AC 2012-4668: A FIRST STEP IN THE INSTRUMENT DEVELOPMENT OF ENGINEERING-RELATED BELIEFS QUESTIONNAIRE

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A First Step in the Instrument Development of Engineering-related Beliefs Questionnaire

Abstract

Acquisition of new knowledge, skills, and dispositions is recognized as a process of change, largely influenced by learners' beliefs (i.e. domain-specific beliefs, epistemological beliefs, and ontological beliefs) and the richness of their learning environment. Previous researchers have noted the influence of students' beliefs about knowledge on their learning and problem-solving specifically in math, science, and physics, yet little research has been done to examine a similar relationship in engineering. In this paper, we argue for the importance of such research and present a conceptual framework of engineering-related beliefs, as a vital first step. The purpose of this study is to develop a reliable and valid measure of Engineering-related Beliefs Questionnaire with desirable psychometric properties. First, the nature of engineering related beliefs were defined and described, including how they are likely to impact students' learning and problem-solving. Second, relevant instruments and research pieces were identified to construct a first version of Engineering-related Beliefs Questionnaire. Third, content validity test was conducted to discuss the critical steps of construct definition and delineation of the construct's content domain. For Engineering Epistemic Beliefs, five relevant constructs were revealed: engineering knowledge, skills, attitudes, identity, and values. For Engineering Epistemological Beliefs, four relevant constructs were revealed: certainty of engineering knowledge, simplicity of engineering knowledge, source of engineering knowledge, and justification for engineering knowing. For Engineering Ontological Beliefs, three relevant constructs were revealed: the ways that power shapes engineers (i.e. how society creates values of engineering), the ways engineers see themselves, and the ways they perceive their roles as engineers. Further testing of the instrument in engineering student population is needed to develop the final version of instrument.

Introduction

As a discipline evolves and matures from a rough, ambiguous territory toward an arena of systematic, reasoned inquiry, central intellectual issues come into focus. The discipline of engineering education now faces such a time, as scholars, researchers, and practitioners are devoting attention to creating categories for engineering education practices and engineering education research, articulating methods and processes[1]. *The Research Agenda for Engineering Education* suggests that the area of *engineering epistemologies*, as a key area for future research, is conceptualized as "research on what constitutes engineering thinking and knowledge within social contexts now and into the future (p.259)"[2]. They initiated a call for investigation about the essence of engineering knowledge and knowing, focusing on its technical, social, and ethical aspects, which are critical for solving engineering problems within dynamic and interdisciplinary environments. Accordingly, a number of scholars have investigated the nature of engineering knowledge and the role of engineers.[3 4 5 6 7 8 9 10 11]

This scholarly interest in engineering epistemologies is rising along with the emergence of the constructivist-interpretivist paradigm in engineering education. Increasingly, researchers have addressed that there are the benefits of and the need for an epistemological and methodological diversity within engineering education.[12 13 14 15] They argue that these changes in epistemic culture have been driving systemic reform in engineering education; and as a result began to influence engineering students' interpretation of their experience and the generation of their behavior. In other words, the change of epistemic culture lies in a core of basic beliefs and assumptions, which, despite often being unconsciously held, develop noticeably to become values and behavioral norms, which in turn guide intellectual choices and actions.[16]

This notion corresponds with the *social practices* view of epistemology that describes the ways of being a member within a specific *epistemic culture*[17]; such as observing from a particular point of view, representing data, persuading peers, engaging in special discourse, and so forth, locally defining knowledge[17 199]. The further a student progresses academically, the more they should be explicitly taught these disciplinary norms, and thus the more their academic learning experiences should mirror the authentic intellectual work of professionals. Accordingly, a number of researchers have shown an increased interest in exploring how, through particular learning events, questions of justification, reasonableness, and knowledge claims are negotiated among members of a group.

Understanding the belief structures of students is essential to improving their professional preparation and practices. Specifically, students' beliefs about the nature of engineering are keys to engineering education researchers' attempting to understand the intricacies of how students learn. It is thus worthwhile to investigate how students connect their educational experiences to engineering in practice; how they think about engineering knowledge; and how they conceptually understand engineering reality. However, the implicit interest and fascination that engineering educators and researchers have in beliefs have not become explicit, neither in their educational practices nor in research endeavors. When engineering students' specific beliefs are carefully conceptualized and appropriate assessment design and methodologies are chosen, their endeavors might become more viable and more rewarding engineering practices.

