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Systemic Thinking Skills: Relationship to Epistemological Beliefs and Mathematical Beliefs

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Abstract: Systemic thinking skills are an increasingly important aspect of contemporary life for all students. Therefore, the first aim of the present study was to investigate the relationship between systemic thinking skills, epistemological beliefs, and mathematical beliefs in a sample of 120 secondary school students aged 16-18 years in Saudi Arabia. The second objective was to examine gender differences in these three variables. Participants answered scales measuring the Systemic Thinking Inventory (STI) and the Mathematical Beliefs Scale (MBS) created by the researcher. Additionally, participants answered the Epistemic Belief Inventory (EBI). Results showed a positive correlation between systemic thinking skills, epistemological beliefs, and mathematical beliefs. In addition, significant differences were found in favor of men on the systemic thinking skills on the holistic vision of the system and systemic synthesis skills subscales and females on the systemic analysis subscale. Significant differences were found in epistemological beliefs. A particular difference was innate knowledge and omniscient authority in favor of males, simple knowledge, certain knowledge, and rapid learning in favor of females. In addition, differences were found for mathematics teacher competence and self-efficacy beliefs in favor of males and the usefulness of learning mathematics, difficulty in mathematics, and enjoyment of mathematics in favor of females. The results are discussed in light of the relevant literature, and suggestions are made.

Keywords: *Epistemological beliefs, mathematical beliefs, systemic thinking.*

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Introduction

Systemic thinking is a form of higher-level thinking through which an individual can formulate a comprehensive view of an issue without losing sight of the smaller components or elements. In addition, systemic thinking can be taught and learned and is increasingly used in behavioral interventions (Moore et al., 2018). Moving from linear to systemic thinking allows a person to view many elements as integrated themes. Systems thinking allows a person to perceive a system as an integrated, complex composition of many interconnected components that must work together for the system to function effectively (Shaked & Schechter, 2017).

Systems thinking can be examined as the ability to see the whole beyond its parts, and consider the details in the context of the whole. Systems thinking is a holistic approach that focuses on how the parts function together in the network of interaction, rather than breaking systems down into pieces to understand them separately (Shaked & Schechter, 2020). According to Arnold and Wade (2017), the ability to gain systemic insights and use that knowledge to understand and influence systems is a prerequisite for systems thinking. Systems thinking involves using cyclical processes to solve evolving problems. It is described as a way of thinking that thinks outside the box and does not ignore what is inside the box. Systems thinking enhances our ability to develop innovative ideas by helping us understand the complex human factors involved in change, uncover hidden problems, and envision a better future as collective problem solvers (Gonzales, 2020).

Beliefs can also have a positive impact on problem-solving. Research shows that beliefs support mathematical success by encouraging individuals to persevere when they do not know how to reach a solution (Sumpter, 2013). In addition, the role of beliefs is related to the nature of the task. Within a well-structured framework, beliefs appear to have greater influence, whereas their impact is more uncertain in non-routine tasks (Liu, 2010). Research suggests a relationship between cognitive variables and the use of metacognitive skills, as well as a significant relationship between

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epistemological beliefs, knowledge type, and learning problem solving (e.g., Hofer, 2004; Schommer-Aikins & Duell, 2013).

Individuals typically take an experimental approach to understand various natural and unnatural events by breaking them down into elements that can be scientifically explored and studied. This approach presents the natural world as unchanging, linear, and mechanistic. However, this worldview has been shown to be inadequate, and the solution lies in applying systems thinking skills to various human problems (Randle, 2014). Systems thinking is related to complex attribution, creativity, and important personality factors such as openness to experience, agreeableness, and extroversion. It is considered a broader and more thorough cognitive framework that encompasses a propensity to attribute complexity to understanding events in our social and natural world. Randle and Stroink (2018) hypothesized that individuals who think systemically are more likely to view social behavior through a broader and more complex lens than people who think linearly.

