Epistemology in Engineering Education: An Overview

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Abstract

Epistemology is a branch of philosophy, a study of how a person knows and knowing. Engineering epistemology is one of the new disciplines in engineering education research. Unfortunately, little research has been done on engineering education. In this paper, epistemology is discussed in the general context then, specifically for the engineering education context. Furthermore, the engineering epistemology framework and instrument to investigate engineering epistemology among engineering educators and students have been presented. Theory for knowledge development has been discussed in general and how that developmental model is important for higher education. Finally, epistemology in teaching and learning has been introduced in the context of engineering educators and engineering students. In summary, engineering educators' epistemology will shape future engineers based on their class design. Therefore, developing engineering students from dualists to commitments of the relativist is very important. Finally, suggestions for engineering faculty management in developing engineering educators and engineering students for a better teaching and learning experience are provided.

Keywords: Epistemology, Engineering Educators' Epistemology, Engineering Students' Epistemology, Critical Thinking.

Introduction to Epistemologies

One of the branches of philosophy is epistemology. Epistemology comes from Greek words 'episteme' and 'logos' where episteme can be defined as 'knowledge' or 'understanding' or 'acquaintance' whilst logos brings a meaning of 'account' or 'argument' or 'reason'. Therefore, epistemology is a study of knowledge and knowing that concerns the nature and justification of human knowledge (Hofer, 2001; Hofer & Pintrich, 1997). The interest in epistemology is to know what knowledge is, how a person acquires it and what does a person knows.

Research related to epistemology was initiated by Piaget (1950) where he inquired about the individual development of the conception of knowledge and knowing. He used the term genetic epistemology and his work has grown with different terms such as epistemological belief, ways of knowing, epistemology reflection, epistemic belief, and reflective judgment.

A person who knows what knowledge is must be able to justify the knowledge as well as belief in it. To make justification, good quality, logical and reasonable evidence are required. Therefore, the two branches of epistemology are empiricism and rationalism (Ezebuilo, 2020; Shah et al., 2020). Empiricism obtained true knowledge from sensory for example by observation and experience. Nevertheless, rationalism is primarily based on reasoning such as rational and logical human minds.

As mentioned before, epistemology is a branch of philosophy but why it is important in the engineering field? Based on the definition of epistemology itself, a study of knowledge, epistemology in engineering is important in discussing the limits and possibility of creating and reporting new knowledge. Moreover, epistemology and pedagogical implication give a big impact in transforming the current engineering curriculum towards a holistic curriculum. As mentioned by Fatehiboroujeni (2018), an educator needs to have a conception of the field as a whole, of the aims, methods, and standards (Scheffler, 1973). For that reason, engineering educators should not only deal with skills and engineering knowledge only but need to equip themselves with a method to deliver the knowledge to non-practitioners, novices, or students. Hence, formulation of overall conceptions, methods, and standards of engineering and delivering those components to the curriculum of educator training is a task of philosophy of engineering (Fatehiboroujeni, 2018).

This paper is presented as follows. In the next section, engineering epistemologies are introduced. After that how knowledge is developed is discussed in the Developmental Model section. Then, epistemology in teaching and learning has been discussed in the

context of engineering educators and engineering students. Finally, this paper is concluded by suggesting action that can be taken by engineering faculty management in improving better teaching and learning experience for engineering educators and engineering students.

Engineering Epistemologies

Barker et al. (2006) reported the five research areas for the new discipline of Engineering Education as engineering epistemologies, engineering learning mechanism, engineering learning systems, engineering diversity and inclusiveness, and engineering assessment. Engineering epistemologies are defined as research on what constitutes engineering thinking and knowledge within social contexts now and into the future.

