AC 2010-91: A PILOT VALIDATION STUDY OF THE EPISTEMOLOGICAL BELIEFS ASSESSMENT FOR ENGINEERING (EBAE): FIRST-YEAR ENGINEERING STUDENT BELIEFS

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A Pilot Validation Study of the Epistemological Beliefs Assessment for Engineering (EBAE): First-Year Engineering Student Beliefs

Abstract

This paper presents a study assessing first-year students' engineering epistemological beliefs or beliefs about engineering knowledge and knowing. A small cohort of first-year engineering students pilot tested a new quantitative instrument called the Epistemological Beliefs Assessment for Engineering (EBAE). Student responses to the EBAE were used to validate the instrument and analyze the epistemological beliefs – certainty of knowledge, simplicity of knowledge, source of knowing, and justification for knowing – of first-year engineering students. Results of this study produced thirteen validated items, which gauged first-year engineering students' epistemological beliefs as slightly sophisticated – mean score of 63.8 ± 8.4 out of 100.

Introduction

In 2006, a special report addressing *The Research Agenda for the New Discipline of Engineering Education* identified five research areas to "inform how the content should be taught as well as how future learning environments should be designed";[1] one of these areas was Engineering Epistemologies. Epistemology is a branch of philosophy that concerns the nature and scope of knowledge and the process(es) by which knowledge is gained. Epistemology of engineering, therefore, addresses the questions of how we come to know engineering, what engineering learning is, and what constitutes engineering thinking and knowledge.

The inclusion of engineering epistemology as a main area of engineering education research exemplifies a shift in what is important to know, teach, and research about engineering. Emphasis placed on characterizing the nature of engineering knowledge is a major step into analyzing the "*inherently philosophical character of engineering*".[2] This aspect is often overlooked in engineering education even though a discussion of a philosophy of engineering and engineering education has occurred for some time.[3-11]

In this paper we will discuss a study we conducted looking at first-year engineering students' engineering epistemological beliefs; *i.e.,* the beliefs students hold to be true about the nature of engineering knowledge and the nature of knowing engineering.[12] We will first supply a brief history of the theory and the work that has been conducted to investigate epistemological beliefs with some insight into a philosophy of engineering. We will then describe the development of a quantitative instrument designed to measure engineering epistemological beliefs. Finally we will discuss the results of a pilot study that we conducted using our instrument to analyze first-year engineering students' engineering epistemological beliefs. These steps will be taken to answer two research questions:

1) Does our instrument accurately measure engineering epistemological beliefs?
2) What are the engineering epistemological beliefs held by first-year engineering students?

Literature Review

Epistemological Beliefs

Research of epistemological beliefs stem from Piaget's Theory of Intellectual Development (genetic epistemology [13]) and later Perry's Theory of Epistemological Development.[14] Perry's theory was intended to gain an understanding of how college students interpret pluralistic educational experiences; *i.e.,* how students make meaning of their educational experiences. His approach to investigating this question was to collect both quantitative questionnaire data and qualitative interview data. Analysis of the combined data sources supported a developmental theory consisting of nine positions or stages clustered into four sequential categories: 1) *dualism* (positions 1 & 2) – authorities or experts know the truth and convey it to learners or novices; 2) *multiplicity* (positions 3 & 4) – all views are equally valid; individuals have the right to hold a personal opinion; 3) *relativism* (positions 5 & 6) – knowledge is relative, contingent, and contextual; everyone is capable of making meaning; and 4) *commitment within relativism* (positions 7 through 9) – responsibility, engagement, and the forging of commitment to values, careers, relationships, and personal identity. Drawing on Piaget's theory, Perry hypothesized that shifts or changes from one position or category to another are brought on by disequilibrium or a state of flux. Interactions with the environment present the individual with an opportunity to assimilate the new information into their existing cognitive framework or accommodate the entire framework itself. Perry's work established a baseline for subsequent research studies to refine and extend Perry's developmental sequence;[15-19] unfortunately, very little agreement regarding the stages has ever been achieved across studies.