Mathematical beliefs consist of multiple dimensions, such as the content of mathematics, learning mathematics, problem-solving, motivation, self-efficacy, control beliefs, and goal orientation. These are all beliefs that students hold, and the role of the teacher and the student, as well as beliefs about acceptable social norms in the classroom (Kıbrıslıoğlu & Haser, 2015). The systemic approach facilitates the learning process by increasing understanding of mathematical operations, making learning meaningful, and increasing student motivation. This facilitation would make mathematics an interesting subject and develop systemic thinking (Hester & Adams, 2017).

Previous studies did not focus on the effects of systemic thinking on epistemological beliefs and mathematical beliefs. Hence, the current research focuses on examining the nature of the relationships between systemic thinking skills, epistemological beliefs, and mathematical beliefs. It also aims to determine the significance of differences between men and women in systemic thinking skills, epistemological beliefs, and mathematical beliefs.

Literature Review

Systemic Thinking Skills

Systems thinking is a cognitive skill in which an individual considers the faculties and interrelationships that determine the behavior of a system. It involves understanding how these relationships are constructed to understand the system's basic structure better and how its behavioral patterns emerge. Most problems that individuals face in their daily lives have become very complex and require understanding their relationships. Phenomena do not exist separately, and a detailed analysis of a problem in isolation from its environmental context interferes with our understanding. Accordingly, multiple perspectives must be applied to solve any problem, as a one-sided view of problems is no longer sufficient for a comprehensive understanding.

Arnold and Wade (2015, p. 7) define systemic thinking skills as "a set of analytical skills that support each other and serve to enhance the ability to define and understand the organization, anticipate its behaviors, and make adjustments until we achieve the desired outcomes, these skills work together as a system." Systemic thinking is based on a comprehensive view of the subject without neglecting its parts, and on analyzing a situation to identify relationships between elements. Through systems thinking, the learner becomes more accurate and can explore everyday situations and figure out the relationships between the components of a single system to get a complete picture without forgetting the details. Systemic thinking skills focus on four main skills: analyzing main systems into subsystems, understanding relationships within the system, reconfiguring systems from their components, and bridging gaps within the system. Systemic thinking skills focus on four main skills, which are composed of (12) sub-skills as follows:

Table 1. Systemic Thinking Main and Sub-skills

Main skills	Sub-skills
Realize the relationships between the systems.	- Recognize the connections between subsystem components. - Realize the relationships between one system and another. - Realize the structural relationships in each part.
Analysis of the systems.	- Deduce a subsystem from the main system. - Deduce conclusions from a system. - Detecting the wrong parts of the system.
Synthesis of the systems.	- Building a system from several concepts or elements. - Deduce generalizations from a system. - Writing a report on the system.
Evaluation of the systems.	- Judging the correctness of relationships between parts of a system. - Development of systems (providing alternative methods of building the system). - Decision-making is based on the system.

Systems thinking is an appropriate practical way to address the complex problems we face every day. It provides an overall view of the system and its elements, recognizing that elements have value only within the whole framework. In addition, the application of systems thinking represents the ability of individuals to form mental structures in such a way as to move from linear thinking to complex thinking.

Systemic thinking requires students to infer and analyze information - higher-order thinking. Higher-order thinking skills include analysis, synthesis, interpretation, application, and perception of context. In summary, systemic thinking encompasses many skills, classified as follows: Understanding systemic relationships: Understanding relationships within a single subject, between parts of a subsystem, or between one system and another. Systemic analysis: a systemic analysis of the subject material, understanding the similarities and differences, the relationships and parts, and recognizing the principles that govern these relationships. Systemic synthesis: the systemic grouping of the various elements of the major subject or topic to discover something new that is different from the existing parts (building a system from multiple concepts). Systemic development: taking a holistic perspective of the problem through a system and assessing the validity of the relationships between the parts of the system.

Systemic thinking skills aim to develop a comprehensive vision of the individual's future for any given issue without losing sight of its parts. This skill allows one to see the issue in a holistic framework to understand the complex and rapidly changing world, which is the best achievement in any respected educational system. Previous studies (Brandstädter et al., 2012; Randle, 2014; Randle & Stroink, 2018; Riess & Mischo, 2010) have found that the effectiveness of teaching methods contributes to the development of students' systemic thinking skills. For example, concept maps contribute to developing systemic thinking skills because they allow students to see and understand that complex phenomena are made up of interconnected elements. In addition, correlations have been found between systemic thinking, the top five personality factors, creative behavior, abstract thinking, and the need for knowledge, creativity, and idea generation.