A conceptual framework of engineering epistemology adopts from Yu & Strobel (2011, 2012) as shown in Figure 1. Engineering epistemology was renamed as engineering beliefs which consist of epistemological beliefs, ontological beliefs, and epistemic beliefs. The definition of epistemological belief is the same as mentioned before, but the knowledge will be in the context of engineering. Ontological is a branch of metaphysics that brings the meaning of the nature and role of reality. Therefore, in the context of engineering epistemology, the definition is defined as a belief in the reality that engineering deals with. Kitchener K. S. (2002) defines epistemic belief as a belief of knowledge. Yu & Strobel (2012) refer the knowledge as discipline and practice in engineering. In other words, epistemic belief in engineering epistemology based on Yu & Strobel (2012) can be defined as a belief what the discipline and practice in engineering.

The dimensions for each belief are listed in Table 1 (Yu & Strobel, 2011, 2012).

Table 1. Dimension of engineering beliefs

Engineering Beliefs	Dimensions
Epistemological Beliefs	• Certainty of Engineering knowledge • Simplicity of engineering knowledge • Source of engineering knowledge
Ontological Beliefs	• Realism • Pragmatism • Idealism
Epistemic Beliefs	• Human Sciences • Basic Sciences • Design • Crafts

The epistemological beliefs were adopted from Hofer & Pintrich (1997) that contain two areas: nature of knowledge and nature of knowing. Two domains within the area of nature of knowledge are certainty of knowledge and simplicity of knowledge while two domains within the area of nature of knowing are the source of knowledge and justification for knowing. However, Yu & Strobel (2012) incorporate justification for knowing into a source of engineering knowledge.

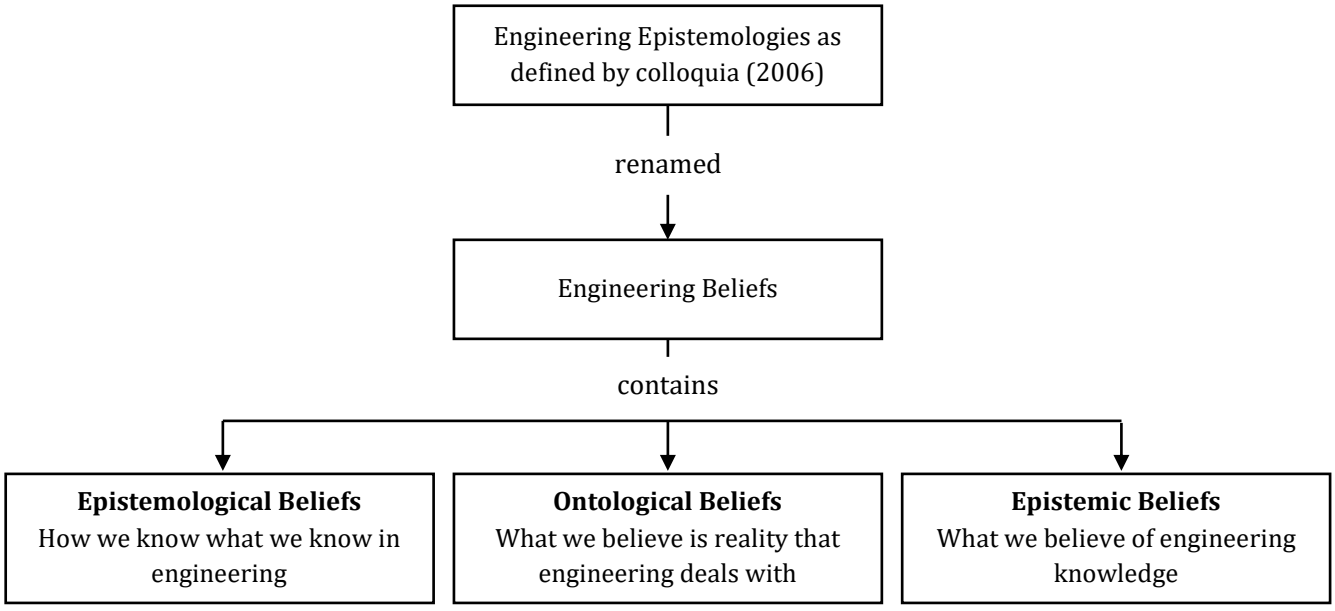

Figure 1. Engineering epistemology conceptual framework

The ontological beliefs were developed based on a unidimensional scale on the continuum (Yu & Strobel, 2012). Realist educators will deliver knowledge beyond textbooks and belief curriculum as a universal curriculum. They will educate their students centered on reality regardless of students' individual context. This is in contrast to idealism educators, that consider different student will have different realities. Therefore, idealism educators will use the approach as a facilitator. Moreover, pragmatism educators are more natural and apply multiple techniques in their class.

