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The Pattern of Epistemological Belief in Design among Engineering Students

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Abstract

This study was geared toward identifying the pattern of epistemological belief in design among engineering students enrolled in one of the research universities in Malaysia. To this end, data collection was carried out by employing an adapted instrument of a Likert-type questionnaire with five scales consisting of 68 items. Then, 120 engineering students from several engineering disciplines, such as electrical engineering, mechanical engineering, and civil engineering, were selected from the overall population of Universiti Teknologi Malaysia to determine their epistemological beliefs on design. According to the literature, six dimensions of beliefs were commonly perceived. The students were to describe their beliefs about design knowledge and the nature of knowing and learning design, including the source of knowledge, the certainty of knowledge, structure of knowledge, speed of knowledge acquisition, innate ability of personal and general knowledge, and real-world applicability of knowledge. The study's findings revealed that the epistemological beliefs of engineering students in each dimension yielded a difference across varying engineering majors.

Keywords: Epistemology, Epistemological Beliefs on Design, Engineering Education.

1. Introduction

1.1 Epistemological Beliefs on Design

Over the years, the beliefs and theories held by students regarding knowledge and knowing, or personal epistemologies, have received increasing recognition from researchers overall (Schommer, 1994). Historically, the field of epistemological development research was pioneered by Perry and colleagues around the 1950s to 1960s, which has served as the key element of Perry's model of intellectual development (Duffy, Chance, & Bowe, 2012).

Throughout time, researchers have examined the epistemological beliefs of engineering students by qualitative and quantitative research methods (Cunningham & Kelly, 2017; Faber & Benson, 2017). Despite the volume of research carried out by adapting Schommers' Epistemological Beliefs Questionnaire in many fields (Demet, Demirci, Tüysüz, Bektas, & Geban, 2011; Gainsburg, 2015), many have yet to do this in specifically assessing engineering students' design knowledge in each of its dimensions and their field of majoring (e.g., civil, mechanical, electrical, etc.). Therefore, this research aims to adapt Schommer's Epistemological Questionnaire (Schommer, 1990) to measure the epistemological beliefs of engineering students hailing from four majors to answer the primary research question:

1. Do epistemological belief dimensions of engineering students significantly differ across engineering disciplines (e.g., civil, mechanical and electrical)?

1.2 Student's Epistemological Beliefs

According to philosophers, personal epistemology can be interpreted as a system of independent beliefs, further conceptualized as a belief in the simplicity, certainty, source of knowledge, and control and speed of knowledge acquisition (Schommer, 1990).

In terms of the education field, its researchers have ventured to explore varying facets, such as 1) how students know; 2) how the essence of knowledge and knowing is correlated to student learning processes, and 3) how inherent student epistemological beliefs affect the way instruction is delivered in the classroom across different contextual areas (Faber and Benson, 2017; Makhathini *et al.*, 2020). Regardless of the increasing number of researchers who express their keenness in studying student epistemological beliefs, they have yet to reach an undivided consensus regarding the definition of epistemological beliefs itself (Qian & Alvermann, 2011).

Meanwhile, Schommer (1990) has distinguished the epistemic belief system into infinite authority, certain knowledge, simple knowledge, quick learning, and fixed ability (Demet et al., 2011). In particular, Schommer's (1990) conceptualization is built using an exploratory study in which the questionnaire construction has been reported accordingly. The instrument has been adopted in many fields, looking into specific epistemological beliefs on a particular knowledge theory (Aslan, 2017; Yıldırır and Çirkinoğlu-Şekercioğlu, 2018; Uzuriaga López, 2021). To this end, Schommer (1990) presupposes five epistemological dimensions, three of which relate to knowledge (i.e., structure, certainty, and source). In contrast, the remaining two describe the acquisition of knowledge (i.e., control and speed). For each of these dimensions, Schommer (1990) has constructed a set of items grouped into the appropriate subsets accordingly (Clarebout, Elen, Luyten, & Bamps, 2001).

