Measuring Engineering Epistemic Beliefs in Undergraduate Engineering Students

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***Abstract*—This study utilized a quantitative survey and open-ended items to understand engineering students' epistemic beliefs and gather content and face validity evidence. The survey included 22 items from the Engineering-Related Beliefs Questionnaire. Fifty undergraduate bioengineering students completed the survey. In addition to responding to the items on an anchored scale, the students were asked to provide short written explanations of their responses in a textbox below each item. Students' open-ended responses were analyzed using qualitative content analysis to gather content validity evidence and gain a general understanding of students' engineering epistemic beliefs. This analysis revealed inconsistencies with how students interpret the items and ambiguous terms used in the items. Based on the results of this analysis suggestions are made to improve the items on the survey for future use.**

I. Introduction

One method to prepare students to work in rapidly changing, multi-disciplinary environments is by encouraging students to make evaluative judgments and develop self-regulated learning and problem solving strategies. These skills have been shown to be influenced by students' epistemic beliefs [1]–[3]. Additionally, epistemic beliefs (beliefs about the nature of knowledge and knowing) have been shown to influence other attributes of learning and development such as metacognition and conceptual change [4], [5]. Students' discipline-specific epistemic beliefs have been measured using a variety of quantitative instruments; however, these instruments have been criticized recently due to a lack of reliability and validity [6]. Thus there is a need to improve existing measures for epistemic beliefs to establish valid and reliable instruments.

This paper presents the work from a larger study that seeks to understand connections between students' engineering epistemic beliefs and their epistemic cognition in the context of problem solving. The goals of this study were 1) to begin assessing the validity of engineering epistemic belief survey items by looking for a match between students' interpretations of the items and the intention of the items and 2) to gain a more complete understanding of students epistemic beliefs.

II. Prior Quantitative Studies on Engineering Epistemic Beliefs

Numerous studies conducted in Science, Technology, Engineering, and Mathematics (STEM) disciplines have utilized quantitative methods to study students' epistemic beliefs. These quantitative epistemic belief instruments have been met with criticism in recent years due to a lack of reliability and validity [7]. However, some insight can still be gained from the quantitative studies that have been done, providing the results are interpreted carefully.

Schommer [6] developed one of the first quantitative surveys to study epistemic beliefs, the Epistemological Questionnaire (EQ). This instrument is domain general and seeks to understand students' beliefs about certain knowledge, omniscient authority, simple knowledge, quick learning, and innate ability. Certain knowledge is conceptualized as an individual's beliefs about whether knowledge is stable or can change. Omniscient authority is the belief that knowledge is handed down by an authority figure rather than being constructed by an individual. Simple knowledge means that knowledge is made up of a series of facts rather than complex, interconnected concepts. Quick learning is the belief that individuals learn knowledge quickly or not at all. Innate ability is the idea that you are born with the ability to learn and this ability cannot be acquired. Domain general surveys, like the EQ, have received criticism, as students' epistemic beliefs have been shown to be dependent on discipline [7].

Hofer and Pintrich [8] developed a multi-dimensional theory of epistemic beliefs similar to Schommer's [6] that includes the nature of knowledge (certainty and simplicity of knowledge) and the nature of knowing (source of knowledge and justification for knowing). Based on this conceptualization of epistemic beliefs, Hofer [9] developed a discipline specific instrument to assess students' epistemic beliefs within a specific domain. Hofer's instrument is similar to Schommer's [6]; however, it includes justification for knowing and excludes innate ability and quick learning. This is important because innate ability and quick learning are not considered to be epistemic in nature as they measure students' beliefs about intelligence rather than knowledge [8].

Drawing on Hofer's [9] instrument, the Epistemological Beliefs Assessment for Engineering (EBAE) was developed and is composed of thirteen items across four dimensions: certainty of engineering knowledge, simplicity of engineering knowledge, source of engineering knowledge, and justification of engineering knowledge. The items on this instrument are measured using a 100 point scale. Compared to other epistemic belief instruments that have been used to study engineering students, this instrument is domain specific and asks students about their epistemic beliefs in engineering. Carberry et al. [10] conducted a pilot study (n = 43) to validate the EBAE instrument and assess first-year engineering students' epistemic beliefs. Analysis of students' general engineering epistemic beliefs revealed that the first-year engineering students surveyed believe that engineering knowledge is relatively fixed (certainity of knowledge construct) and that engineering knowledge is complex (simplicity of knowledge construct). The authors hypothesize that these students' beliefs about the certainity of engineering knowledge may be due to the majority of their prior learning coming directly from fixed knowledge sources like textbooks.

