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Reframing STEM Education through Ontological and Epistemological Perspectives of Science

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Abstract

Ontological-epistemological convergence plays a significant role in learning science. Therefore, the relationship between ontological and epistemological stances in science was examined to understand the context for integrating STEM education in science learning. A systematic review of the literature was carried out using the PRISMA method. Articles were scrutinised following the inclusion and exclusion criteria and finally, 51 articles were retained. The overall inter coder agreement reached was ICA =88% well above the minimum threshold of 70%. A common agreement resulted in developing a theme/category. The findings revealed that STEM education emphasises epistemic cognition, ontological framing of real-world issues, and the integration of different STEM disciplines. Teacher educators should be equipped to understand how knowledge is validated in science and how designing in engineering and mathematical modelling enable them to guide transdisciplinary inquiry without ignoring STEM discipline.

Keywords: Ontology of Science; Epistemology of Science; STEM Education and Transdisciplinary Inquiry

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INTRODUCTION

Science is increasingly viewed from social and environmental contexts due to its profound impact on society. For example, genetically modified foods represent the interplay of science with environment. Analyzing such issues raises ontological and epistemological questions of learning science. In this context, science learning addresses questions about the natural world, which focuses on what science is and how it works. Sandoval and Redman (2015) reported the relationship between the nature of scientific knowledge and the world. They argued that science is the process of systematically generating knowledge about the natural world. For instance, in describing secondary students about magnetism, the ontological stance of magnetism explains how the interaction between a magnet and nonmagnetic materials are distinguished. Similarly, the epistemological stance of magnetism captures students' ability to account for and predict attraction and repulsion of materials by a magnet (Papadouris & Constantinou, 2017). The status of knowledge generation is epistemology, and what knowledge exists in the world is ontology. Hence, the relationship between scientific knowledge and scientific truth sheds light on the epistemology and ontology of science.

The Rationale of the Study

Teaching-learning of science is based on inquiry about the natural world. Science learners learn about 'forces' associated with different activities in their daily lives. For example, a ball rolling along the ground gradually slows down and finally comes to rest. In this situation, learners use reasoning and inquiry techniques

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to understand this phenomenon. They build conceptual understanding that a force of friction between the ball's surface and the ground brings the moving ball to rest. Thus, science is oriented toward real-world-based schemes that create scientific concepts (Ministry of Education, 2020). Additionally, it can facilitate mathematical, technological, and engineering problem-solving abilities in this process (Lee et al., 2016). A focus on inquiry in learning science, which is relevant to real life, enables STEM learning opportunities. Science learning supports inquiry structuring students' thinking about scientific phenomena and integration of Science, Technology, Engineering, and Mathematics (Ortiz-Revilla et al., 2020). Thus, inquiry-based learning provides learners with epistemological considerations of science. Hence, the necessity of epistemic knowledge of science is argued by many.

The learners' existing ideas are based on their observation of the natural surroundings, which helps them in applying scientific concepts. For example, when 'sound' is produced, the ontological dimension helps in deciding how the different dimensions, such as amplitude, frequency, time period, loudness, and pitch of sound, can be explained with different experiments in the classroom. At the same time, epistemological dimensions help validate the experiment in real-world scenarios. Sere et al. (2001) claimed that scientific models and their experimental correspondences deal with the ontological dimension, and the validity of explanations ensures the epistemological dimension. These two dimensions of science determine the state of scientific knowledge. Thus, a true understanding of science is based on where science and the scientific process are embedded through ontological and epistemological stances. Therefore, a relationship between ontological and epistemological understanding and inquiry in learning science needs to be articulated.

It is necessary to reflect explicitly on ontological and epistemological stances of science for an integrated STEM education in solving real-world problems. STEM is a dominant construct in research analysis. A sound argumentation is necessary from a philosophical point of view (Ortiz-Revilla et al., 2020). A few research studies have been reported which reflect on ontological and epistemological components of science in STEM education. A probing question on the ontological and epistemological basis of STEM integration in terms of meta-synthesis is a missing element in the literature. Therefore, both stances of science grounded in STEM integration were explored

Research Objectives:

Science is best understood when its' ontological and epistemological aspects are focused on during learning. Prioritizing these in science learning strengthens all four STEM disciplines, making their integration in STEM education a critical area for exploration. Therefore, the following research questions were posed to guide a systematic synthesis of literature.

1. What is the ontological stance of science?
2. What is the epistemological stance of science?
3. What is the context of the integration of both stances of science?
4. How does the integration of both stances of science situate itself in STEM education?

METHOD

Systematic literature reviews were employed using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method (Moher et al., 2015). PRISMA is adaptable to our research for systematic reviews surrounding three main activities: (1) development of a search strategy, (2) selection of relevant studies, and (3) extraction of the articles from the included studies. A systematic review was done by presenting a descriptive summary of each article's critical points about the ontology and epistemology of science in response to the research questions. Then, a systematic synthesis was focused on the ontological and

epistemological points of view, issues, and ideas presented in those articles. The schematic representation of the systematic review search strategy is given in Figure 1.

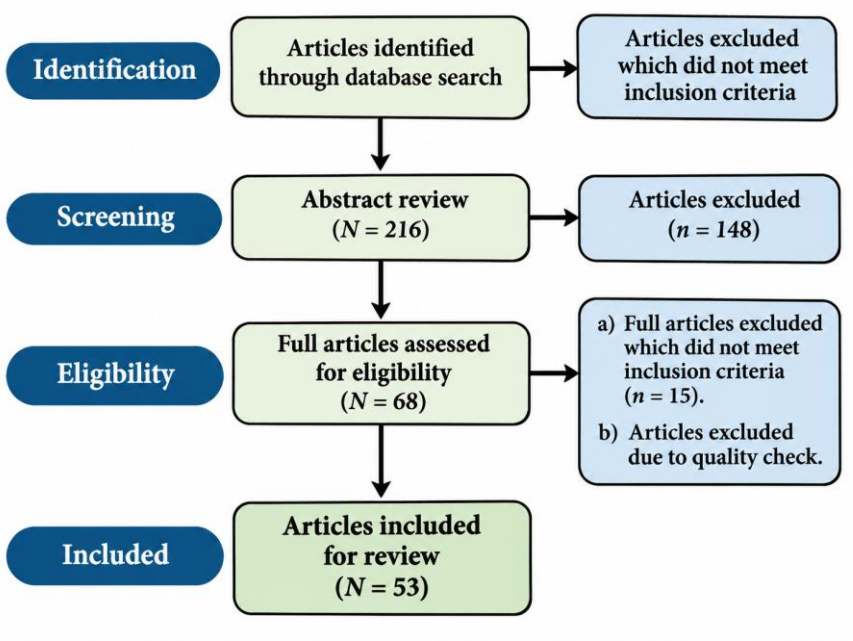


Figure 1: PRISMA Flow Diagram for the Systematic Review Search Strategy (Adopted from Moher et al., 2015)

Development of Search Strategy

A search strategy was defined to search for all possibly relevant studies. The authors identified the domain of keywords and selected the appropriate database as cited in Bano et al. (2018).