Epistemological Beliefs

Students' beliefs about acquiring knowledge are referred to as epistemological beliefs. Wang et al. (2013, p. 98) defined epistemological beliefs as "a system that includes a set of dimensions related to the nature of knowledge and learning, reflected in the source of knowledge, its stability and structure, the speed of knowledge acquisition, and the ability to learn." In academia, epistemological beliefs are associated with student persistence, inquiry, integration of information, and dealing with complex and poorly structured domains. These qualities are related to higher-level learning, as they are of little use or importance in memorization, for example. However, as society becomes technologically advanced and information-oriented, higher-level learning is becoming increasingly important. Epistemological beliefs refer to individual perceptions of learning and knowledge and include five dual dimensions (Berding et al., 2017; Schommer-Aikins & Duell, 2013). These dimensions are the ability to learn: static/improvable, speed of learning: fast/gradual, stability of knowledge: fixed/variable knowledge and certain/uncertain, Structure of knowledge: simple/complex knowledge, source of knowledge: authority/evidence.

Epistemological beliefs focus on individuals' beliefs about knowledge, how it is acquired, and its importance for learning, self-regulation, and academic achievement. Empirical evidence shows that intervention programs can change these beliefs and thus significantly improve learning (Leal-Soto & Ferrer-Urbina, 2017). Several studies (e.g., Berding et al., 2017; Ertekin et al., 2010; Hannula et al., 2016; Schommer-Aikins & Duell, 2013; Uçar, 2018) indicated that epistemological beliefs could be changed by intervention and training programs as they are related to critical thinking strategies, self-efficacy in learning, information processing level, and mathematical beliefs. The research also showed differences in some dimensions of epistemological beliefs according to gender.

Mathematical Beliefs

Beliefs are psychological, hypothetical views and conclusions about the world that an individual believes to be true. They can be viewed as lenses influenced by an individual's perception of certain concepts and are views and preferences that individuals form from a subjective cognitive component. The effects of epistemological beliefs on individual behavior can be observed in mathematics, where these beliefs are considered concerning teaching and learning. There is a weak negative relationship between epistemological beliefs and anxiety about teaching mathematics (Ertekin et al., 2010). According to Hughes (2016), students' beliefs about mathematics include their views about the usefulness of mathematics and how to teach its content from a constructive perspective.

Beliefs about mathematics can be defined as "the individual's concepts that represent how an individual views his or her connection, and behavioral inclination toward mathematics and that is generated and manifested as thoughts in the mind" (Sumpter, 2013, p. 1118). Perception, motivation, and emotion are the three components that make up human learning. While most research addressing these psychological categories has focused on one of these three components, there is growing interest in students' beliefs, desires, and feelings as critical elements of their self-perceptions as math learners (Roesken et al., 2011). In addition, high achievement was associated with enjoyment, while low achievement was associated with frustration, anger, anxiety, shyness, and low self-esteem. Hughes (2016) found that teachers who held traditional cognitive beliefs about mathematics believed that a mathematical mind is required to be a good mathematics student. Teachers with traditional beliefs may believe that there is only one way to solve math problems and that males are better at math than females.

Similarly, students' beliefs about mathematics affect their effort in completing tasks. Students' interest and enjoyment in mathematics are related to life and school activities. Students' beliefs about achievement affect their academic success and attitudes toward learning new experiences. While research has shown a relationship between students' learning of mathematics and their beliefs about it, researchers do not agree on a common definition. Kıbrıslıoğlu and Haser (2015) define beliefs about mathematics as "the implicit or explicit subjective concepts that students hold as correct, affecting learning and solving mathematics problems." Several previous studies (e.g., Di Martino & Zan, 2011; Hughes, 2016; Roesken et al., 2011; Schommer-Aikins et al., 2005; Schommer-Aikins & Duell, 2013) indicated that epistemological beliefs could predict academic achievement and mathematical problems. Furthermore, there is a statistically significant relationship between epistemological beliefs and mathematical difficulties as well as self-efficacy in mathematics studies.