The present study is part of a larger study initiated to how individual's naïve theories (i.e. domain-specific beliefs[1], epistemological beliefs, and ontological beliefs) impact their performance in engineering. In this paper, a first step in the instrument development to establish a conceptual framework was addressed. We aimed to 1) conduct a thorough literature review that shows previous attempts to conceptualize the construct of Engineering-related Beliefs, in which the construct has been used as a useful independent or dependent variable, 2) extract relevant items and classify them into meaningful sub-dimensions, and 3) construct multidimensional scales of selected engineering-related beliefs domains.

Methods

The study conducted in two steps. First, a systematic literature review was conducted to find relevant research pieces and relevant items of Engineering-related Beliefs that were later sorted

[1] The present study uses 'domain' and 'discipline' interchangeably. According to Alexander (2006), it means formalized bodies of knowledge that constitute a subject area. She described that domain knowledge must be formally taught to students because they may not acquire it through their everyday experiences.

into sub-factors. Second, to come up with multidimensional scales of Engineering-related Beliefs items, a content validity test was conducted.

Systematic Literature Review

We selected three representative journals of engineering education: such as *Journal of Engineering Education* (JEE), *European Journal of Engineering Education* (EJEE), and *International Journal of Engineering Education* (IJEE). The search for JEE and IJEE were performed in Web of Science (up to January 2012) with the following search terms: "beliefs" or "perception" or "understanding" – AND – "survey" or "test(s)" or "questionnaire" or "scale"– AND – journal name (i.e. "Journal of Engineering Education", "International Journal of Engineering Education"). The search for EJEE was performed in EBSCOhost Academic Search Premier with the same search terms above. We also employed the ''snowball'' method to find additional empirical studies from the selected papers.

Studies were excluded according to predefined criteria such as non-English papers, editorials, studies of children and teenagers, and studies focusing on too specific situational themes. To identify the largest possible number of items, the initial search was not set up to discriminate between quantitative assessment and qualitative assessment. Some qualitative studies and performance-based tests were found to be irrelevant for Engineering-related Beliefs, however, and were, therefore, excluded.

The titles and abstracts of the selected papers were reviewed to identify relevant research pieces and instruments. Papers with no named instruments in the title or in the abstract were excluded for further study. When an assessment instrument had a clear name, the full-text paper was obtained. The original papers that explained the construction of the identified instruments and address the content of the instrument were thereafter retrieved. To exclude no well-grounded theory and widely used Engineering-related Beliefs instruments, books on engineering philosophy and scale development were consulted.[21 21 22]

For personal epistemology, we referred to Hofer and Pintrich's book, *Personal Epistemology: Psychology of Beliefs about Knowledge and Knowing*[23], which compiled all major works in the field with comments on similarities and differences and introduced to relevant instruments. This book was an invaluable aid to gain a great understanding of epistemological beliefs and their relationship to education. From this book, we selected three representative instruments, such as Schraw et al.'s Epistemic Beliefs Inventory (2002)[24], Wood and Kardash's Epistemological Beliefs (2002)[25], Hofer's Discipline-focused Epistemological Beliefs (Hofer, 2000)[26]. Additionally**,** we reviewed Carberry's *Epistemological Beliefs Assessment for Engineering* (EBAE)[27], which is the most current scale to assess engineering-specific epistemological beliefs. However, we found that there are some limitations in this scale. For example, the main factors of general epistemological beliefs instruments were adapted as a template without any domain-specific construct. The *Epistemological Beliefs assessment for Physical Science* (EBAP) supplied the main base for the EBAE. Only two items were detected to directly relate to engineering epistemology: one is about the differentiation of engineering from science: the other is about the importance of design in engineering.

Framework for Classification of Engineering-related Beliefs Items

To operationalize Engineering-related Beliefs, a framework was needed. The National Engineering Education Research Colloquies initiated a call for investigation about the essence of engineering knowledge and knowing, focusing on its technical, social, and ethical aspects, which are critical for solving engineering problems within dynamic and interdisciplinary environments[28].