Identification of the Domain of Keywords

The authors identified four domains of keywords: nature of science, belief in knowledge, way of knowing science, and cognitive process in science. In order to generate the alternative terms from the domain of keywords, authors made a preliminary survey on existing literature reviews of science education, considering the ontology of science and epistemology of science. From these literature reviews, the authors came up with a list of alternative terms from the keyword domain.

Inclusion and Exclusion Criteria

A total of three web databases were consulted, including the Educational Resources Information Centre (ERIC), ProQuest, and Scopus. The following inclusion criteria were used in the synthesis:

1. Research Articles, Thematic Papers and Conceptual Papers on Science Education
2. Peer-reviewed publications on science education
3. Studies published between January 2013 and January 2026

The following were excluded:

1. Editorials, commentaries, conference proceedings, and book chapters
2. The articles that were not published in English
3. Studies for which the full text was unavailable

The authors used a spreadsheet to represent the data extraction form, including the journal's name, title, research questions, objectives, findings, and key concepts relevant to the search and publication year. Content analysis of the text of each related literature was done.

Search Strategy

A search of keywords was carried out to answer the research questions. A list of similar keywords was created in order to pick the broadest range of potentially relevant literature. Searches were done by combining at least one word from each category listed below. The same search word combinations were applied across three databases to ensure a systematic process. The identified keywords under the ontological and the epistemological stance of science are depicted in table1. At the initial identification, 329 records were identified across ERIC, Scopus, and ProQuest. Duplicates and titles & keywords were screened at the first level, where 113 articles were removed. Only 216 titles and abstracts were reviewed. Considering eligibility exclusions, 148 articles were excluded. Consequently, only 68 full-text articles were retrieved and assessed. Of these, 15 articles lacked a substantive ontological and epistemological focus, and 2 articles did not meet the quality appraisal criteria. A domain of keywords was prepared consistently with the criteria of quality articles. These quality check criteria were adequacy of research context, framing the research question(s), analysis adequacy, and stating methodological limitations (Garcia et al., 2019). Thus, 51 articles were finally included for systematic review. In this way, 51 articles were retained on satisfying these quality criteria.

Table 1: Domain of Searching Keywords for Screening Articles

SN	Domain of Keywords	Alternative Terms	Searching	Screening	Eligibility
	Nature of Science	Epistemology in Science	10	5	5
		Ontology in Science	20	17	3
2	Belief in Scientific Knowledge	Epistemological Belief	60	46	14
		Ontological Belief	7	4	3
3	Way of Knowing and Science	Epistemic Knowledge	5	4	1
		Truth Seeking in Science	18	17	1
		Epistemic Understanding	8	5	3
		Epistemic Argumentation	5	3	2
		Epistemic Insight	6	5	1
		Ontological Knowledge	11	5	6
4	Cognitive Process in Science	Epistemic Orientation	3	2	1
		Ontological Orientation in Science	26	22	4
		Epistemic Cognition	12	7	5
		Epistemic Process	25	23	2
		Total	216	165	51

Inter-coding agreement (ICA) was measured to estimate how two experts named the same term. The unit of analysis comprised peer-reviewed articles on science education published from 2013 to 2026. Two independent coders performed article coding using inductive-deductive approach. The key words discerned in the articles were regarded as themes. The keywords were examined according to inclusion and exclusion criteria. The themes were categorized under a comprehensive domain of keywords. The thematic semantic meanings were consolidated into a category. Disagreements on these categories were systematically settled

through negotiated agreement between the two coders. The data were collected on a nominal scale (i.e. the presence and absence of a theme/ category). ICA was calculated in basic percentage agreement which was dividing the number of agreements by the total number of agreements plus disagreements. The actual overall intercoder agreement reached was ICA =88% well above the minimum threshold of 70%. It provided confidence that the agreement transcends only one element (Kurasaki, 2000). A common agreement resulted in developing a theme/category.

Mapping the Themes into Categories

The themes around ontological and epistemological bases of science were grouped into ten categories (Figure 2). The semantic meanings of themes were organized. The relatedness of meanings was observed. Themes with similar meanings were included under one category.

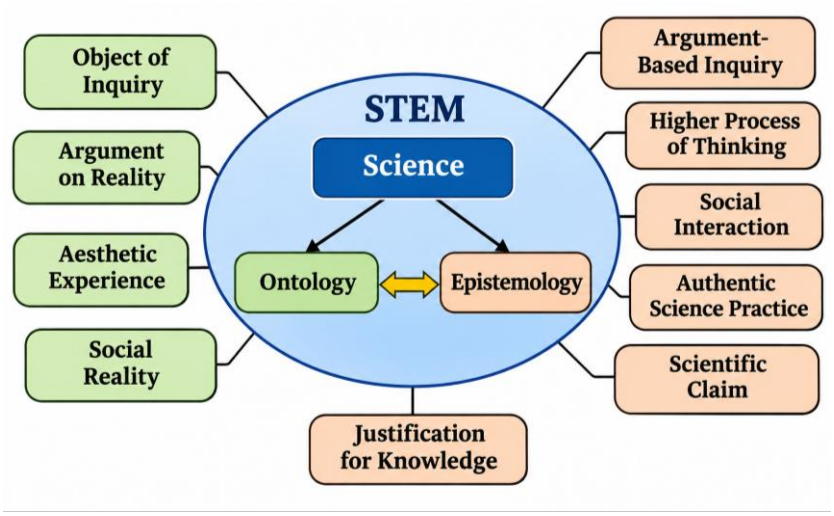


Figure 2: Mapping the Themes into Categories

RESULTS

RQ1. WHAT IS THE ONTOLOGICAL STANCE OF SCIENCE?