Schommer [19] approached the task from a different angle by challenging the notion that epistemological beliefs are unidimensional. She hypothesized that there is no general stage sequence, but rather a set of five dimensions with separate continuums ranging from naïve to sophisticated. Schommer's first three dimensions – structure of knowledge, certainty of knowledge, and source of knowledge – conceptually relate to Perry's work, while the latter two – control of knowledge acquisition and speed of knowledge acquisition – relate to research on beliefs about the nature of intelligence and contextualized beliefs.[20, 21] Schommer tested and validated the dimensions using purely quantitative measures from the Epistemological Questionnaire (EQ); an instrument designed to measure epistemological beliefs.

Schommer's work initiated a number of subsequent quantitative assessments of general epistemological beliefs [22-24] as well as context-specific epistemological beliefs.[25-28] Again the problem of consistency of dimensions persisted among the purely quantitative studies. Hofer and Pintrich [12] conducted a meta-analysis to clarify the construct of epistemological beliefs. From their analysis, four dimensions under the general categories of nature of knowledge and nature of knowing emerged to define and delineate the construct (Table I).

Table I: Dimensions of epistemological beliefs identified by Hofer and Pintrich.

Nature of Knowledge	
Certainty of Knowledge –	Is knowledge seen as fixed (absolutism - thinking all engineering knowledge is set in stone) OR fluid (relativism - making no distinctions between evidence-based reasoning and mere opinion)
Simplicity of Knowledge -	Is knowledge a bunch of weakly connected pieces without much structure, consisting mainly of an accumulation of facts and formulas (discrete, concrete, knowable) OR is it a coherent group of highly interrelated concepts (relative, contingent, contextual, unified whole)
Nature of Knowing	
Source of Knowing -	Is knowledge mostly a matter of fixed natural ability residing in external authorities (experts) OR can most people become better at or learn the ability to construct knowledge
Justification for Knowing -	Does learning consist mainly of absorbing information OR does it rely crucially on constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding

Engineering Epistemology

According to Grimson, *"It is important that engineers understand the nature and provenance of knowledge[…] How knowledge is 'discovered', recorded, communicated to others, used, and subsequently revised [...]"*.[5] Grimson's statement is the essence of engineering epistemology. When contextualized within the dimensions proposed by Hofer and Pintrich, the question that remains is how do engineers develop sophisticated beliefs about the nature of engineering knowledge and knowing?

In the literature, a prevalent pathway that has emerged from the discussion of a philosophy of engineering and engineering education has been the study of historical engineering endeavors.[3, 4, 29] Bucciarelli argues for the inclusion of the history of science and technique in engineering teaching to establish origins of the knowledge that facilitate a rooting of the knowledge. Vincenti[29] supports Bucciarelli's argument by using past engineering tasks to discuss '*What Engineers Know*'. The use of historical events provided Vincenti with a way to show that engineering knowledge is autonomous from scientific knowledge. As Loverde states, "science is to engineering as metaphysics is to common sense".[30]

The discussion of what constitutes engineering knowledge and knowing is still debated under the umbrella of a philosophy of engineering and/or engineering education; however, the philosophical writings presented here supply a sufficient basis to develop our epistemological assessment.

Research Methods

Participants & Procedure

The following study was conducted at a small private institution in the Northeast. Participants were obtained from a required first-year engineering course at the institution. Prior to data collection, the IRB approval and the professor's permission were obtained to allow us to distribute an online version of the instrument to students at the beginning of a lab session. Of the 191 first-year engineering students at the site of the study, only 51 students consented to participate in the study. From the 51 students who started the instrument, eight participant responses were removed because they did not complete the instrument fully or the student was not a first-year student; *i.e.* the lab instructor. The low participation rate (27%) is believed to be a result of reliance on the lab instructors to administer the survey to the students; lack of incentive, financial or curricular support (grade), for the students; and the time of year at which responses were requested (end of academic term).