Epistemology is a field of philosophy, whose object of study is the construct "knowledge" itself. That is, engineering epistemology is a topic of philosophy and engineering, whose object is the construct 'engineering knowledge' concerning the concept of 'truth', the logical structure of justification, and the relationship of engineering knowledge to 'reality'. We deal with epistemological beliefs, on the other hand, which are a special kind of belief, which is often treated as an empirical object of psychological inquiry.

Since we aimed to have a comprehensive model of Engineering-related Beliefs, we expanded the range of approaches as shown in Figure 1. As domain-specific beliefs, *epistemic beliefs* mean 'what we believe what the discipline and practice of engineering is'. As naïve theories, *epistemological beliefs* mean 'how we know what we know in engineering', whereas *ontological beliefs* mean 'what we believe is reality that engineering deal with'. These beliefs refer to assumptions within a specific discipline that individuals unconsciously assume, accept, or desire, irrespective of verifiability. [30]

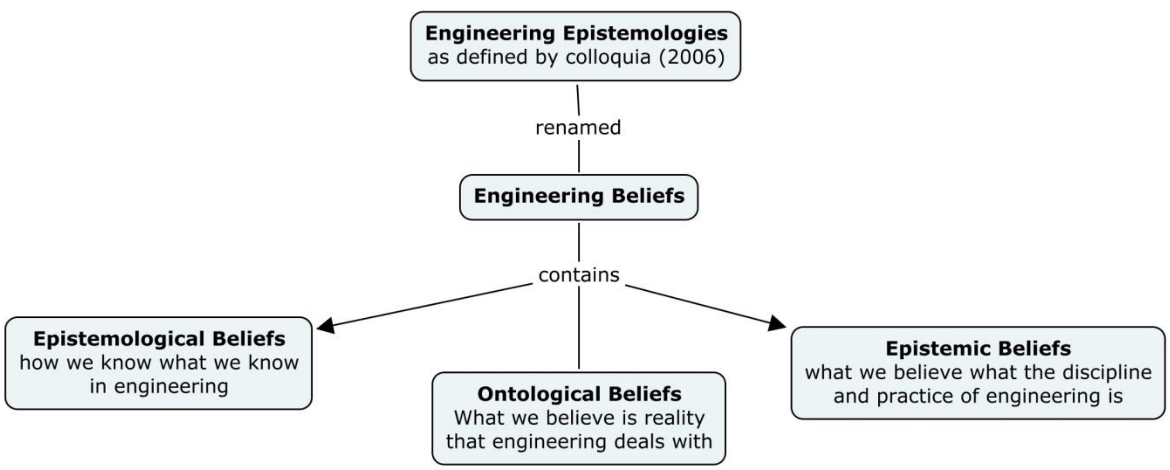

Figure1. Proposed Conceptual Framework of Engineering-related Beliefs System

This approach towards a three-factored belief system corresponds with cognitive science research on beliefs and knowledge development focusing on conceptual change in mental model. Since Vosniadou and Brewer (1992)[31] argued that learners' domain-specific beliefs consist of ontological and epistemic beliefs, many conceptual change scholars claim that both kinds of beliefs influence learners' interpretations and perceptions of domain concept information. For example, many educational researchers, such as Buehl and Alexander (2001)[32], Hofer (2000)[33], and Vosniadou (2002, 2007)[34 35], discriminate beliefs about knowledge into kinds, such as domain-specific beliefs, epistemological beliefs, and ontological beliefs.

Epistemological beliefs relate to how individuals believe the nature of knowledge and the process of knowledge development, while *Ontological beliefs*[36 37] refer to beliefs about the nature of the world, and the nature of being/becoming. The concept of *Epistemic Beliefs*, as domain-specific beliefs, was initially borrowed from Figueiredo's transdiciplinary framework (2008, 2011). Obviously, these three beliefs play critical roles in individual's intellectual development, because they evolve through daily experiences within specific socio-cultural settings. Although the inherent complexity in examining these inter-related beliefs is compounded by the fact that they are multi-dimensional and multi-layered in nature, it is thus imperative that engineering educators understand students' domain knowledge and beliefs in tandem.