Methodology

Research Design

A quantitative research design investigated the correlation between secondary school students' systemic thinking skills, epistemological beliefs, and mathematical beliefs. In addition, the study aims to identify gender differences in systemic thinking skills, epistemological beliefs, and mathematical beliefs.

Sample and Data Collection.

The research population included all second and third-grade secondary school students in Al-Ahsa governorate in the Kingdom of Saudi Arabia. The research sample consisted of 130 male and female students randomly drawn from this population. Ten individuals were excluded because they had not completed the research measures. The final sample consisted of 120 students. There were 60 males and 60 females aged 16-18 years. There was a mean of 17.8 and a standard deviation of 1.23.

Instruments

Systematic Thinking Inventory (STI): The researcher reviewed many scales to assess systems thinking, including the Systems Thinking Scale (Davis & Stroink, 2016; Randle, 2014) and the Systemic Thinking Scale for Adolescent Behavior Change (Moore et al., 2018). The researcher created the original version of the STI. It contains 40 items and five subscales. Each subscale represents a facet of systemic thinking: Systemic Holistic Viewing Skills (8 items), which seek to bridge gaps within a system by looking at the situation and problem holistically and address it in a systemic holistic way rather than in isolation; Systemic Relationship Recognition Skills (7 items), which understand the relationships between parts of the system and between subsystems, within a single issue or idea, between parts of a subsystem, or between one system and another; systemic analysis skills (9 items) breaking down the system into its components and deriving subsystems from the main system; analyzing the given instructional material and understanding the similarities and differences, the relationships and parts, and identifying the principles that govern these relationships; system synthesis skills (9 items) rebuilding a system from multiple concepts, i.e., systemically grouping the different parts of the content or main position or ideas to find something new that is different from the previous parts; systemic evaluation skills (7 items) evaluating the correctness of the relationships between the parts of the system and taking a comprehensive view of the situation through a system. A five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) was used to answer. The overall level of Cronbach's Alpha was found to be .816, indicating high internal consistency.

Table 2. Correlation Between Dimensions and Total Scores of (STI)

Dimensions	SHVs	RSRs	SAs	SSs	SEs	
System holistic view skills						
Perceiving systemic relations skills	.764	-				
Systems analysis skills	.762	.739				
Systems synthesis skills	.751	.710	.773	-		
Systems evaluation skills	.757	.707	.759	.774	-	
Total	.827	.822	.846	.836	.832	-

Note: (SHVs) Systemic holistic view skills, (RSRs) Recognize systemic relation, (SAs) Systemic analysis skills, (SSs) Systemic synthesis skills, (SEs) Systemic evaluation skills.

Table 2 shows that the reliability coefficients for the dimensions of the STI, and the overall score are high. This makes us confident in the stability of the inventory and that scores reflect students' level of systemic thinking skills.

Factor structure: An exploratory factor analysis (principal components analysis) was used to investigate the factor structure of the STI. An initial solution yielded a five-factor structure that accounted for 42.695% of the variance. The five retained factors are 40 items "Systemic holistic view skills" (8 items), "Recognize systemic relations skills" (7 items), "Systemic analysis skills" (9 items), "Systems synthesis skills" (9 items), and "Systemic evaluation skills" (7 items). Items with loadings less than 0.3 were removed.

Table 3. Analysis Factor of Dimensions of (STI)

Rotation Sums of Squared Loadings			Extraction Sums of Squared Loadings		
Cumulative %	**% of variance**	**Total**	**Cumulative %**	**% of variance**	**Total**
12.402	12.402	6.201	14.570	14.570	7.285
22.883	10.481	5.241	25.254	10.481	5.342
30.127	7.244	3.622	32.909	7.244	3.827
36.921	6.794	3.397	38.002	6.794	3.547
42.695	5.774	2.887	42.695	5.774	2.346