Synthesis of Reviews

Ontology expresses entities of knowledge that exist in reality. It is the true understanding of reality through the learning of science (Kirbaslar et al., 2021). Reality in science is the outcome of experiments, which are interpreted in terms of scientific beliefs, facts, and arguments. The ontological aspects of science are captured through the study of nature (Limbu et al., 2025) which are contemplated on scientific concepts, phenomena, scientific laws, theories, principles or models. The ontological value of science represented the discovery of scientific concepts. These concepts are human-conceived and are used as science content. During learning science, the reality and existence of social concepts and ideas are often neglected for argumentation. The nature of science should be interpreted as how scientific knowledge is created and how the truth shapes that knowledge. Ontology helps to understand how socially constructed scientific knowledge can be built in reality (Yucel, 2018). The reviews of ontological literature revealed some factors influencing science knowledge. Our pedagogies are covered under these factors. These are summarized in Table 2.

Table 2: Summary of Reviews on the Ontological Stance of Science

SN	Theme	Authors	Major considerations	Factoring
1.	Ontology in Science	Datt, S. (2015)	Ontology as explanation of reality in scientific concepts.	Concepts from the larger world of science possessing ontological validity can be developed collaboratively by a community of learners to remove learners' misconceptions.
2.	Ontological Belief	Kirbaslar, F. G., Arica, B., & Cingil Baris, C. (2021).	Ontological Belief in science is the true correspondence of and the understanding of truth in scientific studies.	Constructivist inquiry approaches can be used to develop ontological beliefs among students through the use of epistemic tools such as language, dialogue, and argument.
3.	Truth Seeking in Science	Abegglen, S., & Bustillos, J. (2016)	exploring reality in scientific ideas which shapes our understanding of the world.	Science is a discourse which shapes our understanding of the transformative world and creates knowledge and truth.
4.	Ontological Knowledge	Papadouris, N., & Constantinou, C. P. (2017) Yucel, R. (2018) Ostergaard, E. (2017) Svedholm, A. M., & Lindeman, M. (2013) Ostergaard, E. (2014).	Conceptual understanding of nature as a construct, gathered through daily life experiences	Discourse on epistemic and ontological aspects enriches the views and appreciation of ideas about the nature and process of science. Grounded aesthetic experiences broaden students' consciousness, notion of science & scientific inquiry and develop insight into dealing with several environmental, technological & social challenges. Ontological knowledge significantly affects educational research, curriculum, and classroom teaching, including the framing of indigenous science in school science programs.
5.	Ontological Orientation in Science	Kirbaslar, F. G., Arica, B., & Cingil Baris, C. (2021), Datta, R. (2016), Limbu, S., Rajbanshi, R., & Kumar, R. (2025).	A means of re-examining and re-configuring everyday experiences of reality.	The ontological orientation is evident in the emphasis on collaboration and engagement in the process of inquiry, active participation, reflection, and the co-construction of knowledge among mentors, researchers, and participants.

Understanding fundamental knowledge about the natural world in a systematic way is science. Knowledge about real-life situations is scientific. Scientific knowledge does correspond to reality (Sandoval & Redman, 2015). Thus, learning science implies giving everyday life experience. Ontology orients the everyday life experiences of students, rooted in scientific concepts. Students' everyday knowledge is grounded in aesthetic experience. The value of aesthetic experience allows open inquiry (Ostergaard, 2014). The field of ontology explores the 'inquiry process'. Such a type of knowledge fosters ontological sensibility (Ostergaard, 2017). Hence, students need to be sensitive towards everyday life situations. Ding (2019) highlights ontological challenges for the generation of knowledge. He emphasized the pragmatic basis of science during the investigation of reality. Therefore, the goal of learning science should be based on practical aspects of life. Students should not be compelled to adopt a particular worldview without understanding the scientific principles governing it. Understanding includes knowing about scientific principles when it is appropriate to use the knowledge, and how to use it (Svedholm & Lindeman, 2013). Ontology is a discourse that shapes our understanding of the world. Discourse-based producers of reality yield the effects of truths (Abegglen &

Bustillos, 2016). Kirbaslar et al. (2021) explained this phenomenon as 'reaching the reality', which includes scientific entities.

Science is embedded and entwined with our world, not simply contained within it. So, the ontology of science describes claims and assumptions about the nature of social reality, claims about what exists, what it looks like, what units make it up and how these units interact with each other (Verdin et al., 2018). That is, becoming a learner of science is to interpret social reality. Dall'Alba (2009) described ontology as 'being in the world'. The world covers disciplines like mathematics, physics, engineering and others, which derive knowledge claims from interpreting lived experiences of individuals or groups. One's ontological understanding of a concept can contribute to knowledge construction. Exploring how to interpret the meaning of what it means to a mathematics learner, science learner and/or engineering learner through the philosophical study of the nature of being is ontology. Ontology centers on how the world makes itself known and the forces that form our everyday life (Datta, 2016). The science behind reality is one of the most potent means of re-examining and reconfiguring everyday practices in a way that values interconnectedness among multiple scientific entities (Yucel, 2018). Therefore, scientific knowledge seeks something new and unknown which emerges from reality.

Critique of Reviews

The researchers reflect on their ontological commitments, which enabled them to talk about the integration of diverse content knowledge encapsulated in science education. This part of the review demonstrated that the ontology of science provides relevant support to design STEM education with regard to scientific practice. These supports

- Science is inquiry beyond the realm of the actual.
- Science is derived from social reality.
- Science is an exploration of socially constructed scientific knowledge in which reality can be anchored.
- Aesthetic experience is the base of pragmatic inquiry into the nature

RQ 2. What is the Epistemological Stance of Science?

Synthesis of Reviews

The reviews of related literature revealed some factors influencing science knowledge. Science practices are associated with these factors. These are summarized in Table 3.