Content Validity Test

Following the guidance of the literature across multiple domains, we took a first step to develop an item pool and identify construct definition and content domain. For content validity test, a focus group consisted of a total of eight participants, including faculty and graduate students. To develop an item pool, all included instrument from the literature review were scrutinized to detect Engineering-related Beliefs items that had been selected as relevant. Then, they evaluated construct definition and content domain by rating the importance of items and classified items according to sub-factors.

Results

The Literature Review

As shown in Figure 2, a total of seventy one papers retrieved from the systematic literature search. To identify well-grounded instruments with psychometric qualities, the search term for "or factor analysis" were retrieved, leaving ten papers (i.e. one out of nineteen from EJEE, one out of thirty one from IJEE, and eight out of thirty one from JEE). As noted earlier, four instruments were manually detected from the literature. Thus, a total of fourteen different instruments were included, which supports to define the constructs and develop and polish items to be situated in the field of engineering education. During this process, we removed redundant items, rephrased the statements of items, and created new items, to be specified in the context of engineering education. In total, eighty eight items for three beliefs (i.e. thirty two items for the four constructs of Epistemic Beliefs, thirty two items for the four constructs of Epistemological Beliefs, and twenty four items for the three constructs of Ontological Beliefs) were generated for the next step, content validity test.

Selection of Three Engineering-related Beliefs and Items

The initial item pool was evaluated by the focus group of faculty and doctoral students in engineering and education disciplines. They evaluated by matching each statement to constructs and identifying their confidence of those decisions.

Epistemic Beliefs We had explored the interdisciplinary nature of engineering as a discipline as well as a professional practice, by adopting Figueiredo's transdiciplinary framework of engineering epistemology (2008, 2011)[38 39]. He proposed a four-dimension epistemology of engineering: basic sciences, human sciences, design, and crafts. Table 1 presents the three-factored ranked statements from Epistemic Beliefs domain, as suggested by the focus group and evaluated by the authors with the final decisions.

Table1. Items of Epistemic Beliefs Ranked by Focus Group, with Final Decision on Item Pool

Construct	Ranked Activities Extracted from Epistemic Beliefs Items	Responses (n=8)	Final Item Pool
Engineering as Basic Science	Engineering is the application of science using a mathematical language.	7	Unchanged
	The language of mathematics is important to understand both science and engineering.	5	Unchanged
	Science and engineering are complementing each other.	4	Unchanged
	Engineers as a scientist require accurate record keeping, peer review, and replication.	4	Unchanged
Engineering as Human Science	Engineering's work somehow matters more than science's because of how it solved 'real' problems.	5	Changed to: no comparison
	Engineers and the engineering community generally display the professional standards of openness of mind and honesty.	6	Changed to: integrating two subjects
	Engineers themselves are influenced by cultural and personal factors, such as cultural norms and their own experiences.	6	Changed to: cultural norms and… deleted
	Engineers study the world in which they are a part and as such their work is not objective or value free.	5	Deleted: overlapped with ontological beliefs
	People from all cultures contribute to engineering.	6	Unchanged
Engineering as Design	Engineering design is problem-solving, where complex problems can be simplified to levels where they can satisfy minimal criteria for positivist solutions.	4	Unchanged
	Engineering design is a problem-setting, which views design as requiring the discovery and negotiation of unstated goals, implications, and criteria, following constructivist epistemologies.	4	Deleted
	Engineering is about designing artifacts and systems to change the world and overcome resistance and ambiguity.	6	Unchanged
	Engineering artifacts can be viewed as entities	6	Unchanged

	developed by key engineering design processes.		
	Engineers need to study aesthetic concepts and incorporate them in engineering design decisions.	5	Unchanged
	Engineering design, as scientific design, refers to modern, industrialized design—as distinct from pre-industrial, craft-oriented design-based on scientific knowledge but utilizing a mix of both intuitive and non-intuitive design methods.	5	Divided by two different sentences
	The development methods of engineering are design, invention, and production, whereas those of science are discoveries controlled by experimentation.	4	Deleted
	Engineering artifacts should have the appeal of being well made and well-functioning at its very early interaction with the customer.	4	Deleted

When the statements included two meanings, only one meaning (sentence) should be presented at the time. Thus, for these statements, the most inaccurate and irrelevant meaning was excluded. Despite a moderate level of agreement, some statements were suggested to be deleted, revised, and/or integrated.