A few will be described accordingly among the many definitions for epistemological beliefs generated by prior works, for example, Hofer and Pintrich (1997) refer to this term as an individual's interpretation of the essence of knowledge and the process of knowing. Their research has thus described epistemological beliefs as the certainty of knowledge (i.e., stability), simplicity (i.e., structure) of knowledge, source of knowing (i.e., authority), and justification for knowing (i.e., evaluation of knowledge claims) (Hofer & Pintrich, 1997).

1.3 Epistemological Beliefs and Engineering Education

Engineering education researchers are especially interested in understanding the technical, social, and ethical aspects of engineering epistemologies ("The Research Agenda for the Discipline of Engineering Education," 2006; Cunningham and Kelly, 2017). By achieving such comprehension, engineering students can make a coherent and successful transition in applying the theoretical skills they have gained during university to the practical skills acquired upon their career entry. Therefore, assessing the epistemological beliefs of these students marks a preliminary attempt to understand and investigate engineering epistemologies (King & Magun-jackson, 2012).

In general, epistemological beliefs are crucial as they influence how students approach learning, thinking, and solving problems (Wilkes, 2012; McNeill et al., 2016). This statement is supported by Schommer's (1990) research findings, which have detailed how students who consider knowledge as definite have a higher chance to emerge with a definite conclusion sourced from information that may change. Besides, the same study has indicated that students who believe that knowledge is quickly learned are more likely to perceive the information poorly (Schommer, 1990). Additionally, another research has reported findings detailing how students who believe that knowledge is fixed are less likely to value school (Schommer & Walker, 1997).

1.4 Epistemological Beliefs, Engineering Education, and Design

Systems thinking has not been deemed an important facet of engineering education research; however, it is recently becoming more recognized as a core engineering element (Lammi & Becker, 2013). A well-known engineer named Henry Petroski once stated "science is about knowing, engineering is about doing." Therefore, an engineer works by combining science, math, technology, and creativity to find the solutions for different problems and develop a product that can consistently carry out the solution to ensure they are solved and remain resolved (Cunningham & Kelly, 2017). Furthermore, today's age of technology and innovations underlines the important role of design thinking in educating the newer generations of engineering personnel to cope with the current social needs and development (Parmar, 2014). Design, in particular, is the center of all types of activities in engineering (Moazzen, Miller, Wild, Jackson, & Hadwin, 2014), rendering engineering design highly fundamental for all engineering students (Bailey & Szabo, 2007). Considering this notion, a careful assessment of students' design knowledge is thus especially crucial in creating an effective learning environment and facilitating the development of design knowledge among them (Moazzen et al., 2014).

Moreover, the epistemology of design has evolved from the positivist conscientization of design instilled by the 'modern movement of design' and witnessed a backlash against the science-inspired design methodologies. Besides, previous literature suggested that the knowledge of epistemology of design is in a tangle and has little to approach. Whereby figures of knowledge misappropriate the awareness and ability of the designer. As a result, the focus should be placed on the 'designerly' ways of knowing, thinking, and acting (Figueiredo, 2014).

2. Method

2.1 Participants

120 undergraduate (first degree) engineering students from UTM voluntarily participated in this study. The surveyed respondents were students from engineering disciplines, namely civil,

electrical, and mechanical engineering.

2.2 Materials

Developed by Marlene Schommer, Schommer's Epistemological Questionnaire (Schommer, 1990) is a commonly employed instrument in studies on epistemological beliefs (Clarebout *et al.*, 2001). In the context of this study, the questionnaire developed was an adapted version of the original questionnaire encompassing the implementation of the design elements of design in all questions wherever it or any suitable phrases appeared. Some items of the original instrument were discarded since they were deemed irrelevant to the epistemology of design in the engineering context.

Table 1. Items in Adapted Instrument Distributed to Engineering Students.