Their results also suggest that these students have an understanding that engineering knowledge is comprised of interconnected concepts. Despite the discipline specific nature of the survey items, they may still be too general for engineering students, as they may think of knowledge in engineering design very differently than they think of their content knowledge in courses such as statics. Also, students in different engineering disciplines may think differently (i.e. mechanical engineering vs. bioengineering). More work is needed to investigate the degree to which epistemic beliefs are domain specific. Additionally, this survey was validated with a sample size below the minimum value suggested for factor analysis, which brings into question the validity of the instrument. Despite the limitations of the study, EBAE is a step towards a validated, domain-specific instrument to investigate epistemic beliefs in engineering.

Yu and Strobel [11], [12] developed the Engineering Related Beliefs Questionnaire (ERBQ) to measure beliefs about the nature of knowledge and knowing. Items on the ERBQ were informed by Hofer and Pintrich's [8] framework and have similarities to the EBAE. This instrument was developed through a two step process that included a systematic literature review followed by a content validity study. Once an initial pool of items was established, a focus group was held with faculty and doctoral students in engineering and education disciplines. The focus group evaluated the items by matching them to one of the three constructs (simplicity, source, and certainty of knowledge). This instrument has not been widely used and further validation tests are needed to ensure reliability and validity of the instrument.

III. Theoretical Framework

The quantitative instrument used in this study included items from Yu and Strobel's [12] ERBQ. This instrument is based on Hofer and Pintrich's [8] epistemic beliefs framework and was designed to assess students' beliefs about the certainty, simplicity, and source of engineering knowledge. Beliefs about the certainty of knowledge range from absolute to contextual to relative. The structure of knowledge can be conceptualized from simple to complex based on the complexity of underlying concepts. Beliefs about the source of knowledge range from reliance on authority to self-construction. In Yu and Strobel's [12] instrument, these constructs (certainty, simplicity, and source of knowledge) are situated in the context of engineering. This instrument was used in our study to gain a general idea of the epistemic beliefs that students hold about engineering knowledge. Additionally, these items were assessed for their face and content validity because of the limited use of the ERBQ and the general concern in the field about the reliability and validity of scales measuring epistemic beliefs.

An example item from the certainty of engineering knowledge construct is "Principles in engineering cannot be argued or changed." One of the items from the simplicity of knowledge construct is "Engineering knowledge is an accumulation of facts." "First-hand experience is the best way of knowing something in engineering." represents one of the items from the source of knowledge construct.

IV. Methods

A. Participants

Participants were recruited from a junior-level biomechanics course at a land grant institution. Students in the course were invited to complete the survey instrument to gain extra credit in the class; however, the students were not required to participate in the study to get the extra points. Fifty of the sixty-eight students in the course completed the survey and were include din the study. Of the 50 students, 12 had been at the institution for two years, 35 for three years, and three for four years. The students reported a range of co-curricular experiences, including research, co-operative education, industry, and clinical experiences. Twenty-eight of the students had a least one semester of research expeirence, two students had co-operative education experience, six students had insdustry experience, and fifteen had clinical experience.

B. Instrument

The 22 items from the ERBQ were measured on a seven-point anchored scale from "Strongly disagree" to "Strongly agree." For each item, students were also asked to provide a written explanation of their response to the anchored scale in a text box below each item. This open-ended component was included to allow for deeper exploration of students' beliefs and to assess the validity of the items. Assessing the items' validity was particularly important becasue of a lack of studies establishing the instruments' reliability and validity.

An example item from the certainty of engineering knowledge construct is "Principles in engineering cannot be argued or changed." An item from the simplicity of knowledge construct is "Engineering knowledge is an accumulation of facts." An example item from the source of knowledge construct is "First-hand experience is the best way of knowing something in engineering."