The remaining 43 participants had an average age of 18.6 ± 0.5. The gender of the study participants was not collected; however, the institution's school of engineering had 29% female enrollment during the school year in which these data were collected.

Instrument

The instrument developed for this study was named the Epistemological Beliefs Assessment for Engineering (EBAE). This instrument was developed for the purposes of measuring an individual's engineering epistemological beliefs quantitatively.

The first step in developing the EBAE was to identify possible items to be included that would address engineering epistemological beliefs. This was accomplished by establishing a general idea for the focus of questions that should be asked by using items from previously used epistemological beliefs instruments as examples and templates. [25-28] The Epistemological Beliefs Assessment for Physical Science (EBAPS) [28] supplied the main base for the new instrument (Note: permission was obtained from the authors to use and modify their survey as needed). Some items were simple modifications of previously used items so that the new items addressed engineering. Additional items were developed to reflect the discussion of epistemology in the philosophy of engineering and engineering education writings. Using these methods we developed twenty-two items. Participants scored each item on a 100-point Likert-type scale with ten-unit intervals. A zero to 100-response format was used because it is a stronger predictor of performance than a five interval Likert scale [31] and because the population of interest – students – have a comfort level in using a 100-point scale. Care was taken to make sure that questions included equal numbers of those worded both negatively and positively to represent naïve and sophisticated beliefs respectively.

Items were then analyzed theoretically through the lens of Hofer and Pintrich's four hypothesized dimensions. This construct validity consideration was performed to test how well each item related to the chosen theoretical framework concerning engineering epistemological beliefs. Modifications to the items were made so that each of the twenty-two items could be classified under one of the four dimensions – certainty of engineering knowledge, simplicity of engineering knowledge, source of engineering knowledge, and justification of engineering knowledge. Each of the twenty-two items was subsequently used for the study; however, factor analysis, discussed in the Results section, was used later to determine which items would contribute to the analysis of first-year engineering students.

It should be noted that the sample size ($N = 43$) described in this study is less than the suggested minimum for factor analysis and as a result is a limitation of the study reported herein.[32-34] The first-year students do however represent a subset of a larger overall data source ($N = 322$) for which results of an unpublished factor analysis suggest that the results of the factor analysis described for this subset of first-year students are accurate.

Results

Survey Validation

The first step for this study was to perform factor analysis to validate the twenty-two items developed for the instrument. Principal Component Analysis (PCA) with Varimax rotation and a cutoff eigenvalue of greater than one [35] was performed to identify the number of factors. The initial PCA component matrix yielded seven components accounting for 68.1% of the variance. An analysis of the scree plot indicated that a more usable number of factors would be four, aligning the components with the number of dimensions identified by Hofer and Pintrich.

A secondary PCA was subsequently performed setting the number of factors to four and excluding loadings with eigenvalues less than 0.3. Results of the secondary PCA suggested that nine of the twenty-two items be removed from the analysis, as they did not show a significant loading for any of the prominent factors. The remaining thirteen items (Table II), comprising the four factors, accounted for 61.0% of the variance.

Table II: EBAE factors and items.

Factor 1: Certainty of Engineering Knowledge
"There is often an ideal solution for engineering design problems."
"Most engineering principles are set in stone and cannot be argued or changed."
"In most instances, traditional engineering ideas should be considered over new ideas."
Factor 2: Simplicity of Engineering Knowledge
"Engineering involves more than collecting information and developing solutions."
"When engineers don't understand an engineering concept, they should just ignore it and move on."
"A good engineering textbook should show how the material in one chapter relates to the material in other chapters."
Factor 3: Source of Engineering Knowing
"If an engineering student is having trouble in an engineering course, studying in a different way could make a difference."
"Someone who lacks natural engineering ability most likely cannot learn engineering."
"Most people can learn to think more like an engineer if they are given enough time."
Factor 4: Justification for Engineering Knowing
"Students usually understand engineering better when they present their solutions to their classmates and teachers."
"Engineering students learn best when a teacher or expert transmits his or her knowledge to them."
"Engineering textbooks written by engineering experts present the best way to learn engineering."
"Being good at engineering is a talent someone is either born with or not."