The epistemic belief, the domain-specific belief was adopted from four dimensions of engineering knowledge which are basic science, social science, design, and practical accomplished (Figueiredo, 2008). It is linked as a transdisciplinary view in engineering epistemology which combines engineers as a scientist, sociology, designer, and doer.

Faber et al. (2016) used the epistemological beliefs questionnaire developed by Yu & Strobel (2012) to measure epistemic beliefs among biomedical engineering students. Suggestion have been made by Faber et. al. (2016) to improve the questionnaires developed by Yu & Strobel (2012).

Furthermore, the instrument developed by Yu & Stroble (2012) should be tested on the reliability and validity since it is not widely used in the engineering field. As for now, epistemic beliefs resulting from the mutual interpenetration of the four dimensions as in Table 1 are not further investigated. Where epistemic belief can be general domain or specific-domain. For instance, in domain-specific, epistemic belief in electrical engineering students might differ from mechanical engineering students. In addition, engineering educators should be familiar with the terminologies, because the terminologies used are different among scholars based on their operational definitions.

Developmental Models

Each individual has a pattern in developing their beliefs about knowledge and knowing. Hofer & Pintrich (1997) discussed five models in a sequence starting with "the Perry Scheme" (Perry, 1970, 1981), "women's ways of knowing" (Belenky *et al*., 1986; Goldberger *et al*., 1996), the Epistemological Reflection Model (Baxter Magolda, 1992), reflective judgment (King and Kitchener, 1994) and Kuhn's attention to the levels of epistemological perspective which underlie argumentative reasoning (Kuhn, 1991).

Perry is considered by many as the pioneer of epistemological development studies of college students (Hofer & Pintrich, 1997; Muis, 2004). Using open-ended questions, Perry (1970, 1988) conducted two longitudinal studies in which he interviewed male college students about their perceptions of what influenced their college experience. He noticed changes in the students' thinking processes (Perry, 1970), and these changes occurred in patterns as they progressed through college (Perry, 1988). Using these patterns, Perry (1988) mapped the students' college experiences and developed the foundation of his epistemological development theory.

Perry's theory consists of four broad classifications that represent the students' overall views: in dualism, knowledge was based on one right answer from an authority figure, in multiplicity, knowledge was based on differing opinions, in relativism, knowledge was dependent on a given scenario, and in commitment in relativism, knowledge was a decision based on known information.

In engineering education, a number of researchers have explored students' epistemology (Faber et al., 2016b; Saavedra-Caballero et al., 2019; Zhu et al., 2019). Therefore, higher education is associated with the level of the developmental process. From the first year until the fourth year of study, engineering students are introduced to 21st century skills to prepare them to be able to integrate various knowledge in the problem-solving process.

Epistemology in Teaching & Learning

Engineering educators require a theory of knowledge to assist them to make sense of what they are doing and to give them control over their own inquiry processes. The theory of knowledge can be said as engineering educators' practical knowledge which means primarily an experiential form of knowledge developed by educators through their professional experience. Educators' practical knowledge can be categorized into three basic aspects which are sources, content, and process (Gholami, 2009). Therefore, engineering educators' practical knowledge relies on different backgrounds.

Engineering educators' knowledge can be measured by asking "whats, hows, and whys" of knowledge. The "whats" refers to the content, "hows" associated with the delivery methods, and "whys" reasoning between content and delivery methods to be tailored to specific disciplines. Unfortunately, engineering educators lack of pedagogical and philosophical knowledge (Pluskwik et al., 2020). Therefore, engineering educators have difficulty constructing activities to develop students' knowledge which causes current engineering students as dualist thinkers (Hamzah et al., 2012).