Table 3: Summary of Reviews on the Epistemological Stance of Science

SN	Theme	Authors	Major Consideration	Factoring
1	Epistemology in Science	Koponen, I. T. (2021). Cheng, C. H., Braten, I., Yang, F. Y., & Brandmo, C. (2021). Memisoglu, A. S., & Ercelik, B. (2022), Allchin, D. (2024)	Epistemology in science is the empirical process of creating valid scientific explanations.	Science is embedded in and is an interdisciplinary area that explores the ontological and epistemological foundations of science.
2	Epistemological Beliefs	Zorlu, Y. (2017). Prasadini, L., Hamid, J. A., Khatibi, A., & Azam, S. M. (2018). Bahcivan, E. (2019). Demirbag, M. (2021). Cheng, C. H., Braten, I., Yang, F. Y., & Brandmo, C. (2021). Kirbaslar, F. G., Arica, B., & Cingil Baris, C. (2021). Koutsianou, A., & Emvalotis,	Epistemic beliefs as Individuals' beliefs about the true nature of knowledge and how epistemic emotions and knowledge-related beliefs are acquired	Epistemic beliefs help in the justification of knowledge and processes of idea generation, judgment, and decision-making. Dialogic-practical work facilitates the key features of argument-driven inquiry. Constructivism and inquiry-based education help in enhancing the students' ontological and epistemological beliefs.

SN	Theme	Authors	Major Consideration	Factoring
		A. (2021). Lopez-Banet, L., & Martínez-Carmona, M. (2021). Guo, J., Hu, X., Marsh, H. W., & Pekrun, R. (2022), Tan & Koh (2023),		
3	Epistemic Knowledge	Yang, F. Y., Liu, S. Y., Hsu, C. Y., Chiou, G. L., Wu, H. K., Wu, Y. T., ... & Tsai, C. C. (2018), Soysal, Y. (2025).	Epistemic knowledge as the comprehension of science principles.	Epistemic knowledge helps students better understand the epistemic nature of scientific knowledge and learning, which is influenced by instructional decision-making. It enhances critical/creative thinking among teachers.
4	Epistemic Understanding	Koponen, I. T. (2021), Soysal, Y. (2025).	Epistemic understanding is to verify the empirical findings.	Thinking, causation, hypothesis testing, argumentation, evaluating, critiquing, interrogating and arguing are epistemic understanding practices.

Epistemology of science examines the association of knowledge in science with the nature of science (Memisoglu & Ercelik, 2022). Scientific knowledge is ever evolving. Scientific knowledge arises through logical argumentation, empirical verification, and human reason. Justification of such knowledge through experimentation is required (Pluta et al., 2011). The epistemic understandings help the learners to verify the empirical findings and enable them to construct knowledge (Guo et al., 2022), improve argumentation skills for experimental justification (Bahcivan, 2019; Demirbag, 2021), understand the epistemic nature of science learning (Kizkapan & Bektas, 2021) and promote deep learning approaches (Prasadini et al., 2018; Sandoval, 2009). Students' creative representation of knowledge helps in their thinking process (Grushka et al., 2018), decision-making (Cano, 2005), scientific inquiry and argumentation (Yang & Tsai, 2010), critical thinking (Koponen, 2021) and scientific reasoning (Hogan & Maglienti, 2001). These were the dimensions of the epistemological framework.

Major constructs of epistemologies of science emerging from the studies include epistemic beliefs and views, nature of science, epistemic emotions, epistemic metacognition, epistemic practices, and epistemic resources (Lee et al., 2021). Epistemic beliefs about the certainty of knowledge, source of knowledge, control of knowledge and speed of knowledge acquisition are related to science learning (Lee et al., 2016). Driver et al. (2000) gave an account of the practice of scientific knowledge, which is essential for improving scientific literacy. Duschl (2008) also mentioned that epistemic learning develops scientific literacy. This component supports learners' participation in STEM education.

Epistemologies of science addresses issues related to philosophical assumptions, values and conceptual inventions in science (Tsai & Liu, 2005). Epistemic resources involve cognitive resources for understanding knowledge and how it is generated (Soysal, Y. (2025). Epistemologies specific to science focus on students' ideas to construct knowledge. This perspective emphasized students' learning through inquiry. Yang et al. (2018) mentioned that epistemological knowledge of science embraces the status of scientific knowledge and the nature of the scientific enterprise.

Science is practiced with epistemic goals. Learners should be engaged in authentic scientific practice to develop epistemological understandings. Science practices are means to develop scientific knowledge and scientific processes to explain the natural world (Krajcik et al., 2014), because science is embedded in and embodied by students' life experiences (Carol-Ann et al., 2018). Science, as a practice of systematic

understanding of the natural world, focuses on what students know, emphasizing how learners construct knowledge. Epistemology facilitates student engagement in knowledge generation through science practices (Park et al., 2022). Epistemic orientation is the driver in implementing argument-based inquiry. Implementing scientific practices needs a more learner-centered and epistemological view of learning (McNeill et al., 2017).

Learners will not be able to participate in scientific actions and processes meaningfully with limited epistemic understandings. Engagement in research experiences can contribute to the development of epistemology and processes of science (Kuhn et al., 2017). Learners' epistemological knowledge is revealed through their science learning, and the nature of scientific knowledge acquired. It also promotes their reasoning, discussion, and learning approaches (Zorlu, 2017; Marra & Palmer, 2005). Learners develop a model or receive a revised scientific model for discussion and argumentation to determine a scientific claim. So, the learner's argumentation involves epistemic cognition (Wei et al., 2021).

Students encounter multiple epistemic stages in developing scientific claims: observation, interpretative reasoning, consensus and credibility (Allchin & Zemplen, 2020). The epistemic procedures involve appropriate approaches to validate and standardize the results. Students need argumentation while carrying out science projects. This involves their epistemic knowledge and belief (Lopez-Banet & Martinez-Carmona, 2021). They develop a logical understanding of the steps to claim the scientific results (Allchin, 2013).

Critique of Reviews

Research findings suggest that students bring critical practices into the classroom. All students' ways of knowing and doing science are appreciated, recognized and used to support meaning-making in such practices (Gonzalez-Howard & McNeill, 2020). Cheng et al. (2021) argued that students should have beliefs about knowledge in science, its justification and claims in learning science. So, epistemic orientation is the driver in implementing argument-based inquiry. An epistemology of science provides relevant support to design STEM education with regard to scientific practice. The study reveals the following categories of support:

- Inquiry involves making explanations.
- Cognitive processes interpret the reliability of scientific claims.
- Authentic science practice
- Science seeks empirical justification

RQ3. What is the Context of the Synergetic Integration of both Stances of Science?