However, the second evaluation of the selected items revealed that Figueiredo's four-dimension transdisciplinary epistemology of engineering has some limitations to develop clear definitions of the constructs and consistent dimensionality of Epistemic Beliefs, as domain-specific beliefs. The arguments were that the four constructs (i.e. basic sciences, human sciences, design and crafts) were unclear with regard to which specific belief they covered. It was not applicable in generating items about formalized bodies of knowledge, performance, and dispositions that constitute engineering as a specific subject area. Following the second review, David W. Shaffer's *epistemic frame*[40 41 42]was taken as the alternative theory in specifying dimensionality of Epistemic Beliefs. Shaffer defines *epistemic frame* as a network of connections between specific *identity* (i.e., the way in which members of the profession see themselves), *skills* (i.e., the things that people within a profession do), *knowledge* (i.e., the understandings that people in the profession share), *values* (i.e., the beliefs that members of the profession hold), and *epistemology* (i.e., the warrants that justify actions or claims as legitimate within the profession). Now, this five-factored structure of Epistemic Beliefs need to be further tested with operationalized definitions and relevant items, whereas the last component, *epistemology,* was distinctively conceptualized within in the domain of epistemological beliefs.

<u>Epistemological Beliefs</u> Under the guidance of personal epistemology literature, we adopted Hofer and Pintrich's claim[23] that beliefs about learning need to be distinguished conceptually from beliefs about knowledge and knowing. As a result, we extracted four possible constructs for epistemological beliefs. For example, the nature of knowledge includes certainty of knowledge (from absolute to contextual to relativism) and simplicity of knowledge (from simple to complex), while the nature of knowing includes the source knowledge (from reliance on authority to self-construction) and the justification for knowing (acceptance of facts to critical re-evaluation of expertise and context).

Table2. Items of Epistemological Beliefs Ranked by Focus Group, with Final Decision on Item Pool

Construct	Ranked Activities Extracted from Epistemological Beliefs Items	Responses (n=8)	Final Activity Item Pool
Certainty of Engineering Knowledge	Principles in engineering cannot be argued or changed.	7	Unchanged
	All engineering experts understand engineering problems in the same way.	5	Unchanged
	Most engineering problems have only one right answer.	5	Unchanged
	Most words in engineering knowledge have one clear meaning.	5	Unchanged
	Engineering knowledge should be accepted as an unquestionable truth.	6	Unchanged
	There is one universal engineering method.	7	Unchanged
	If you read something in a book for engineering, you can be sure it is true.	6	Unchanged
	If your personal experience conflicts with 'big ideas' in a book, the book is probably right.	4	Changed: book replaced
	Engineering knowledge cannot be subject to change with new observations by individual engineering students.	5	Unchanged
	Engineering textbooks written by experts presents the best way to learn engineering.	4	Changed: textbook replaced
Simplicity of Engineering Knowledge	Engineering knowledge is an accumulation of facts.	6	Unchanged
	Engineers can solve engineering problems by just following a step-by-step procedure.	4	Unchanged
Source of Engineering Knowledge	Traditional engineering ideas should be considered over new ideas.	4	Unchanged
	Correct solutions in the field of engineering are more a matter of opinion than fact.	4	Unchanged
	New engineering knowledge is produced as a result of discovery (mainly by controlled experimentation).	5	Deleted
	Engineering knowledge is created only from an expert's logical thinking.	7	Unchanged
	A theory in engineering is accepted as correct if engineering experts reach consensus.	5	Unchanged
	Engineering knowledge should rely on experts' observation, experimental evidence, and rational arguments.	5	Unchanged
	First-hand experience is the best way of knowing something in engineering.	6	Unchanged
	We can develop engineering knowledge, whenever an engineering expert transmits his or her knowledge to us.	7	Unchanged
	Understanding engineering principles written by experts is equivalent to getting the right solution for engineering problems.	4	Unchanged
	Engineering students learn when a teacher or expert transmits his or her knowledge to them.	7	Unchanged