C. Analysis

For each item from the ERBQ, students were prompted to explain their response in a text box below each item. Students' explanations of their responses were analyzed qualitatively to assess the content and face validity of the survey items and gain a deeper understanding of students' engineering epistemic beliefs. These responses were analyzed using conventional qualitative content analysis [13]. First, all responses to a single item were read through multiple times to gain a general understanding of students' beliefs in relation to that item and the diversity in the responses to that item. Next, statements about a single item were coded using open coding, allowing codes to emerge from the data. During the coding process, the researcher used both the quantitative and qualitative responses to the survey item to develop the codes to ensure that the students' beliefs were appropriately captured. These codes were compared across participants to understand the variations in how students responded to a single item. Codes were also compared to the constructs identified by Yu and Strobel's [12] to assess the agreement between students' interpretations of the items and the researcher's intended interpretation. To ensure quality in the qualitative analysis the primary researcher discussed emerging codes and trends with the other members of the researcher team. Additionally, the researchers discussed the items students interpreted differently than each other and/or Yu and Strobel's [12] work to rephrase the items for clarify and in turn increase the instruments' validity.

V. Results and Discussion

The aim of this study was to gather evidence of content and face validity by looking at student interpretations of items. A subset of data collected from the source and certainity of knowledge constructs are presented here to display the main challenges observed with the instrument. A summary of suggestions for rephrasing the items based on our analysis of the data collected can be found in Table 1.

A. Certainty of Engineering Knowledge

1) Principles in engineering cannnot be argued or changed: A few students made statements that suggested that their belief is dependent on the type of knowledge they are considering. Students who expressed this idea did not provide consistent numerical responses to this item, ranging from two to seven. One student that responded with a five stated, "Principles such as equations cannot be changed and these are the foundation to solve many engineering problems. However, different approaches can be argued or changed." Another student whose numerical response was two explained, "Basic mathematical and physical laws cannot be changed but the ideas and implementations can." The similarity in the students' written responses but difference in their numerical responses suggest that students' responses might not accurately reflect their beliefs. This may be further explained by students' lack of a single conceptualization of engineering principles. Students interpreted the phrase "engineering principles" as mathematical equations, laws, theories, and founding ideas. Rephrasing this item to use language more familiar to students, such as "theories or laws," may lead to more consistent interpretation.

2) Engineering problems have only one right answer: While most of the students disagreed with this item, there was some inconsistency in students' written explanations. Some students responses to this item referred to a problem's answer and others referred to the solution. For example, one student responded with a two and stated, "While there may be one answer to a problem, there can be multiple conclusions as far as how it was achieved." This statement suggests that this students beliefs about the answer and the solution to an engineering problem are different. Perhaps rephrasing the item to "Engineering problems have only one right numerical answer" would take into account this distinction.

Additionally, some students' responses suggest that they have different beliefs about engineering problems in the classroom compared to the broader engineering community. One student stated, Perhaps not in real world scenarios with many variables, such as cost and effectiveness. Another student made a similar comment and explained, "It depends on the situation. There are many different ways to fix different fractures and medicines, however given problems tend to be only one answer." Both of these students made statements suggesting that they were thinking about both problems in the classroom and in the broader engineering community. Additionally, their beliefs about problems are dependent on context, problems in the classroom and outside the classroom. For most of the other students responses, it is not possible to tell what context they are thinking about when they answered this item. This presents a challenge for data analysis because it creates inconsistency across student responses making it difficult to compare students responses. To account for this ambiguity the item could be rephrased to specify the context that the researcher wants the participant to think of when answering the item, such as the engineering classroom, an engineering research lab, or in engineering practice.

3) There is one universal engineering method: Almost all of the students disagreed with this item. Students described that they disagreed because there are multiple ways to solve problems and everyone thinks differently. For example, one student stated, "There are multiple methods to solving [a] problem." Another student said, "Definitely not, people have different techniques to solve problems which gives us [in] the engineering world an advantage to have many solutions because everyone's doing it differently." Students' numerical and written responses to this item suggest that students are interpreting this item in similar ways and rewording is not necessary.