The knowledge generated through observation of nature is the epistemology of science. Epistemic practices are associated with creating, communicating and evaluating knowledge in science. The epistemology of science is the understanding of the role and functions of process in justifying the knowledge produced by science (OECD, 2017). Osborne et al. (2003) argued that science is the process of knowledge justification. In the PISA framework, scientific knowledge is considered to be epistemic knowledge. Epistemic knowledge refers to understanding the constructs, defining features of science, and the way to justify scientific claims.

Learners experiencing practical skills in the laboratory, observing effectively, responding to particular demands of a task, and assessing one's performance are facets of the epistemology of science. As a result, the epistemology of science is contextualized as:

- Critical analysis and practical skills must explicitly be focused.
- Epistemic knowledge is used to justify scientific claims.
- Cognitive skills must be used to identify the truth of knowledge through the scientific process.

Nevertheless, science is based on the reality of the surroundings. This truth of knowledge is grounded in scientific inquiry, which deals with the realities of one's natural surroundings. This gives an ontological orientation to the learners. Learning science provides learners with a platform to explain scientific facts in a natural way by which they gain aesthetic experience. The learners should be oriented towards a real-life scenario which is scientific, authentic, and free from biases. The ontology of science is contextualized as:

- Contents must be linked with everyday science and independent social reality.
- Aesthetic competency should be identified among learners.

Critique of Reviews

The integration of the two stances concerns a balance between the quest for knowledge and the search for the truth of the natural world. Epistemology emphasizes the empirical method towards quest for knowledge. Nevertheless, scientific investigation is both discovery and creativity. Additionally, the ontological domain of science provides the ultimate aim of scientific investigation. Scientific practices are embedded within the social context. Social events are justified through causal explanations, which rely on scientific practices and hence are grounded in the truth of society.

The aim of science is, therefore, to discover true knowledge about the world. However, science attempts to unravel the ground of reality to explain the cause of phenomena. A framework of the context of integrating both stances of science is developed and shown in Figure 3. The claims of scientific explanations about the truth of the world help to understand scientific constructs in an integrated way. Inquiry, argumentation, designing and constructing knowledge are aligned with social reality.

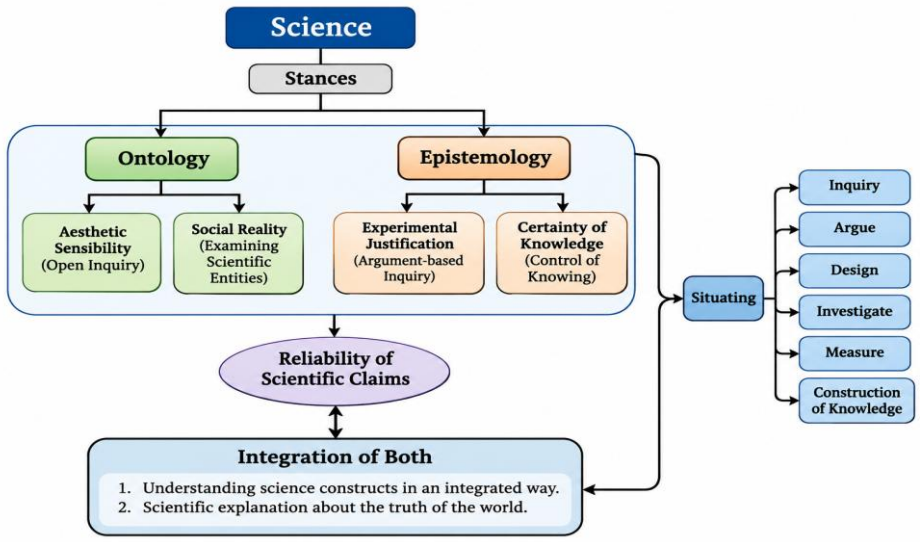


Figure 3: Framework of Synergetic Integration of Ontology and Epistemology Stances of Science

The domain of science requires critical justification of scientific claims and counterarguments (Duncan et al., 2018). Certainty of knowledge and truth in the scientific process is relevant to the epistemology of science. Natural science is open to inquiry. It has a linkage with the natural world. Scientific knowledge examines scientific entities, presupposing the natural world as its ontological foundation. So, integrating both stances of science is understanding the truth of the world and providing scientific explanations.

RQ4. How does the Integration of both Stances of Science Situate in STEM Education?

The components of STEM education are well articulated through science. STEM integration provides a broad scope of creation of scientific knowledge for the contents of Science, Technology, Engineering and Mathematics. Science is oriented through inquiry in epistemological and ontological platforms. The epistemological and ontological underpinnings of science activities help in creating scientific knowledge. These activities are shown in Table 4.

Table 4: Ontological and Epistemological Bases of Science

Ontological and Epistemological Bases of Science	Affordances
Inquiry on a Topic	Interactive session, Planning and Thinking of a Problem
Creating an Argument	Supporting Evidence-Based Rationale
Developing a Design	Creating Links and Representing the Linkage of Concepts
Investigation	Doing Experiments
Making Measurements and Results	Data Sharing
Knowledge Building	Collaboration, Communication

Situating Integration

Learners need to view everyday life experiences through scientific phenomena. An open inquiry about their daily life experiences helps them discover the world in its reality. In this regard, a scientific process is required to understand the world. The epistemology of science examines the nature of science, such as verifying the empirical findings, analyzing scientific methods, etc., whereas the ontology of science explores the existence of the reality of scientific entities. Thus, science aims to acquire not only knowledge about the truth but also how to use such knowledge in life. Therefore, epistemological understanding of the certainty of the knowledge and ontological understanding of the reality of the knowledge are the two facets of scientific claims.

The nature of science has a potential role in accommodating learners to claim truth in science. The ontological and epistemological nature of science enables learners to judge the reality of entities. Therefore, studying natural phenomena cannot be limited to science subjects only. Learning science as an isolated subject hinders holistic thinking and the explanation of scientific facts. This shows the need to integrate science learning with STEM education. The learners find opportunities to search for the truth through interdisciplinary subjects of STEM education (Groff, 2004). They can explain the various forms of scientific practices through STEM education.

Ontological considerations are inseparable from an epistemological point of view in the context of the nature of science. Of course, epistemological views are influencing the reality of entities proposed for integrated learning (Lee et al., 2021). It is important to conceptualize numbers and other mathematical entities in relationships, considering the nature of mathematics (Bano et al., 2018). Similarly, Engineering and Technology are interpreted within design-oriented concepts (Yalcin & Ozturk, 2022). Epistemic science is the creation of knowledge and scientific explanations. Technology can be depicted as the construction of things. Technology is understood as operation, while engineering pertains to the application of scientific knowledge.