Dimensions	Items
Source of Knowledge	"Learning design depends mostly on having a good lecturer."
	"I learn to design better when the lecturer works on sample problems."
	"I learn design best by working on a practical design."
	"A lecturer said, "I do not understand something until I teach it." However, in reality, teaching does not help a lecturer understand the content better; instead, it reminds one of how much they have already apprehended."
	"If design lecturers have clear lectures with many and good sample problems, I would not have to do so many exercises on my own."
Certainty of Knowledge	"Most of what is correct in design is already known."
	"Design is just knowing the right theory for a design."
	"I favor a design lecturer who shows their students many different approaches to view the same sample problem."
	"Design is like a game that uses creativity to create something."
	"Design theories are the product of creativity."
Structure of Knowledge	"It is crucial to know how something works compare to memorizing theory."
	"When learning design, I can understand the content best if I link it to the practical world."
	"Design is mostly facts and procedures that have to be

	memorized." "I learn best when the big picture is presented before the specific steps are for working a problem." "I like to find different ways to work problems."
Speed of Knowledge Acquisition	"When it comes to design, most students either get it quickly or not." "It takes a lot of time to learn design." "If I cannot solve a problem adequately swiftly, I get discouraged and will likely give up." "When I come across a hard design problem, I hold onto it until I solve it." "Given enough time, almost everyone could learn design if they tried."
Innate Ability (Personal)	"When I have trouble in a design class, better study habits can make a big difference." "I am confident that I can learn design if I exert more effort." "When I cannot understand something, I continuously ask questions." "Learning good study skills can improve my design ability." "Design is like the other language to me, and even if I try my best, I will never really understand it."
Innate Ability (General)	"Better study habits are the key to success for people who struggle in design." "Someone who does not possess a high level of natural ability is still able to learn hard design content." "When you cannot understand a material, you should continuously ask questions." "Learning good study skills can increase one's design ability." "Some people are born with great design ability, while some are not."
Real-World Applicability	"I will rarely use design in real life." "Understanding design is crucial for engineers, designers, and architects but not for most people."

"The only reason I would take up a design class is if it is a requirement."

"I would prefer working on real-life problems than samples in the textbook."

"I need to learn design for my future work."

The adapted version of Schommer's Epistemological Questionnaire was used to evaluate the epistemological beliefs upheld by the students according to the six dimensions of design knowledge. They are 1) source of knowledge (e.g., the origin of knowledge and the importance of having a good teacher); 2) certainty of knowledge (e.g., knowledge is either absolute and not changing or constantly evolving); 3) structure of knowledge (e.g., knowledge is simple and consists of isolated pieces of information, or it is complex and comprises of interdependent pieces of information); 4) control of knowledgeability (e.g., knowledge is fixed or incrementally increased and improved); 5) speed of knowledge acquisition (e.g., knowledge is quickly obtained or perceived as a gradual process); and 6) real-world applicability of the knowledge itself (e.g., the function taught in the classroom regarding every day's practicality). Therefore, the participants were presented with 68 design knowledge and learning statements. They were asked to rate the statements using a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Table - I shows the five items of each epistemological belief on design dimensions.

2.3 Procedures

Engineering students of this study were recruited from UTM to participate willingly and informed beforehand that it aimed to collect data on their beliefs and views on design. Then, the participants were allocated the epistemological questionnaire and background detail surveys during their routinely scheduled class time, whereas some were approached at the cafeterias and libraries. Besides, they were divided into three groups per their engineering discipline of study, either civil, electrical, or mechanical.

2.4 Data Analysis

Analysis of the quantitative data collected was carried out using the Statistical Package for Social Sciences software. Conceptually, this study looked into the pattern of epistemological beliefs on design among engineering students across three major disciplines, namely mechanical, electrical, and civil engineering. Therefore, frequencies and percentages were utilized to analyze the dominant dimensions of epistemological beliefs on students' design from each discipline. Then, Analysis of variance (ANOVA) was employed to determine any significant difference in epistemological beliefs on design among the three major disciplines of engineering students.

3. Results and Discussions

Table 2. Participants Demographic Informations

		Electrical	Mechanical	Civil
Gender	Male	25	28	16
	Female	5	14	11

After examining the respondents' responses for errors, 99 surveys were included in the analysis. Of this number, 69 students identified themselves as males, while the remaining 30 were females. A majority of the students reported being in mechanical engineering (42.4%), whereas electrical engineering students (30.3%) and civil engineering (27.3%) made up the rest of the sample size. All students reported age is below 30 years old.