4) Engineering knowledge should be accepted as an unquestionable truth: Almost all of the students disagreed with this item and said that engineering knowledge should not be accepted as unquestionable truth. Students stated that they disagreed with this item for multiple reasons, such as engineering has failed in the past, nothing is certain, and everything should be questioned and tested multiple times. One student said, "Engineering fails all the time. To call it unquestionable would be to ignore every collapsed bridge, every recalled drug, and every failed automobile." Another student explained, "No, it can always be questioned. The focus of engineering is developing the best possible solution, there is always a better way to do something." Like the previous item, students' responses to this item were consistent and rewording is not necessary.

B. Source of Engineering Knowledge

1) Engineering knowledge cannot be subject to change with new observations by individual engineering students: Within the students who disagreed with this item, some believed an individual student could influence change while others believed it takes a group of individuals. For example, one student explained, "Usually the students work non-individually, but when they work in groups, engineering knowledge absolutely can change." In contrast, another student stated, "If one person makes an observation, it can begin a cycle of new discoveries." While both of these students disagreed with this item, differences in their beliefs were not captured by the instrument. Some of the students' description of their responses suggested that they hold different beliefs about whether students or individuals can influence engineering knowledge. Breaking this item into two separate items may result in more consistent interpretation by capturing students' beliefs about both individuals and engineering students.

2) New engineering knowledge is produced as a result of controlled experimentation: The majority of the students agreed with this item, explaining that new engineering knowledge comes from experimentation and that controlled experimentation is necessary to truly test a hypothesis. One student expressed that "Engineers use experiments to develop new ideas and theories." Another student stated, "You need to have a controlled experiment to reduce the different variables that can affect it." Based on students' responses to this item it seems like some students are thinking about experimentation and others are specifically thinking about controlled experimentation. This may lead to inconsistency in their responses. The detail of "controlled experimentation" might also make it more difficult for students to answer as some of the students expressed the belief that in engineering it is impossible to control anything, "Yes and no. I don't think you can control an environment too well in engineering but to be certain, technically it should be a controlled experiment." Rephrasing this item to read "New engineering knowledge is produced as a result of experimentation" may help students more reliability respond to this item.

3) The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us: Students' responses to this item were split between agreeing and disagreeing. The students who agreed with this item seemed to hold the belief that learning from an expert is the easiest way to learn. One of the students stated, "The best way to learn is to learn from someone who knows significantly more and can explain the background," suggesting that this student believes that she is gaining an additional benefit by learning from an instructor. Another student that agreed with this item said, "...and to teach the knowledge interactively," adding a stipulation about how she feels instruction should look. Based on this students' justification of her answer it does not seem like this student truly agrees with the statement as it is written despite her numerical response of 6. Perhaps this student read past the "transmitting his or her knowledge" piece of the item, slightly changing the item's meaning. This was not the only student who struggled with the phrase "transmitting his or her knowledge." Another student said, "If by transmit his or her knowledge it is meant that the expert acts as an adviser and facilitator to experimentation, then yes. If by this you mean lectures, then no." This student's statement suggests that the phrasing of this item is ambiguous and adding more detail might help to clear it up. This may also decrease some of discrepancies that seemed to exist between student' numerical and written responses.

4) If your personal experience conflicts with the 'big ideas' in a book, the book is probably right: Students responses to this item are split between agreeing and disagreeing with the statement. A few of the students who agreed expressed that "I trust the books selected for us" and "If it is published then it should be right." While other students who agreed did not seem to believe as strongly that the book should be trusted and stated, "The book is usually right because there are multiple professors that have written and researched about. However, there is always a chance that they are wrong." Based on these two students' written responses it is apparent that these students hold different beliefs about this item; however, this item is not capturing this difference. Removing "probably" from this item may help distinguish students' responses and further differentiate students who hold different beliefs. Additionally, a number of students expressed a similar belief as the second example, but disagreed with the item stating "there is a chance the book is right." The fact that students who hold similar beliefs are not providing the same numerical response suggests that this item is not consistently capturing students' beliefs. Other students who disagreed with this item mentioned that "there's probably more to it" and that "for a grade-yes. in reality, the book probably just goes about it in a different way." These statements suggest that for some students their beliefs are influenced by the context of the situation, but this item does not currently take context into consideration. Based on students' responses, making this item more specific to a context such as the engineering classroom or engineering practice will help ensure that the students are thinking about the same context and their responses are being interpreted correctly.