Integrated STEM education functions as an ecosystem where science, technology, engineering, and mathematics maintain reciprocal equivalence. While science provides the ontological framing of natural phenomena and epistemological justification of empirical claims, engineering contributes design and optimization of epistemologies; technology provides operational mediation and mathematics establishes quantitative modelling. The ontological and epistemological perspectives of science serve as an unveil collaborator that intersects with engineering and mathematical problem-solving fostering STEM learning environments.

DISCUSSION

The approaches to studying the nature of science are considered from ontological and epistemological stances. The epistemological questions of knowledge are often not widely debated. The creation of knowledge and dissemination of such knowledge by learners must be critically examined in order to ensure its certainty. Epistemic beliefs significantly influence students' interactions with scientific concepts (Tothova and Rusek, 2025). Ontology examines the reality of knowledge creation. Learners' thought processes help to build epistemological and ontological beliefs during inquiry-based learning (Koutsianou and Emvalotis, 2021). Hence, understanding of fundamentals of science and the scientific process are embedded through ontology and epistemology of science (Tan and Koh, 2023). It is important that students develop epistemological and ontological beliefs corresponding to the nature of knowledge.

Competencies such as scientific explanations, inquiry, and data interpretation are necessarily assessed in science. Program for International Student Assessment (PISA) standards include epistemic knowledge (OECD, 2022). Therefore, learners must learn to analyze and evaluate data, argue in various representations and draw appropriate scientific conclusions (OECD, 2017). Hence, epistemological and ontological concerns regarding the nature of science need to be taught to learners. The major goal of the curriculum should be the communication of ideas about the world's reality. The scientific discussion in the classroom should contain terms such as laws, theories, models, explanations, truth, knowledge, observation, hypothesis, data interpretation, and generalization on real-life issues. Therefore, knowledge gained through science subjects in schools is imperative to explore interdisciplinary knowledge of STEM education.

The current literature perceives STEM integration, epistemic cognition, empirical justification, social reality and nature of science in silos; whereas the present work identifies the scope for synthesis among these areas. This includes a unified structure which maps ontological dimensions like social realities and epistemic practices like epistemic cognition. Instead of considering ontology and epistemology as rhetorical constructs this work signifies interdisciplinary design and problem-solving attributes. The missing element of grounded conceptual anchoring as per the nature of sciences (NOS), truth seeking approach integrated with technology and engineering as part of systematic synthesis for interdisciplinary co-constitution without subordinating one discipline with another.

The broader scholarly contribution of this synthesis lies in positioning ontological framing and epistemological justification as complementary foundations for interdisciplinary STEM education. Rather than prescribing a uniform instructional model, the proposed framework offers a conceptual basis for examining how scientific inquiry, engineering design, technological applications, and mathematical modelling can be meaningfully integrated across different educational systems. This perspective contributes to international STEM education discourse by identifying principles that can inform curriculum development while accommodating differences in educational contexts, resources, and disciplinary practices.

IMPLICATIONS FOR STEM EDUCATION

The integration of ontological and epistemological stances of science in STEM education would unveil opportunities for both teachers and students to explore diverse elements outlined in the conceptual framework. It will enable integration of essential learning under ontological and epistemological domains, promoting a more rational methodology towards teaching-learning. This approach, in contrast to the frequently practiced piecemeal approach of teaching STEM subjects, will foster not only creative and tangible learning experiences but also sustainable learning practices. This may also result in a paradigm shift from content-centric education to competency-based learning that encompasses creative thinking, collaboration, communication, problem-solving, experiential learning, problem-based learning, and hands-on learning. STEM education emphasizes

epistemic cognition, ontological framing of real-world issues, the integration of different STEM disciplines, and the expansion beyond traditional disciplinary confines.

Teacher educators should be equipped to understand how knowledge is validated in science and how designing engineering and mathematical modelling enable them to guide transdisciplinary inquiry without ignoring STEM discipline. For international STEM education, the framework may inform curriculum design and teacher professional development across diverse educational settings, including resource-constrained environments. Its application should be adapted to local curricula, available technologies, and learners' sociocultural experiences while maintaining the central principles of inquiry, evidence-based justification, and interdisciplinary problem-solving. Future empirical studies across different countries and educational levels are needed to examine its applicability and educational effectiveness.

CONCLUSION

The study translates ontology and epistemology into integrated learning units where Science, Technology, Engineering, and Mathematics interact each other. Hence, STEM education signifies the expansion beyond traditional disciplinary confines. Ontological and epistemological knowledge of science contributes for STEM education in solving real-life problems. The ontological and epistemological perspectives of science provide essential cognitive structure that synergistically engages with engineering design, technological innovation and mathematical modeling. An effective approach should be to redesign the STEM curriculum and its implementation in the context of STEM integration.

REFERENCES

Abegglen, S., & Bustillos, J. (2016). Science education: Beyond a liminal understanding of knowledge production and dissemination. *Journal of Education in Science, Environment and Health, 2*(1), 13-20. https://doi.org/10.21891/jeseh.84535

Allchin, D. (2013). *Teaching the nature of science.* Perspectives and Resources. St. Paul, MN: *SHiPS Education Press*. http://shipseducation.net/press/TNOS-preface.pdf

Allchin, D., & Zemplen, G. A. (2020). Finding the place of argumentation in science education: Epistemics and Whole Science. *Science Education, 104*(5), 907-933. https://doi.org/10.1002/sce.21589

Bahcivan, E. (2019). Examining the Structural Relations among PSTs' Scientific Epistemological Beliefs, Epistemic Emotions and Argumentativeness: Sample from Turkey. *International Journal of Education in Mathematics, Science and Technology (IJEMST), 7*(3), 271-280. https://files.eric.ed.gov/fulltext/EJ1223839.pdf

Bano, M., Zowghi, D., Kearney, M., Schuck, S., & Aubusson, P. (2018). Mobile learning for science and mathematics school education: A systematic review of empirical evidence. *Computers & Education, 121*, 30-58. https://doi.org/10.1016/j.compedu.2018.02.006

Cano, F. (2005). Epistemological beliefs and approaches to learning: there change through secondary school and their influence on academic performance. *British Journal of Educational Psychology, 75*(2), 203-221.https://doi.org/10.1348/000709904X22683