3.1 Epistemological Beliefs on Design among Mechanical Engineering Students

Table 3. Epistemological beliefs of mechanical engineering students on design according to the dimensions measured

Construct	Disagree (%)	Neutral (%)	Agree (%)
Source of Knowledge	6.7	36.7	56.7
Certainty of Knowledge	6.7	53.3	40
Structure of Knowledge	3.3	23.3	73.3
Speed of Knowledge Acquisition	3.3	56.7	40
Innate Ability (Personal)	3.3	33.3	63.3
Innate Ability (General)	6.7	23.3	70
Real-World Applicability	3.3	36.7	60

After conducting the frequencies analysis, most mechanical engineering students showed the dominance of the structure of knowledge dimension among the six dimensions of epistemological beliefs on design. Out of nine items measured under the dimension, 73.3% agreed with most statements. In contrast, only 3.3% of the students disagreed. The remaining 23.3% reported neutral opinions, indicating that more than half had definite opinions regarding the importance of epistemological belief in design. Table III shows a division of the answers generated according to the students encompassing the six dimensions of epistemological beliefs on design.

3.2 Epistemological Beliefs on Design among Electrical Engineering Students

Table 4. Epistemological beliefs of electrical engineering students on design according to the dimensions measured.

Construct	Disagree (%)	Neutral (%)	Agree (%)
Source of Knowledge	9.5	4.8	58.7
Certainty of Knowledge	9.5	14.3	76.4
Structure of Knowledge	7.2	4.8	88.1
Speed of Knowledge Acquisition	11.9	19	69
Innate Ability (Personal)	7.1	14.3	78.6
Innate Ability (General)	9.5	11.9	78.9
Real-World Applicability	7.2	11.9	80.9

In the context of electrical engineering students, they yielded almost comparable results to their aforementioned mechanical engineering peers. Most students revealed the dominancy of the structure of the knowledge dimension. However, 88.1% of the students agreed with most of the statements of all nine items measured under this dimension. In contrast, a higher percentage of the remaining students indicated they disagreed (7.2%) with the statements, while a lower percentage was obtained for those with a neutral opinion (4.8%). Table IV shows a division of the answers obtained among the electrical engineering students according to all dimensions of epistemological beliefs on design measured in the study.

3.3 Epistemological Beliefs on Design among Civil Engineering Students

Table 5. Epistemological beliefs of civil engineering students on design according to the dimensions measured.

Construct	Disagree (%)	Neutral (%)	Agree (%)
Source of Knowledge	7.4	4.4	85.2
Certainty of Knowledge	7.4	33.3	59.2
Structure of Knowledge	7.4	11.1	81.4
Speed of Knowledge Acquisition	7.4	22.2	70.4
Innate Ability (Personal)	7.4	22.2	70.4
Innate Ability (General)	3.7	11.1	85.2
Real-World Applicability	7.4	18.5	74.1

As the third discipline was assessed, the civil engineering students revealed slightly different outcomes regarding their epistemological beliefs on design than mechanical and electrical engineering students. For civil engineering students, the dominance was shared between the dimensions of Source of Knowledge and Innate Ability (General) (85.2% for both). However, the neutral opinions obtained were 7.4% and 11.1%, respectively. Therefore, it could be concluded that, even though most civil engineering students agreed Source of Knowledge and Innate Ability (General) were equally important in design, more were confident with the decision for Source of Knowledge compared to Innate Ability (General). Table V shows a division of answers revealed by civil engineering students among all dimensions of epistemological beliefs on design measured in the study.

3.4 Epistemological Beliefs on Design among Mechanical, Electrical, and Civil Engineering Students

Table 6. Epistemological beliefs of engineering students on design according to the dimensions measured.

