassmen (freshmen and sophomores) to Upperclassmen (juniors and seniors). Like Paulsen and Wells (1998) and Schommer (1993), this study found that engineering students' beliefs in Quick Learning became more sophisticated in their junior and senior years.

SUGGESTIONS FOR BEST PRACTICES

An implication of this study is that engineering students are less likely to believe that learning is quickly acquired as they progress through college. This supports that older engineering students, as suggested by Schommer's 1990 study, comprehend engineering course information better as juniors and seniors than when they started their program of studies as freshmen and sophomores. Although it is encouraging that the results of this current study suggest that engineering students become more sophisticated thinkers as they progress through college, these results also suggest that engineering instructors should anticipate that freshmen and sophomores are likely to believe that learning is quickly acquired. As a result, engineering curriculum for underclassmen should include study strategies that will help freshmen and sophomores understand that engineering concepts are not necessarily learned quickly and that it is totally normal to gradually learn these concepts. Engineering instructors should also reinforce to students that sophisticated problem solving, mathematics, and scientific concepts, such as those associated with the engineering field, will take time, discipline and consistent practice to master.

As engineering faculty and staff update and modify curriculum to meet their students' needs, it is important to control the effects that the changes will have on the quality of the overall engineering program. Quality is a major concern for engineering programs, as they must meet the standards defined by the Accreditation Board for Engineering and Technology (ABET, 2009). With this in mind, engineering faculty and staff may need to consider assessing engineering students' epistemological beliefs as a part of the self-study that must be completed for the ABET evaluation process. The process is data-driven in that it requires engineering programs to define desired student outcomes by describing what students are expected to know at the completion of their degree programs. Based on these defined outcomes, ABET then requires programs to collect and evaluate their students' technical skills, behavior and knowledge. If designed properly, a longitudinal study that includes an epistemological beliefs assessment will give engineering and technology programs insight to whether their students have become more advanced and sophisticated thinkers during their matriculation.

CONCLUSIONS AND FUTURE RESEARCH

Currently, there are many initiatives underway to increase student enrollment in the fields of science, technology, engineering, and mathematics (STEM). Engineering education researchers are contributing to these initiatives by focusing their research on five major areas, and one of these areas of interest is engineering epistemologies or what constitutes the nature of engineering knowledge and ways of engineering thinking.

First, this study contributes to the overall epistemological beliefs literature in that it expanded King and Magun-Jackson's (2009) study and used Schommer's (1990) Epistemological Questionnaire (SEQ) to quantitatively measure the epistemological beliefs of engineering students across educational levels. This study's design and results also contribute to the engineering epistemologies research in that a comparison of engineering students' epistemological beliefs across educational levels has not been examined prior to this study, except for King and Magun-Jackson's (2009) research.

The findings of this study also suggest that engineering students' epistemological beliefs, at least their beliefs in Quick Learning, do indeed become more sophisticated as they progress through college. These findings are important to engineering education because they can be used to understand students' perspectives as they relate to learning engineering concepts. Furthermore, engineering educators would be able to use such findings as a quality control tool to identify the specific parts of the engineering curriculum that would influence learning outcomes relating to sophisticated or advanced cognitive processes (e.g., problem solving, critical thinking) in engineering students.

There are some limitations to this study. First, this study examined students from only three universities, and the universities were located in Tennessee. Therefore, the results cannot be generalized to all engineering students. Future research should be conducted to examine the epistemological beliefs of engineering students in other regions of the United States. A second limitation is that this study was cross-sectional. As a result, no assumptions should be made about engineering students' epistemological beliefs development. In order to begin to understand engineering students' epistemological beliefs development, a longitudinal study is also needed as future research.

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