5) Engineering textbooks written by experts present the best way to learn engineering: The majority of the students disagreed with this item. Students described that textbooks may not help understanding. "No, books are the worst, they are missing that ability to help new minds understand the material, they just say it." Additionally, students believed that everyone thinks differently and that interactive teaching methods are the more helpful, "In class practice and exercise would be more useful than just reading a book." Students' responses to this item did not seem to suggest problems with how the item is worded; however, it might be useful to be more specific about how the books are being used. For example, the item could be rephrased to read, "Reading engineering textbooks written by experts present the best way to learn engineering." This might be necessary for the use of this instrument with a larger, less homogenous population where there might be more unique interpretations of this item.

6) A theory in engineering should be accepted as correct if engineering experts reach consensus: Most of the students agreed with this item; however, they provided two unique explanations for their responses, which included the idea that theories can be disproven and that if experts agree then the theory is most likely the truth. Despite agreeing with this item, some students described that even after being accepted as correct the theory could be disproven. One student stated, "...at least until a better theory is found", showing how she believes that new knowledge can prove prior knowledge to be inadequate. The students who mentioned that it could be accepted unless it is disproven seem to be expressing their belief about the certainty of engineering knowledge more so than their belief about the source of engineering knowledge. These students' responses suggest that even though the item was developed to measure students' beliefs about the source of knowledge it is also getting at their beliefs about the certainty of knowledge.

Other students' explanations of their responses seem more consistent with their numerical responses than the example above. Some students believe a theory should be accepted since it was accepted by experts: "If experts agree the theory is correct then it should be considered correct seeing as that the experts should be the most knowledgeable on the subject." Other students described that it should be accepted since multiple people agree: "If multiple people reach the same consensus then it is most likely true." This item does not allow the distinction between expert consensus and a consensus among multiple people regardless of expertise. If this distinction is important to the researcher, then this item could be split and rephrased to make two distinct items to capture this nuance.

7) Traditional engineering ideas should be considered over new ideas: The majority of the students disagreed with this item and described how the new ideas may improve upon traditional ones. One student described, "If the new ideas are corrected and takes into account variables that have not been looked at before then you should definitely look at the new ideas." Other students expressed the belief that all ideas should be considered: "They should be utilized but new ideas are valid too." Based on students' numerical and written responses to this item there do not seem to be any major inconsistencies that would suggest rewording is needed.

8) Engineering knowledge is created only from an expert's logical thinking: Students seemed to either focus on whether they believe an expert or logical thinking can create engineering knowledge; it is unclear if they considered both parts of this compound item (expert and logical thinking). A student might believe that engineering requires experimentation and not just logical thinking, so the fact that an expert is doing the thinking does not matter. One student said, "Logical thinking alone either does not give you new information or can be wrong. Engineering utilizes experimentation and results combined with logical thinking to come to its conclusions." Likewise, a student might hold the belief that anyone can create engineering knowledge and disagree with the item because it says "expert". One student described, "Nope, [they] can be a crafty soccer mom on Pinterest making her life easier with a new way to fold socks." Based on students' responses to this item, it may be beneficial to split this item into two items to capture students' beliefs about knowledge coming from experts and knowledge being created by logical thinking.

9) First-hand experience is the best way of knowing something in engineering: The majority of the students agreed with this item and explained that this type of instruction helps them learn better, stating that "Experiencing something yourself helps you learn and understand how something works." Students' responses on this item appeared to be consistent with their numerical response. Additionally, there did not appear to be any inconsistencies with how students were interpreting this item. Since there is not much variation, this item may not prove to be very valuable when comparing students; however, the lack of diversity in responses may have been the result of the population that was surveyed. A few students either disagreed or gave a neutral response, stating that "It is a good way but if you don't have the basic knowledge to understand what is happening it does no good and [it is] not necessarily the best for everyone". It would be interesting to investigate these specific cases to further understand the students' responses and possibly modify this item to capture more diverse beliefs.

10) You can count on the information you find in engineering books to be true: Many students made statements that revealed their belief that engineering knowledge is constantly changing, which gives insight into students' beliefs about the certainty of knowledge. This may negatively influence the internal consistency of this construct (source of engineering knowledge). Some of the students who agreed with this item also expressed the belief that engineering knowledge is constantly changing. One student said, "For the most part, yes. But in a developing field, it's hard to say that anything is true absolutely." Students that expressed similar beliefs but responded with different numerical responses to this items suggests that this item may not be reliably measuring beliefs. Perhaps rephrasing this item to say, "You can count on the information you find in engineering books" may help students focus on the source of knowledge rather than the certainty of knowledge.