The thirteen items were further tested using confirmatory factor analysis (CFA). The four distinct factors were labeled with descriptive titles based on high-loadings of items (factor loadings greater than 0.50). These titles were aptly named after the four dimensions identified by Hofer and Pintrich: 1) certainty of engineering knowledge (*certainty*); 2) simplicity of engineering knowledge (*simplicity*); 3) source of engineering knowing (*source*); and 4) justification for engineering knowledge (*justification*). Each factor consisted of three items except for justification, which consisted of four items. The scores for the confirmed thirteen items were used to analyze the epistemological beliefs of first-year engineering students.

First-Year Engineering Students' Epistemological Beliefs

The general engineering epistemological beliefs of first-year engineering students were analyzed using the confirmed thirteen-item instrument. Average scores were used to generalize where the student cohort generally fell on the naïve to sophisticated scale.

An overall average of the thirteen items pertaining to the four dimensions of epistemological beliefs was 63.8 ± 8.4. The broken down scores show that first-year engineering students have a slightly sophisticated belief about both the nature of engineering knowledge and knowing. Their beliefs about the nature of engineering knowledge (certainty and simplicity; $M = 69.2 \pm 10.8$) were slightly greater than their beliefs about the nature of knowing engineering (source and justification; $M = 65.3 \pm 9.0$). Table III breaks down the average scores across the four dimensions. The most sophisticated engineering beliefs that first-year engineering students held regarded the simplicity of engineering knowledge. Their beliefs about the source of engineering knowing and the justification for engineering knowing were both slightly sophisticated scores. The highest naivety concerned the certainty of engineering knowledge, but even this mean score was on the sophisticated side of the scale.

Table III: Mean epistemological belief factor scores with standard deviations.

Factor	Mean	SD
certainty	57.8	17.5
simplicity	80.5	10.7
source	66.4	12.7
justification	64.1	12.8

Discussion

From our analysis, we were able to investigate a small sample of first-year engineering students' engineering epistemological beliefs. The four factors analyzed allow us to make some generalizations about the sophistication of the group's engineering epistemological beliefs. Overall, students held slightly sophisticated engineering epistemological beliefs ($M = 63.8 \pm 8.4$). The scores for the four dimensions were investigated to understand this overall score more clearly.

The mean score for certainty of engineering knowledge was 57.8 ± 17.5. This score presumes a slightly sophisticated belief. What we can conclude is that first-year students are just beginning to believe that engineering knowledge is not fixed. Just over half of the students accept new knowledge as fixed rather than fluid. It is hypothesized that internally they debate about the certainty of knowledge because most of their previous learning came directly from books representative of fixed knowledge resources. Depending on their first-year of higher education, many of them may still be learning in this fashion, further fostering a belief that knowledge is fixed.

The mean score for simplicity of engineering knowledge was 80.5 ± 10.7. This score presumes a moderately sophisticated belief. We can conclude that first-year engineering students are very clear on the fact that engineering knowledge is a coherent group of highly interrelated concepts and not just an accumulation of facts and formulas. The mean score's deviation from 100 suggests that perhaps the separation of the many different disciplines within engineering (mechanical, electrical, etc…) fosters a belief that some engineering knowledge is separate.

The mean score for source of knowing engineering was 66.4 ± 12.7. This score presumes a slightly sophisticated belief. We can conclude that first-year students slightly believe that engineering knowledge can be learned by all; however, the perceived sense of difficulty attached to engineering learning is hypothesized to be the reason for why engineering may not be something that all can learn or do.[36-37] Students throughout their education learn among diverse groups of learners. The perception that is gained through such an education system is that some individuals are better in certain areas than others. The natural inclination is to develop a belief that not everyone is capable of doing everything.