Construct	Disagree (%)	Neutral (%)	Agree (%)
Source of Knowledge	7.7	14.4	77.9
Certainty of Knowledge	7.7	31.7	60.6
Structure of Knowledge	5.7	12.5	81.8
Speed of Knowledge Acquisition	7.7	30.5	61.5
Innate Ability (Personal)	5.8	21.2	73
Innate Ability (General)	6.8	14.4	78.8
Real-World Applicability	5.7	21.2	73.1

Engineering students collectively yielded a very agreeable answer across all three engineering disciplines assessed. The data collected showed a constant number of common agreeable answers for all six dimensions measured. Therefore, a majority of the engineering students perceived that all six dimensions were important in learning design in an engineering course.

Table 7. Analysis of Variance Comparing Engineering Student Epistemological Beliefs on Design across Different Engineering Disciplines

Belief Dimension	df	F	μ^2	p
Source of Knowledge	3	3.443*	2.525	0.020
Certainty of Knowledge	3	0.715	0.390	0.545
Structure of Knowledge	3	1.610	1.250	0.192
Speed of Knowledge Acquisition	3	0.600	0.282	0.616
Innate Ability (Personal)	3	0.787	0.393	0.504
Innate Ability (General)	3	2.939*	1.745	0.037
Real-World Applicability	3	1.849	1.461	0.143

Furthermore, the findings revealed a difference between the epistemological beliefs of engineering students in each dimension (i.e., source of knowledge, the certainty of knowledge, structure of knowledge, speed of knowledge acquisition, innate ability, and real-world applicability) across the three engineering majors (e.g., civil, electrical and mechanical). This observation was further supported by the data analysis outcomes using ANOVA. Here, two out of six epistemological belief dimensions were found to be significantly different across the engineering majors at $p < .05$ level: source of knowledge ($p = 0.02$) and innate personal ability ($p = 0.037$). Table III below shows the results of ANOVA ran on the data collected.

4. Conclusion

Design is a highly critical subject in the engineering education as it is the fundamental soul of all branches of engineering (Osman et al., 2019). Throughout the years, many initiatives have been undertaken by researchers and educators alike to increase the effectiveness of engineering education in design. Among these, engineering education researchers, in particular, concentrate their interest on five major areas, one of which is engineering epistemologies or the elements contributing to the nature of engineering design knowledge or the way engineers approach design (King & Magun-jackson, 2004).

To this end, this study contributed to the literature on engineering design epistemological beliefs by adapting Schommer's (1990) Epistemological Beliefs Questionnaire (EBQ) in engineering design. This was achieved by quantitatively measuring the pattern of epistemological beliefs on engineering students' design across several engineering disciplines. As a result, the findings revealed significant differences among the dimensions despite the constant pattern of epistemological beliefs on design among engineering students. Besides, they suggested that the engineering students shared the same belief across the different epistemological beliefs on design, particularly in the structure of design knowledge itself. Nevertheless, this study has limitations, such as the analysis carried out among the engineering students from one university, located in the Southern region of Malaysia. Hence, the result cannot be statistically generalized to all engineering students throughout the country. Regardless, future research should be planned to expand the study area and increase the number of participants for these results to be relevant for generalization.

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Appendix A

The adapted version of Schommer's Epistemological Questionnaire

Epistemological Beliefs Questionnaire for Design among Engineering Students

PART 1

Demographic Information

Full Name :

Age : o Below 17 o 17 to 20 o21-30 o31 to 40 oOver 40

Year of Program : o 1st Year o 2nd Year o 3rd Year o 4th Year or Higher

Gender : o Male o Female

Engineering Discipline : o Mechanical o Electrical o Civil o Others

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PART 2

DIRECTIONS: *For each of the following items, please read the statement, and indicate the answer that describes how strongly you agree or disagree.*

A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree

I. Source of Knowledge

No.	Description	A	B	C	D	E
1	Learning design depends most on having a good teacher.					
2	I learn design best when watching the teacher work example problems.					
3	I learn design best by working practice design.					
4	A teacher said, "I don't really understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better, it just reminds her of how much she already knows.					
5	If design teachers gave really clear lectures with plenty of good example problems, I wouldn't have to practice so much on my own.					
6	The quality of a design class is determined entirely by the instructor.					
7	What I get from a design class depends mostly on the effort I invest.					
8	Sometimes you have to accept answers from design teachers even if you don't understand them.					
9	Design is something I could never learn on my own.					
10	To solve design problems you have to be taught the right procedure.					
11	In design you can be creative and discover things on your own.					