A few of the students who agreed with this item expressed that the book should be used as guidance rather than pure fact, saying "Most of the time the information you find in books is correct for the situation the book describes. All the information in the world is no good without the perspective to use it." Other students that agreed with this item expressed that knowledge in engineering books is true because "it is proven and accepted" and "they were able to be published for a reason". Currently this item is not able to distinguish these beliefs. Perhaps separate items are needed to address perceived differences between theoretical and practical knowledge.

11) Engineering students learn when a teacher or expert transmits his or her knowledge to them: Most of the students agreed with this item but expressed that this is not the only way to learn, and experience is needed as well. One student said, "It is helpful to learn from someone with so much background knowledge, but the teacher must also be able to relate the knowledge to students at a level they can understand." Based on students' responses to this item there does not appear to be any major inconsistencies that need to be mitigated by rephrasing the item; however, the item is nearly identical to a previous item on the survey, "The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us." As such, one of the items should either be rephrased or removed to get rid of this redundancy. This item could be rephrased to read "Engineering students learn when a teacher transmits his or her knowledge to them."

VI. General Discussion

This study sought to gather content and face validity evidence by looking into student interpretations of item wording and further explore students' epistemic beliefs. Based on students' open-ended responses, many students hold unique beliefs about knowledge inside and outside the engineering classroom resulting in neutral responses to the items on the instrument as they do not distinguish between these contexts. Designing the survey to target students' beliefs about specific contexts may help make that distinction. Our findings support current research suggesting that epistemic beliefs are both discipline and context specific [7], [9]. Future studies should aim to clarify items to eliminate ambiguities from the context students are thinking about when responding to an item.

There were other ambiguities within the survey items that limit comparisons between student responses. Students interpreted the phrase "principles in engineering" to mean laws, theories, founding ideas, and mathematical equations. Also, when asked about engineering problems having only one right answer, some students thought of a problem solution while others thought of an answer to a problem. This result may be an artifact of the course the students were taking, in which the instructor placed an emphasis on the problem solving process, which may have accentuated students making the distinction between a problem solution as a process and an answer as numerical.

A few items were interpreted by students in two ways, suggesting that these items are compounded. To help ensure that students are interpreting the item in a similar way, these items should be split into two separate items. Additionally, two of the items designed to measure the source of engineering knowledge ("A theory in engineering should be accepted as correct if engineering experts research consensus" and "You can count on the information you find in engineering books to be true") elicited responses related to students' beliefs about the certainty of knowledge. The overlap between these two constructs may negatively impact the internal consistency reliability of the constructs. These items should either be reworded to be more specific to the construct source of engineering knowledge or removed in future iterations of the survey.

Future work should also include the implementation of this survey with a larger sample of engineering students from different majors. The survey was given to students in a single biomechanics course for this study. These students had similar curricular experiences and backgrounds, which may have limited the ways in which students interpreted items. Giving the survey to a more diverse group of students may reveal additional ambiguities with the instrument that need to be addressed.

VII. Conclusion

This work adds to our current understanding of engineering students' engineering-specific epistemic beliefs through both quantitative and qualitative survey data. The results of this work can also be used to inform the development and revision of items to establish more reliable and valid instruments to capture engineering students' epistemic beliefs.

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Table I. Summary of suggested edits to items on the ERBQ.