Epistemological Beliefs Inventory (EBI): The original version of the EBI (Wang et al., 2013) consists of 32 items and five subscales. Each subscale represents one facet of epistemic beliefs: Simple Knowledge (SK; 8 items) ranges from knowledge as compartmentalized and isolated to knowledge as highly integrated and interwoven; Certain Knowledge (CK; 7 items) measures knowledge as absolute to knowledge as constantly evolving; Innate Ability (IA; 7 items) ranges from the ability to learn as genetically predetermined to the ability to learn as acquired through experience; Omniscient authority (OA; 5 items) ranges from knowledge handed down by omniscient authority to knowledge that is grounded in objective and subjective means; and Rapid learning (RL; 5 items) ranges from learning that occurs quickly, or not at all, to learning that is a gradual process. Responses are in the form of a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). External criterion validity was calculated by comparing the EBI results with the revised Epistemological Beliefs Schommer's Questionnaire (Clarebout et al., 2001). The Cronbach's alpha was found to be .79, indicating high internal consistency.

Mathematical Belief Scale (MBS): The researcher reviewed many systems thinking scales (e.g., Hughes, 2016; Kıbrıslıoğlu & Haser, 2015; Roesken et al., 2011). The researcher created the original version of the MBS. The scale has 32 items and five subscales. Each subscale represents a facet of mathematical beliefs. Teacher competence beliefs measure the mathematics teacher's competence in communicating knowledge, explaining concepts and equations, and providing opportunities for students to discover solutions in more than one way, considering listening and discussion skills. Self-efficacy beliefs measure students' belief in their ability to understand mathematics, whether as a subject that evokes anxiety and tension or as an easy and interesting subject. Mathematics usefulness beliefs measure the benefits students derive from learning mathematics and applying it to daily life, reasoning, and problem-solving. Beliefs about the difficulty of mathematics measure the difficulty of mathematics and its reliance on complex symbols and equations. Beliefs about rhetoric without conscience and the extent to which students view it as a source of suffering.

The belief that mathematics is fun measures the enjoyment of mathematics made possible by a capable teacher who makes mathematics an interesting subject that revitalizes the mind. A five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was used to answer. A Cronbach's alpha of .752 was obtained, indicating high internal consistency. In addition, the test-retest reliability is .763. The scale's reliability was calculated by retesting after two weeks on a sample (n=40) of male and female secondary school students outside the original sample. Correlation coefficients were as follows: .76 for teacher competence belief; .74 for self-efficacy belief; .81 for mathematical utility belief; .72 for mathematical difficulty belief; .76 for mathematical enjoyment belief; and .81 for total score. These high scores indicate that the scale reflects students' beliefs about mathematics.

Results

The data were analyzed to determine the relationship between systemic thinking skills, epistemological beliefs, and mathematical beliefs, as shown in Tables 4 and 5. Pearson's simple correlation test examined the relationship between systemic thinking skills, epistemological beliefs, and mathematical beliefs. The results showed a statistically significant positive correlation (p <.01) between these variables. The results of the correlation analysis can be found in Table 4, showing the positive and significant relationship between systemic thinking skills and epistemological beliefs.

Table 4. Correlations Values Between Systemic Thinking Skills and Epistemological Beliefs

Dimensions	SL	CK	IK	OA	QL
Systemic holistic view skills	.861 **	.834 **	.641 **	.643 **	.685 **
Recognize systemic relations	.605 **	.652 **	.655 **	.720 **	.662 **
Systemic analysis skills	.893 **	.685 **	.692 **	.667 **	.724 **
Systemic synthesis skills	.684 **	.751 **	.756 **	.629 **	.432 *
Systemic evaluation skills	.680 **	.435 *	.692 **	.538 **	.615 **

Note: (SK) Simple Knowledge, (CK) Certain Knowledge, (IA) Innate Ability, Omniscient Authority (OA), and Quick Learning (QL). **p < .05. **p < .01.*

Table 5 shows Pearson's test results for the correlation between systemic thinking skills and mathematical beliefs. Accordingly, we noted positive and significant correlations between the subscales of systemic thinking skills and mathematical beliefs at ($p < .01$).