Epistemology is concerned about the way knowledge is delivered to the students and analysis of the concept in the educational environment that offers students the best learning experience (Saavedra-Caballero et al., 2019). Theory in epistemology is very helpful for engineering educators because it helps to reflect on the nature of knowledge which develops to criticize and reflect different ideas. This thinking can be implemented in the classroom to develop engineering students from

dualism, to multiplicity, to relativism, and finally to commitment in relativism.

One engineering student, for example, will act on that knowledge and has a significant impact on society. Additionally, the engineering philosophy needs to examine the engineering knowledge and further analysis for deeper understanding. Based on (Kant & Kerr, 2018), engineering epistemology can be outlined in five themes such as the relationship between scientific and engineering knowledge, engineering knowledge as a distinct field of study, the social epistemology of engineering, the relationship between engineering knowledge and its products, and the cognitive aspects of engineering knowledge.

On the other hand, Frisque and Chattopadhyay state that through epistemic investigation the analysis of the social constructivist epistemology for students from two different computer programming classes can be identified. It aids students with debugging their conceptual understandings, which form the foundation of their cognitive models. At the same time, the study also allows them to spot flaws or limitations in that mental model prior to the real knowledge that they have. In the end, this promotes students to ensure that they successfully self-reflect upon what they are learning (Frisque & Chattopadhyay, 2017).

Another field implementation of epistemological development is done by (Zhu et al., 2019) which focuses on project-based learning (PBL) based on Perry's theory. In this work, demonstrations of students' relativistic thinking in PBL and factors related to students' relativistic thinking were investigated. The findings show students' epistemological thinking is represented in their ability to solve problems within restriction, conduct feasibility evaluations, demonstrate commercial awareness, and broaden their thinking. Meanwhile, factors such as professional mentoring, peer collaboration, communication with other stakeholders, project complexity level influenced their epistemological thinking.

Conclusion

This paper explored the epistemology in engineering education. Epistemology is important in engineering education because it will affect the way engineering educators design their content delivery (Saavedra-Caballero et al., 2019). After all, epistemology relates to the way educators deliver the content of the course. Therefore, the epistemology of engineering educators is influenced by knowledge of the course content and knowledge to deliver the course content. Senior engineering educators might have problems in delivering the course content only but new engineering educators might have problems with the course content as well as delivering the course content. As a result, current engineering students cannot criticize and reflect on the course content. They are focusing on identifying right or wrong answers for a given question or problem.

Engineering faculty management plays a vital role in transforming engineering students learning experience. As a suggestion, engineering faculty management should plan engineering educators for certain course and provide training related to the course content and delivery method. Developing engineering educators' knowledge related to the course content and delivery method up to commitment in relativism is vital before the engineering educators can deliver the content in a better way to the students. Dualist engineering educators cannot produce relativist engineering students. Another suggestion is to introduce team teaching, pairing senior engineering educators with junior engineering educators to develop a better teaching experience for junior engineering educators.

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References

Barker, L. J., Brophy, S. P., & Burrows, V. A. (2006). The research agenda for the new discipline of engineering education. *Journal of Engineering Education*, *95*(4), 259–261. https://doi.org/10.1002/j.2168-9830.2006.tb00900.x

Ezebuilo, H. C. (2020). The Rationalist and Empiricist Epistemological Strategies and their Implications in Ethics. *Igwebuike: An African Journal of Arts and Humanities*, *6*(4).