The mean score for justification of knowing engineering was 64.1 ± 12.8. This score presumes a slightly sophisticated belief. At this point in their education, many first-year engineering students have most likely not had a critical mass of experiences actively constructing their own understanding of a given subject. This is hypothesized to be the reason for why many students might still hold the belief that the only way to learn something is to passively absorb it from experts in a classroom setting. This belief is fostered by courses taught in this fashion at the university level and by how most students have been taught using passive methods throughout their K-12 education.

Conclusions

This study was conducted to validate a new instrument and to provide an assessment of the engineering epistemological beliefs held by first-year engineering students. Four factors were included and evaluated concerning students' beliefs regarding the nature of engineering knowledge – certainty of knowledge and the simplicity of knowledge – and the nature of engineering knowing – source of knowing and the justification for knowing. Factor analysis was used to confirm the four factors through 13 items. The four factors were then used to determine that first-year engineering students at this institution hold slightly sophisticated engineering epistemological beliefs. Average scores for each factor resulted in scores greater than 50 (scale of zero to 100). Further analysis of the instrument and first-year engineering students' epistemological beliefs is needed to ensure that the factors are stable in a larger population. Additionally, it is recommended that an exploration of predictors of epistemological beliefs be conducted to explore the variables that predispose students to have certain engineering epistemological beliefs.

Bibliography

1. Engineering Education Research Colloquies, *The research agenda for the new discipline of engineering education.* Journal of Engineering Education, 2006. 95(4): p. 259-261.
2. Mitcham, C., *The importance of philosophy to engineering.* Teorema, 1998. 17(3).
3. Bucciarelli, L.L., *Engineering Philosophy*. 2003, Delft, Netherlands: Delft University Press.
4. Engineering Meets Philosophy. *Abstracts, Workshop on Philosophy and Engineering,* 2007. Last viewed November 2009; http://philengtech.org/wp-content/uploads/2007/10/wpe2007abstracts.pdf.
5. Grimson, W. *The philosophical nature of engineering - A characterisation of engineering using the language and activities of philosophy.* in *American Society for Engineering Education Annual Conference*. 2007. Honolulu, HI.
6. Heywood, J. *Philosophy and engineering education. A review of certain developments in the field.* in *ASEE/IEEE Frontiers in Education Conference*. 2008. Saratoga Springs, NY.
7. Heywood, J. *Philosophy, engineering education and the curriculum.* in *American Society for Engineering Education Annual Conference*. 2008. Pittsburgh, PA.
8. Koen, B.V., *Discussion of the method. Conducting the engineer's approach to problem solving.* 2003, New York, NY: Oxford University Press.
9. Smith, K.A., *The Academic Bookshelf: Educational Philosophy.* Journal of Engineering Education, 2008. 92(3): p. 203-205.
10. Smith, K.A. and R.F. Korte. *What do we know? How do we know it? An idiosyncratic readers' guide to philosophies of engineering education.* in *ASEE/IEEE Frontiers in Education Conference*. 2008. Saratoga Springs, NY.
11. Royal Academy of Engineering. *Abstracts, Workshop on Philosophy and Engineering*. 2008. Last viewed November 2009; http://www.raeng.org.uk/societygov/phislophyofeng/pdf/abstract_papers.pdf.
12. Hofer, B.K. and P.R. Pintrich, *The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning.* Review of Educational Research, 1997. 67(1): p. 88-140.
13. Piaget, J., *Introduction a l'epistemologie genetique*. 1950, Paris, France: University of France Press.
14. Perry, W.G., *Forms of intellectual and ethical development in the college years: A scheme*. 1970, New York, NY: Holt, Rinehart, and Winston.
15. Baxter Magolda, M.B., *The affective dimension of learning: Faculty-student relationships that enhance intellectual development.* College Student Journal, 1987. 21: p. 46-58.
16. Belenky, M.R., et al., *Women's ways of knowing: The development of self, voice, and mind.* 1986, New York, NY: Basic Books.
17. King, P.M. and K.S. Kitchener, *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. 1994, San Francisco, CA: Jossey-Bass.
18. Kuhn, D., *The skills of argument*. 1991, Cambridge, UK: Cambridge University Press.
19. Schommer, M., *The effects of beliefs about the nature of knowledge in comprehension.* Journal of Educational Psychology, 1990. 82(3): p. 498-504.
20. Dweck, C.S. and E.L. Leggett, *A social-cognitive approach to motivation and personality.* Psychological Review, 1988. 95(2): p. 256-273.
21. Schoenfeld, A.H., *Beyond purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance.* Cognitive Science, 1983. 7(4): p. 329-363.
22. Kardash, C.A.M. and R.J. Scholes, *Effects of preexisting beliefs, epistemological beliefs, and need for cognition on interpretation of controversial issues.* Journal of Educational Psychology, 1996. 88: p. 260-271.
23. Schraw, G., L.D. Benedixen, and M.E. Dunkle, *Development and validation of the epistemic belief inventory (EBI)*, in *Personal Epistemology: The Psychology of beliefs about knowledge and knowing.*, B.K. Hofer and P.R. Pintrich, Editors. 2002, Erlbaum: Mahwah, NJ.