Table 5. Correlations Values Between Systemic Thinking Skills, and Mathematical Beliefs

Dimensions	TCB	SEB	MBB	MDB	MEB
Systemic holistic view skills	.653 **	.664 **	.781 **	.642 **	.693 **
Recognize systemic relations	.785 **	.708 **	.653 **	.823 **	.682 **
Systemic analysis skills	.694 **	.693 **	.724 **	.676 **	.724 **
Systemic synthesis skills	.623 **	.735 **	.756 **	.635 **	.798 **
Systemic evaluation skills	.680 **	.592 **	.698 **	.581 **	.674 **

Note: (TCB) Teacher's competence beliefs, (SEB) Self-efficacy beliefs, (MBB) Mathematical benefits beliefs, (MDB) mathematical difficulty beliefs, and (MEB) Mathematical enjoyment beliefs.

Table 6. Differences in Systemic Thinking Skills According to Gender

Dimensions	Male N=60		Female N=60		T
	M	SD	M	SD	
Systemic holistic view skills	14.583	1.834	13.750	1.420	3.822 **
Recognize systemic relations	14.917	1.164	14.566	1.341	1.302
Systemic analysis skills	13.883	1.402	14.717	1.243	3.503 **
Systemic synthesis skills	15.116	1.163	13.867	1.333	5.751 **
Systemic evaluation skills	14.033	1.712	14.133	1.542	0.359

Table 6 shows a statistically significant difference at ($p < .01$) in favor of males in systemic holistic view skills and systemic synthesis skills, while in favor of females in systemic analysis skills. In addition, no differences in recognizing systemic relations and systemic evaluation skills.

Table 7. Differences in Epistemological Beliefs According to Gender

Dimensions	Male N=60		Female N=60		t
	M	SD	M	SD	
Simple Knowledge	13.783	1.413	15.267	1.102	6.489 **
Certain Knowledge	13.682	1.432	15.150	1.107	6.754 **
Innate Ability	18.933	2.138	17.700	1.916	3.975 **
Omniscient Authority	18.682	2.111	16.067	2.069	4.901 **
Quick Learning	13.682	1.431	15.150	1.107	6.754 **

Table 7 shows a statistically significant difference at ($p < .01$) in favor of males in innate ability and omniscient authority. While in favor of females in simple knowledge, certain knowledge, and quick learning.

Table 8. Differences in Mathematical Beliefs According to Gender

Dimensions	Male N=60		Female N=60		t
	M	SD	M	SD	
Teacher's competence beliefs	14.452	1.464	13.301	1.437	3.540 **
Self-efficacy beliefs	13.824	0.936	12.652	1.514	4.189 **
Mathematics benefits beliefs	13.883	1.408	14.717	1.245	3.503 **
Mathematics difficulty beliefs	12.821	1.584	14.584	1.293	4.405 **
Mathematics enjoyment belief	14.323	1.381	15.824	1.817	4.163 **

Table 8 shows a statistically significant difference at ($p < .01$) in favor of males in teachers' competence and self-efficacy beliefs, while in favor of females in mathematics benefits beliefs, mathematics difficulty beliefs, and mathematics enjoyment belief.

Discussion

The Relationship Between Systemic Thinking Skills and Epistemological Beliefs

The study results show a positive relationship between systemic thinking skills and epistemological beliefs. Although the researcher could not identify previous studies that directly examined this relationship, theoretical frameworks and some previous studies can explain this hypothesis. Students' cognitive structures rely on skills such as viewing objects and systems comprehensively to perform analysis, synthesis, and evaluation. These systemic thinking skills are sophisticated mental processes related to students' epistemological beliefs. Moreover, students' ability to possess, practice, and develop systemic thinking skills depends on the nature of their epistemological beliefs. Systemic thinking is an individual dimension, reflecting differences among individuals in sensitivity to situational cues. These skills can be developed and enhanced through training and intervention programs. Systemic thinking requires thinking outside the box to improve the ability to create innovative ideas and envision a better future to solve problems in an integrated way (Gonzales, 2020). According to Randle (2014) the relationship between systems thinking and the Big Five personality factors was examined, while Randle and Stroink (2018) examined the relationship between systemic thinking and creative behavior, cognitive complexity, and abstract thinking.