Carol-Ann Burke, L. E., Wessels, A., & McAvella, A. (2018). Using theater and drama to expose and expand the epistemic insights of youth regarding the nature of science. *Research in Science Education, 48*(6), 1151-1169.https://doi.org/10.1007/s11165-018-9782-z

Cheng, C. H., Braten, I., Yang, F. Y., & Brandmo, C. (2021). Investigating structural relationships among upper-secondary school students' beliefs about knowledge, justification for knowing, and Internet-specific justification in the domain of science. *Journal of Research in Science Teaching, 58*(7), 980-1009.https://doi.org/10.1002/tea.21689

Dall'Alba, G. (2009). Learning professional ways of being: Ambiguities of becoming. *Educational Philosophy and Theory, 41*(1), 34-45. https://doi.org/10.1111/j.1469-5812.2008.00475.x

Datta, R. (2016). How to Practice Posthumanism in Environmental Learning: Experiences with North American and South Asian Indigenous Communities. *The IAFOR Journal of Education, 4*(1), 52-67.https://files.eric.ed.gov/fulltext/EJ1100625.pdf

Demirbag, M. (2021). Modeling the Relations among Argumentativeness, Epistemological Beliefs and Self-Regulation Skills. *International Journal of Progressive Education, 17*(4), 327-340.https://doi.org/10.29329/ijpe.2021.366.20

Ding, L. (2019). Theoretical perspectives of quantitative physics education research. Physical *Review Physics Education Research, 15*(2), 020101https://doi.org/10.1103/PhysRevPhysEducRes.15.020101

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science education, 84*(3), 287-312.https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching, 55*(7), 907-937.https://doi.org/10.1002/tea.21468

Duschl, R. (2008). Science education in three-part harmony: balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268-291.https://doi.org/10.3102/0091732X07309371

Garcia-Moya, I., Bunn, F., Jimenez-Iglesias, A., Paniagua, C., & Brooks, F. M. (2019). The conceptualization of school and teacher connectedness in adolescent research: a scoping review of literature. *Educational Review, 71*(4), 423-444.https://doi.org/10.1080/00131911.2018.1424117

Gonzalez-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education, 104*(6), 953-982.https://doi.org/10.1002/sce.21592

Groff, R. (2004). Critical realism, post-positivism and the possibility of knowledge (Vol. 11). Routledge.

Grushka, K., Hope, A., Clement, N., Lawry, M., & Devine, A. (2018). New visuality in Art/Science: A pedagogy of connection for cognitive growth and creativity. Peabody *Journal of Education, 93*(3), 320-331.https://doi.org/10.1080/0161956X.2018.1449927

Guo, J., Hu, X., Marsh, H. W., & Pekrun, R. (2022). Relations of Epistemic Beliefs with Motivation, Achievement, And Aspirations In Science: Generalizability Across 72 Societies. *Journal of Educational Psychology, 114*(4), 734-751.https://Doi.Org/10.1037/Edu0000660

Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching, 38*(6), 663-687.https://doi.org/10.1002/tea.1025

Kirbaslar, F. G., Arıca, B., & Barıs, C. C. (2021). Determination of the epistemological and ontological beliefs of secondary school students: Determination of the epistemological and ontological beliefs. *International Journal of Curriculum and Instruction, 13*(2), 986-1005.https://ijci.globets.org/index.php/IJCI/article/view/497

Kizkapan, O., & Bektas, O. (2021). Improving 7th Grade Students' Epistemological Beliefs by Epistemologically Enriched Argumentation Model. *Pedagogical Research, 6*(3), em0095.https://doi.org/10.29333/pr/10949

Koponen, I. T. (2021). Nature of Science (NOS) being acquainted with Science of Science (SoS): Providing a panoramic picture of sciences to embody NOS for pre-service teachers. *Education Sciences, 11*(3), 107.https://doi.org/10.3390/educsci11030107

Koutsianou, A., & Emvalotis, A. (2021). Unraveling the Interplay of Primary School Teachers' Topic-Specific Epistemic Beliefs and Their Conceptions of Inquiry-Based Learning in History and Science. *Frontline Learning Research, 9*(4), 35-75.https://doi.org/10.14786/flr.v9i4.777

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education, 25*(2), 157-175.https://doi.org/10.1007/s10972-014-9383-2

Kuhn, D., Arvidsson, T. S., Lesperance, R., & Corprew, R. (2017). Can engaging in science practices promote deep understanding of them? *Science Education, 101*(2), 232-250.https://doi.org/10.1002/sce.21263

Kurasaki, K. S. (2000). Intercoder reliability for validating conclusions drawn from open-ended interview data. *Field Methods, 12*(3), 179-194.https://doi.org/10.1177/1525822X0001200301

Lee, S. W. Y., Liang, J. C., & Tsai, C. C. (2016). Do sophisticated epistemic beliefs predict meaningful learning? Findings from a structural equation model of undergraduate biology learning. *International Journal of Science Education, 38*(15), 2327-2345.https://doi.org/10.1080/09500693.2016.1240384

Lee, S. W. Y., Luan, H., Lee, M. H., Chang, H. Y., Liang, J. C., Lee, Y. H., ... & Tsai, C. C. (2021). Measuring epistemologies in science learning and teaching: A systematic review of the literature. *Science Education, 105*(5), 880-907.https://doi.org/10.1002/sce.21663

Limbu, S., Rajbanshi, R., & Kumar, R. (2025). Knowing, doing, and embracing local resources and pedagogical shifts in science education through experiments. *International Journal of Research in Education and Science*, 11(3), 724-744. https://doi.org/10.46328/ijres.1304

Lopez-Banet, L., & Martínez-Carmona, M. (2021). Preservice Chemistry Teachers' Epistemic Beliefs After a Student-Centered Approach Training Programme. *EURASIA Journal of Mathematics, Science and Technology Education, 17*(12), em2045.https://doi.org/10.29333/ejmste/11359

Marra, R. M., & Palmer, B. E. T. S. Y. (2005). University science students' epistemological orientations and nature of science indicators: How do they relate? *Science Education International, 18*(3), 165-184.https://www.icaseonline.net/sei/16-03-2005/16-03-2005-165_184.pdf