Faber, C., Vargas, P., & Benson, L. (2016a). Measuring engineering epistemic beliefs in undergraduate engineering students. *Proceedings - Frontiers in Education Conference, FIE*, *2016-Novem*. https://doi.org/10.1109/FIE.2016.7757461

Faber, C., Vargas, P., & Benson, L. (2016b). Measuring engineering epistemic beliefs in undergraduate engineering students. *Proceedings - Frontiers in Education Conference, FIE*, *2016-Novem*, 1–7. https://doi.org/10.1109/FIE.2016.7757461

Fatehiboroujeni, S. (2018). On epistemic diversity of engineering and engineering education. *ASEE Annual Conference and Exposition, Conference Proceedings*, *2018-June*. https://doi.org/10.18260/1-2--30847

Figueiredo, A. D. de. (2008). Toward an Epistemology of Engineering. *Workshop on Philosophy and Engineering, The Royal Academy of Engineering*, 94–95.

Frisque, B., & Chattopadhyay, A. (2017). Conducting a social constructivist epistemology for students of computing disciplines. *Proceedings - Frontiers in Education Conference, FIE*, *2017-Octob*, 1–8. https://doi.org/10.1109/FIE.2017.8190461

Hamzah, R., Ismail, S., & Isa, K. M. (2012). Epistemology of Knowledge for Technical and Engineering Education. *Procedia - Social and Behavioral Sciences*, *56*(August 2015), 108–116. https://doi.org/10.1016/j.sbspro.2012.09.637

Hofer, B, K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, *13*(4), 353–383. http://www.springerlink.com/index/R6R6241GP87047K6.pdf

Hofer, B. K., & Pintrich, P. R. (1997). The development of

epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140. https://doi.org/10.3102/00346543067001088

Kant, V., & Kerr, E. (2018). Taking Stock of Engineering Epistemology: Multidisciplinary Perspectives. *Philosophy & Technology*. https://doi.org/10.1007/s13347-018-0331-5

Muis, K. R. (2004). *Personal Epistemology and Mathematics : A Critical Review and Synthesis of Research Published by : American Educational Research Association Stable URL : http://www.jstor.org/stable/3516027 Personal Epistemology and Mathematics : A Critical Review and Syn*. *74*(3), 317–377.

Pluskwik, E., Mina, M., Heywood, J., & Pears, A. N. (2020). Determinants of initial training for engineering educators. *ASEE Annual Conference and Exposition, Conference Proceedings*, *2020-June*. https://doi.org/10.18260/1-2--34410

Saavedra-Caballero, E., De la Torre-Cabañas, C. A., Suñiga-Muñoz, N., Huerta Rivero, M. E., Ballinas-Lázaro, Z. C., Nasta-Salazar, L., Zurita-Luévano, P. M., Reyes-Cárdenas, P., & Marques-Serdán, S. (2019). Teaching Pragmatist Epistemology to Undergraduate Education Students. In *Teaching Pragmatist Epistemology to Undergraduate Education Students* (Issue September). https://doi.org/10.20850/9781534299580

Scheffler, I. (1973). *Reason and Teaching*. London: Routledge and Kegan Paul.

Shah, N. A., Khan, A., Ahmad, P., & Arshad, M. (2020). *The Use of Empiricism, Rationalism and Positivism in Library and Information Science Research*.

Strohm Kitchener, K., & Kitchener, K. S. (2002). Skills, tasks, and definitions: Discrepancies in the understanding and data on the development of folk epistemology. *New Ideas in Psychology*, *20*(2–3), 309–328. https://doi.org/10.1016/S0732-118X(02)00012-0

Yu, J. H., & Strobel, J. (2011). *Instrument Development : Engineering-specific Epistemological , Epistemic Instrument Development : Engineering-specific Epistemological , Epistemic and Ontological Beliefs*. *January 2011*, 1–8.

Yu, J. H., & Strobel, J. (2012). A first step in the instrument development of engineering-related Beliefs Questionnaire. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--20804

Zhu, J., Liu, R., Liu, Q., Zheng, T., & Zhang, Z. (2019). Engineering Students' Epistemological Thinking in the Context of Project-Based Learning. *IEEE Transactions on Education*, *62*(3), 188–198. https://doi.org/10.1109/TE.2019.2909491