Many aspects of academic learning have been linked to cognitive beliefs, particularly among high school students. For example, the more students believe that knowledge is simple, the less likely they will understand academic materials, assess their understanding, and use advanced learning methods. The more students believe learning is fast, the lower their grades will be. The more they believe that learning ability is innate, the less value they will place on education (Schommer-Aikins et al., 2005). Cognitive beliefs evolve. Cognitive beliefs in secondary education change and become more realistic and complex. These beliefs, directly and indirectly, impact academic achievement (Tali & Dar, 2018). Research shows that students' beliefs about mathematics are shaped by epistemological beliefs about the nature of knowledge, particularly regarding simplicity versus complexity, the source of knowledge, the certainty of knowledge, and the consistency of knowledge. Gallagher (2019) and Uçar (2018) believe that cognitive beliefs comprehensively influence learning and learning aspects such as motivation, performance, strategy selection, and information processing. Students with more mature cognitive beliefs are better able to solve problems than their peers with lower cognitive beliefs.

The Relationship Between Systemic Thinking Skills and Mathematical Beliefs

The study results show a positive relationship between systemic thinking skills and mathematical beliefs. Although the researcher could not identify any previous studies that examined this relationship, theoretical frameworks and previous studies can explain this hypothesis. Systems thinking requires higher-level thinking skills to analyze a situation and flexibly reconfigure its components using various methods of recombination and organization. Systems thinking represents a departure from unproductive linear thinking. It is used in mathematics to perform arithmetic, algebraic, and logical operations, engineering operations, and obtaining proofs from data. Mathematics is inherently a systemic science in which concepts are interconnected in an integrated system, making it a fertile field for developing systemic thinking skills (Randle, 2014; Randle & Stroink, 2018). Students may have difficulty learning mathematics for a variety of reasons. These reasons include the dry nature of the subject, teaching methods, students' attitudes and beliefs about mathematics, and lack of systemic thinking skills.

In contrast to a static mindset that views intelligence as unchanging, the dynamic mindset views intelligence as subject to change and development. It is characterized by a holistic view of the self and the world. One method for developing a dynamic mindset is to teach mathematics through problem-solving. Positive emotions are associated with forming positive beliefs about learning mathematics (Clements & Sarama, 2016; Schommer-Aikins & Easter, 2008).

The effect of epistemological beliefs on mathematics achievement appears to be mediated by other factors, such as students' self-efficacy beliefs (Kıbrıslıoğlu & Haser, 2015). Systemic thinking skills can influence the formation of students' attitudes toward mathematics. Cognitive misinterpretation and lack of acceptance of the difficulties of mathematics can lead to the formation of negative attitudes. In contrast, the opposite is true for those with high levels of systemic thinking skills, which are reflected in the acceptance of mathematics through comprehensive vision, analysis, synthesis, and evaluation of the systems embodied in mathematics (Shaked & Schechter, 2017). These positive or negative attitudes represent a person's cognitive and emotional responses to a subject and motivate positive or negative actions. Thus, students' emotional state influences their opinions and beliefs about mathematics. Their acceptance or dislike of mathematics can be determined by measuring their level of systemic thinking skills.

Gender Differences in Systemic Thinking Skills

This study showed that females could partition learned material, perceive relationships among elements, and make creative connections to form integrated systems with meaning and significance. In addition, females were distinguished by systemic thinking skills, with order dominating their behavior in daily life and science. Males were found to focus on holistic vision and synthesis. The genders were equal in abilities to perceive systemic relationships and evaluate systems. These similarities could be due to parity of academic and developmental levels, uniformity of courses studied, the similarity of social and cultural environments and students' perceptual and evaluative abilities since students in secondary education are characterized by rapid intellectual and emotional development. Systems thinking can be studied as the ability to see the whole outside of its parts and to view the parts in the context of the whole. Systems thinking is a holistic approach focusing on how the parts interact in an interaction network rather than breaking the system down into parts to be understood separately (Shaked & Schechter, 2020). Thus, biological, cultural, and educational differences exist in a systemic holistic perspective, systemic synthesis, systemic analysis, recognition of systemic relationships, and systemic assessment skills according to gender.