	Original Item	**Suggested Phrasing**
Certainty of engineering knowledge	Principles in engineering cannot be argued or changed.	Theories in engineering cannot be argued or changed.
	Engineering problems have only one right answer.	Classroom engineering problems have only one right answer. Engineering problems outside the classroom have only one right answer.
	There is one universal engineering method.	No change needed.
	Engineering knowledge should be accepted as unquestionable truth.	No change needed.
Source of engineering knowledge	Engineering knowledge cannot be subject to change with new observations by individual engineering students.	Engineering knowledge cannot be subject to change with new observations by individuals. Engineering knowledge cannot be subject to change with new observations by engineering students.
	New engineering knowledge is produced as a result of controlled experimentation.	New engineering knowledge is produced as a result of experimentation.
	The best way to develop engineering knowledge is by an expert transmitting his or her knowledge to us.	The best way to develop engineering knowledge is from an expert's teaching.
	If your personal experience conflicts with the 'big ideas' in a book, the book is probably right.	In an engineering class, if your personal experience conflicts with the 'big ideas' in a book, the book is probably right.
	Engineering textbooks written by experts present the best way to learn engineering.	Reading engineering textbooks written by experts present the best way to learn engineering.
	A theory in engineering should be accepted as correct if engineering experts reach consensus.	Remove item because not specific to the source of engineering knowledge.
	Traditional engineering ideas should be considered over new ones.	No change needed.
	Engineering knowledge is created only from an expert's logical thinking.	Engineering knowledge is created only from logical thinking. Engineering knowledge is created only by an expert.
	First-hand experiences is the best way of knowing something in engineering.	No change needed.
	You can count on the information you find in engineering books to be true.	You can count on the information you find in engineering books.
	Engineering students learn when a teacher transmits his or her knowledge to them.	Engineering students learn when a teacher transmits his or her knowledge to them.

References

[1] K. R. Muis, "The Role of Epistemic Beliefs in Self-Regulated Learning," *Educational Psychologist*, vol. 42, no. 3, pp. 173–190, jul 2007. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1080/00461520701416306

[2] R. Bromme, S. Pieschl, and E. Stahl, "Epistemological beliefs are standards for adaptive learning: a functional theory about epistemological beliefs and metacognition," *Metacognition and Learning*, vol. 5, no. 1, pp. 7–26, dec 2009. [Online]. Available: http://link.springer.com/10.1007/s11409-009-9053-5

[3] D. Montfort, S. Brown, and N. Frye, "Work in progress: Theoretical approach to characterizing changes in students' and engineers' conceptual understanding and personal epistemologies," *Proceedings - Frontiers in Education Conference, FIE*, pp. 1–3, 2012.

[4] G. M. Franco, K. R. Muis, P. Kendeou, J. Ranellucci, L. Sampasivam, and X. Wang, "Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics," *Learning and Instruction*, vol. 22, no. 1, pp. 62–77, feb 2012. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0959475211000466

[5] B. K. Hofer, "Personal epistemology research: Implications for learning and teaching," *Journal of Educational Psychology Review*, vol. 13, no. 4, pp. 353–383, 2001.

[6] M. Schommer, "Effects of beliefs about the nature of knowledge on comprehension," *Journal of Educational Psychology*, vol. 82, pp. 498–504, 1990.

[7] T. K. DeBacker, H. M. Crowson, A. D. Beesley, S. J. Thoma, and N. L. Hestevold, "The Challenge of Measuring Epistemic Beliefs: An Analysis of Three Self-Report Instruments," *The Journal of Experimental Education*, vol. 76, no. 3, pp. 281–312, apr 2008. [Online]. Available: http://www.tandfonline.com/doi/abs/10.3200/JEXE.76.3.281-314

[8] B. K. Hofer and P. R. Pintrich, "The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning," *Review of Educational Research*, vol. 67, no. 1, pp. 88–140, 1997.

[9] B. K. B. Hofer, "Dimensionality and Disciplinary Differences in Personal Epistemology." *Contemporary educational psychology*, vol. 25, no. 4, pp. 378–405, oct 2000. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/11001783

[10] A. Carberry, "A pilot validation study of the epistemological beliefs assessment for engineering (EBAE): First-year engineering student beliefs," *American Society for Engineering Education Conference Proceedings*, 2010.

[11] J. H. Yu and J. Strobel, "Instrument Development : Engineering-specific

Epistemological, Epistemic and Ontological Beliefs," *Proceedings of the Research in Engineering Education Symposium*, pp. 1–8, 2011.

[12] ——, "A first step in the instrument development of engineering-related beliefs questionnaire," in *American Society for Engineering Education*, 2012.

[13] H.-F. Hsieh and S. E. Shannon, "Three approaches to qualitative content analysis." *Qualitative health research*, vol. 15, no. 9, pp. 1277–88, nov 2005. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/16204405