II. Certainty of Knowledge

No.	Description	A	B	C	D	E
1	Most of what is true in design are already known.					
2	Design is really just knowing the right theory for the design.					
3	I prefer a design teacher who shows students lots of different ways to look at the same problem.					
4	Design is like a game that uses creativity to create something.					
5	Design theories are the product of creativity.					
6	There is usually one best way to solve a design problem.					
7	In design, the answers are always either right or wrong.					
8	All design professors would probably come up with the same answers to questions in their field.					
9	Truth is unchanging in design.					
10	Answers to questions in design change as experts gather more information.					

III. Structure of Knowledge

No.	Description	A	B	C	D	E
1	It is important to know why something works rather than memorizing theory.					
2	When learning design, I can understand the material better if I relate it to the real world.					
3	Design is mostly facts and procedures that have to be memorized.					
4	I learn best when the big picture is presented before the specific steps for working a problem.					
5	I like to find different ways to work problems.					
6	If there weren't answers in the back of the book, I would have no idea whether I had worked the problem correctly or not.					
7	It is a waste of time to work on problems that have no solution.					
8	Understanding how design is used in other disciplines helps me to comprehend the concepts.					
9	I often learn the most from my mistakes.					

IV. Speed of Knowledge Acquisition

No.	Description	A	B	C	D	E
1	When it comes to design, most students either get it quickly or not at all.					
2	It takes a lot of time to learn design.					
3	If I can't solve a problem quickly I get frustrated and tend to give up.					
4	When I encounter a difficult design problem, I stick with it until I solve it.					
5	Given enough time, almost everyone could learn design if they really tried.					
6	If you don't understand something presented in class, going back over it later isn't going to help.					
7	If you can't solve a problem in a few minutes you're not going to solve it without help.					
8	If you know what you're doing, you shouldn't have to spend more than a few minutes to complete a homework problem.					
9	It is frustrating to read a problem and not know immediately how to begin to solve it.					
10	In classes I've taken, I could have done better if I'd had more time to learn the concepts.					

V. Innate Ability

Personal

No.	Description	A	B	C	D	E
1	When I'm having trouble in design class, better study habits can make a big difference.					
2	I'm confident I could learn calculus if I put in enough effort.					
3	When I don't understand something I keep asking questions.					
4	Learning good study skills can improve my math ability.					
5	Design is like a foreign language to me and even if I work hard I'll never really get it.					
6	I knew at an early age what my design ability was.					
7	If design were easy for me, then I wouldn't have to spend so much time on homework.					
8	It is frustrating when I have to work hard to understand a problem.					
9	I can learn new things, but I can't really change the design ability I was born with.					
10	I'm just not a design person.					

General

No.	Description	A	B	C	D	E
1	Better study habits are the key to success for persons who struggle in design.					
2	Someone who doesn't have high natural ability is still capable of learning difficult material.					
3	When you don't understand something you should keep asking questions.					
4	Learning good study skills can improve a person's design ability.					
5	Some people are born with great design ability and some aren't.					
6	Design ability is really just something you're born with.					
7	You can learn new things, but you can't really change the design ability you were born with.					

VI. Real-world Applicability

No.	Description	A	B	C	D	E
1	I will rarely use design in real life.					
2	Understanding design is important for engineers, designers, and architects but not for most people.					
3	The only reason I would take a design class is because it is a requirement.					
4	I would rather work on real-life problems than those in the textbook.					
5	I need to learn design for my future work.					
6	I can apply what I learn in design to other subjects.					
7	It is easy to see the connections between the design I learn in class and real-world applications.					
8	I'm rarely able to use the design I've learned in other subjects.					
9	I will probably take more design than is required for my degree.					
10	Design provides the foundation for most of the principles used in engineering.					
11	Design helps us better understand the world we live in.					

THANK YOU FOR YOUR TIME!