24. Wood, P. and C. Kardash, *Critical elements in the design and analysis of studies of epistemology*, in *Personal epistemology: The psychology of beliefs about knowledge and knowing*, B.K. Hofer and P.R. Pintrich, Editors. 2002, Erlbaum: Mahwah, NJ. p. 231-260.
25. Halloun, I. and D. Hestenes, *Interpreting VASS dimensions and profiles for physics students.* Science & Education, 1998. 7(6): p. 553-577.
26. Redish, E.F., J.M. Saul, and R.N. Steinberg, *Student expectations in introductory physics.* American Journal of Physics, 1998. 66(3): p. 212-224.
27. Stathopoulou, C. and S. Vosniadou, *Exploring the relationship between physics-related epistemological beliefs and physics understanding.* Contemporary Educational Psychology, 2007. 32(3): p. 255-281.
28. White, B., et al., *The epistemological beliefs assessment for physical science*, in *American Education Research Association*. 1999: Montreal.
29. Vincenti, W.G., *What engineers know and how they know it: Analytical studies from aeronautical history*. 1990, Baltimore, MD: Johns Hopkins University Press.
30. Loverde, L., *Science & engineering, philosophy and common sense.* Ingenierias, 1998. 1(2): p. 24-31.
31. Pajares, F., J. Hartley, and G. Valiante, *Response format in writing self-efficacy assessment: Greater discrimination increases prediction.* Measurement and Evaluation in Counseling and Development, 2001. 33: p. 214-221.
32. Comrey, A.L. and J.W. Osborne, *Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis.* Practical Assessment, Research, & Evaluation, 2005. 10(7).
33. Gorsuch, R.L., *Factor analysis*. 2nd ed. 1983, Hillsdale, NJ: Earlbaum.
34. MacCallum, R.C., et al., *Sample size in factor analysis.* Psychological Methods, 1999. 4: p. 84-99.
35. Rummel, R.J., *Applied factor analysis*. 1970, Evanston, IL: Northwestern University Press.
36. Stevens, R., K. O'Connor, and L. Garrison. *Engineering student identities in the navigation of the undergraduate curriculum.* in *American Society for Engineering Education Annual Conference & Exposition*. 2005. Portland, OR.
37. Stevens, R., K. O'Connor, L. Garrison, A. Jocuns, and D. M. Amos. *Becoming an Engineer: Toward a Three dimensional View of Engineering Learning.* Journal of Engineering Education, 2008. 97(3): p. 355-368.