Ontological Beliefs Ontological beliefs are defined as beliefs about the nature of reality and being.[404 455 466] Compared to epistemic beliefs and epistemological beliefs, the concept of ontological beliefs has not been widely applied to educational and psychological research.[48 498 49] Despite few empirical studies, a few scholars show interest in pursuing personal ontology.[50 511] For example, Packer and Goicoechea (2000)[50] examined how children are actively engaged in the ongoing reproduction of the classroom community of practice and how schools operate as sites for the production of persons. They described that children experience fundamental changes in the "being" of the child, saying "the shift from family member to student is already an ontological transformation" (p.235). Kincheloe (2003)[51] argued the importance of critical ontology for teachers. To become political agents, teachers should research their own practices and their own belief systems and world views. How they see themselves is influenced by the social, political, cultural, economic, and historical world (reality) around them.
Considering the developmental nature of ontological beliefs in the present study, we developed a unidimensional scale on the continuum that ranges from realism to relativism. Ontological realism refers that some entities are independent of our experience or knowledge, and of our concepts of them, while ontological relativism is the view that what exists is relevant to the language or culture in which one lives[52].

Table3. Items of Epistemological Beliefs Ranked by Focus Group, with Final Decision on Item Pool

Construct	Ranked Activities Extracted from Ontological Beliefs Items	Responses (n=8)	Final Activity Item Pool
Realism	Engineering is a study of objectively existing physical entities and the relationships among them.	7	Unchanged
	The statements made in engineering are true or false specifically dependent on the properties of those entities, independent of our ability, or lack of our ability to determine which is true.	5	Divided by two separate sentences
	Engineering has discovered a world, as a real structure, independent of our experiences and knowledge.	5	Unchanged
	If humans were not here, the universe would and the objects would still exist.	6	Unchanged
	There are existing physical entities and those entities are independent of humans.	6	Unchanged
	The ultimate truth is more or less the same thing as an objective reality.	5	Unchanged
Pragmatism	The value of constructed thought in engineering is assessed by the degree of its utility or effectiveness.	5	Unchanged
	Engineering knowledge originates in the learner's activity performed on objects.	4	Deleted
	Engineering community emphasizes the instrumental value of science in the manipulation of natural and social reality.	4	Unchanged
	Engineers seek for verifying the truth to learn the approximative use of engineering concepts in real world situations.	5	Unchanged
	Groups of individuals carve the world up through a process of social interaction and social negotiation.	4	Deleted

	It is meaningless to speak about the absolute reality of engineering objects.	4	Deleted
	We are determined by our social interactions, by environments that we grow up in, the negotiation, etc.	6	Unchanged
Idealism	Engineering model can be built by containing an "*unengineering*" way of thinking.	6	Deleted
	The reality that everyone is seeing is based on their experiences, their conceptions, and their interpretations.	6	Unchanged
	There is no world outside of human experience; the world is constructed or constituted by our discourse and theorizing.	6	Unchanged
	Every individual constructs their own reality based on social interactions that become a mediator of our phenomena or knowledge.	4	Unchanged

The present study developed a unidimensionality for engineering ontological beliefs; however, the possibility of multidimensional approach remains. As Kincheloe investigated how students and teachers see themselves in the relationship to the world, we can investigate "a way of being that is aware of the ways power shapes engineers (i.e. how society creates and maintain the values of engineering), the ways we see the world, and the ways we perceive our roles as engineers. When we have such understandings, we are better prepared to contribute to society by evaluating and improving what engineers are doing and what goals should be more promoted.

Discussion

To develop a valid and reliable instrument of Engineering-related Beliefs Questionnaire, we have performed a thorough literature review in philosophy, psychology, and education, and established the framework of Engineering Belief System, extracted items from existing relevant instruments, and classified the constructs described in the items. Although evidence for content validity revealed the need of critical refinement on the construct definition and item generation, the present study addressed the call for well-grounded research on personal epistemology and ontology within the field of engineering education. Through this study, a huge number of engineering-related beliefs items from existing studies have been collected. The psychometric properties of the three-factored engineering belief item pools developed through the present study need further testing in larger samples of engineering students, and a final version of the instrument should be developed based on the results from such data collection.

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