Gender Differences in Epistemological Beliefs

This finding can be explained by women's interest in education and belief that they must learn and excel in achieving appropriate social status. Since excellence in education requires complex cognitive strategies, women's cognitive beliefs may be more profound and complex. This finding is supported by previous studies (Lodewyk, 2007; Randle & Stroink, 2018; Tali & Dar, 2018) that women have deeper cognitive beliefs about innate abilities, believing that the ability to learn is acquired and not fixed but rather improves and develops through the strategies used in the learning process. In addition, learning occurs gradually through more effort. Naturally, students in secondary school are on the path to excellence in preparation for entering college and enrolling to achieve their goals.

Results showed statistically significant gender differences in high school students' simple knowledge, with male students having more mature beliefs than female students. The study examined students' beliefs about whether knowledge is a set of facts or is made up of constantly changing interconnected ideas and facts. New ideas or scientific information emerge every day, and what is true today may not be true tomorrow (Tali & Dar, 2018). In the accelerated learning dimension, students recognize that learning is a gradual process. Regarding the dimension of cognitive beliefs, high school students believe that learning ability is not fixed. Moreover, there are differences in knowledge structure (simple-complex) in favor of males (Tali & Dar, 2018). Previous studies have found gender differences in cognitive beliefs (fast learning, applied authority, and innate ability), possibly indicating the presence of deeper and more complex cognitive beliefs in females compared to males.

Gender Differences in Mathematical Beliefs

The finding can explain these results that one variable that influences mathematics learning is gender and its relationship to self-confidence and performance skills, as females tend to feel less confident than men about mathematics. Individuals develop beliefs about mathematics based on their personal experiences in school. There is evidence that female students' lack of confidence in mathematics may be due to the methods used by female teachers. In addition, some researchers believe that male students with high intellectual ability are lazy and sloppy, resulting in poor performance. In contrast, female students achieve high performance through hard work and perseverance. This difference may be due to students' characteristics and their ability to perform academically. Those with low achievement have less confidence in mathematics, while those with higher achievement have more confidence (Clements & Sarama, 2016; Hannula et al., 2016).

Conclusions

The results of this article show positive and significant relationships between systemic thinking, epistemological beliefs, and mathematical beliefs. Second, the results show significant differences between males and females in systemic thinking, epistemological beliefs, and mathematical beliefs. The study focused on secondary education because this is the stage of independence in acquiring systemic thinking skills, epistemological beliefs, and attitude formation. The study's results contribute to a better understanding of the relationship between systemic thinking skills, epistemological beliefs, and mathematical beliefs. These findings may support future research on positive attitudes toward mathematics and changing epistemological beliefs by promoting systemic thinking skills. The results of this study may also increase parents' and teachers' awareness of the importance of using systemic thinking skills and the epistemological beliefs students adopt, as well as their potentially emotionally positive impact in the face of an ever-evolving world of knowledge. These findings may help convince educators and those responsible for developing academic courses to emphasize the most effective systemic thinking skills and epistemological beliefs and their importance to students' lives and education in the school context.

Recommendations

Based on the conclusions, this study can serve as a stimulus for educators and educational activists to find the right models, or learning strategies, to improve problem-solving skills based on understanding the nature of systemic thinking skills and epistemological beliefs. In terms of research, further studies need to be conducted on specific topics, such as the effectiveness of a training or counseling program to promote systemic thinking skills in changing high school students' epistemological beliefs. Systemic thinking skills contribute to changing epistemological and mathematical beliefs. A comparative study between high-ability and non-high-ability students on systemic thinking skills and mathematical beliefs among high school students is necessary for further studies. Similarly, more multimethod studies based on longitudinal studies need to be conducted to provide a more comprehensive picture of the relationship between systemic thinking, epistemological beliefs, and mathematical beliefs.

Limitations

This study was conducted only in Al-ahsa, Saudi Arabia, and the sample size was small. Therefore, the results of this study do not describe the overall profile of secondary school students in Saudi Arabia. Due to these limitations, future researchers should expand the subject of this study to a larger area, i.e., provincial or national level.

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