McNeill, K. L., Gonzalez-Howard, M., Katsh-Singer, R., & Loper, S. (2017). Moving beyond pseudo argumentation: Teachers' enactments of an educative science curriculum focused on argumentation. *Science Education, 101*(3), 426-457.https://doi.org/10.1002/sce.21274

Memisoglu, A. S., & Ercelik, B. (2022). Determining Pre-Service Science Teachers' Perceptions of Science, Nature of Science and the Relationship between Them. *International Journal of Contemporary Educational Research, 9*(2), 378-394.https://doi.org/10.33200/ijcer.1058181

Ministry of Education. (2020). *National Education Policy 2020.* Government of India. https://www.education.gov.in/sites/upload_files/mhrd/files/NEP_Final_English_0.pdf

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, 4(1),1-9. https://doi.org/10.1186/2046-4053-4-1

OECD. (2017). *PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic, Financial Literacy and Collaborative Problem Solving, PISA,* OECD Publishing, Paris.https://doi.org/10.1787/9789264281820-en

OECD. (2022). *Opening knowledge through education and science, Centre for educational research and innovation.* OECD Publishing, Paris. https://doi.org/10.1787/28ab3f91-en

Ortiz-Revilla, J., Aduriz-Bravo, A., & Greca, I. M. (2020). A framework for epistemological discussion on integrated STEM education. *Science & Education, 29*(4), 857-880.https://doi.org/10.1007/s11191-020-00131-9

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*(7), 692-720.https://doi.org/10.1002/tea.10105

Ostergaard, E. (2014). How can science education foster students' rooting?. *Cultural Studies of Science Education, 10*(2), 515-525.https://doi.org/10.1007/s11422-014-9604-1

Ostergaard, E. (2017). Earth at rest: Aesthetic experience and students' grounding in science education. *Science & Education, 26*(5), 557-582.https://doi.org/10.1007/s11191-017-9906-2

Papadouris, N., & Constantinou, C. P. (2017). Integrating the epistemic and ontological aspects of content knowledge in science teaching and learning. *International Journal of Science Education, 39*(6), 663-682.https://doi.org/10.1080/09500693.2017.1299950

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching, 48*(5), 486-511.https://doi.org/10.1002/tea.20415

Prasadini, L., Hamid, J. A., Khatibi, A., & Azam, S. M. (2018). The Impact of Scientific Epistemological Beliefs of Sri Lankan Senior Secondary Students on Their Approaches to Learning Science: A Structural Equation Modelling. *Asian Journal of Contemporary Education, 2*(2), 60-69. https://doi.org/10.18488/journal.137.2018.22.60.69

Sandoval, W. A. (2009). In defense of clarity in the study of personal epistemology. *The Journal of the Learning Sciences, 18*(1), 150-161.https://doi.org/10.1080/10508400802581700

Sandoval, W. A., & Redman, E. H. (2015). The contextual nature of scientists' views of theories, experimentation, and their coordination. *Science & Education, 24*(9-10), 1079-1102.https://doi.org/10.1007/s11191-015-9787-1

Sere, M., Gonzalez, M.F., Gallegos, J. A., Gonzalez-Garcia, F., De Manuel, E., Perales, F. J., & Leach, J. (2001). Images of science linked to labwork: a survey of secondary school and university students. *Research in Science Education, 31*(4), 499-523.https://doi.org/10.1023/A:1013141706723

Singer, A., Montgomery, G., & Schmoll, S. (2020). How to foster the formation of STEM identity: Studying diversity in an authentic learning environment? *International Journal of STEM Education, 7*(1), 1-12.https://doi.org/10.1186/s40594-020-00254-z

Soysal, Y. (2025). Estimating epistemic practices loads in elementary and middle school science curricula. *Science & Education*, 34(2), 345–372. https://doi.org/10.1007/s11191-024-00599-9

Svedholm, A. M., & Lindeman, M. (2013). Healing, mental energy in the physics classroom: Energy conceptions and trust in complementary and alternative medicine in grade 10-12 students. *Science & Education, 22*(3), 677-694.https://doi.org/10.1007/s11191-012-9529-6f

Tan, M., & Koh, T. S. (2023). Learning to become ignorant: Improving the quality of epistemic knowledge in science education. *Science Education,* 107(1),9-27.https://doi.org/10.1002/sce.21753

Tothova, M., Rusek, M. (2025). Eye Tracking in Science Education Research: Comprehensive Literature Review. *Science & Education* https://doi.org/10.1007/s11191-025-00644-1

Tsai, C. C., & Liu, S. Y. (2005). Developing a multi-dimensional instrument for assessing students' epistemological views toward science*. International Journal of Science Education, 27*(13), 1621-1638.https://doi.org/10.1080/09500690500206432

Verdin, D., Godwin, A., & Ross, M. (2018). STEM roles: How students' ontological perspectives facilitate STEM identities. *Journal of Pre-College Engineering Education Research, 8*(2), 31-48.https://doi.org/10.7771/2157-9288.1167

Wei, L., Firetto, C. M., Duke, R. F., Greene, J. A., & Murphy, P. K. (2021). High school students' epistemic cognition and argumentation practices during small-group quality talk discussions in science. *Education Sciences, 11*(10), 616.https://doi.org/10.3390/educsci11100616

Yalcin, V., & Ozturk, O. (2022). Examination of the Effects of Design-Oriented STEM Activities on the 21st Century Skills of Pre-School Children Aged 3-4. *Southeast Asia Early Childhood, 11*(2), 1-20.https://doi.org/10.37134/saecj.vol11.2.1.2022

Yang, F. Y., & Tsai, C. C. (2010). Reasoning about science-related uncertain issues and epistemological perspectives among children. *Instructional Science, 38*(4), 325-354.https://doi.org/10.1007/s11251-008-9084-3

Yang, F. Y., Liu, S. Y., Hsu, C. Y., Chiou, G. L., Wu, H. K., Wu, Y. T., ... & Tsai, C. C. (2018). High-school students' epistemic knowledge of science and its relation to learner factors in science learning. *Research in Science Education, 48*(2), 325-344.https://doi.org/10.1007/s11165-016-9570-6

Yucel, R. (2018). Scientists' ontological and epistemological views about science from the perspective of critical realism. *Science & Education, 27*(5-6), 407-433.https://doi.org/10.1007/s11191-018-9983-x

Zorlu, Y. (2017). An Investigation of the Relationship between Preservice Science Teachers' Epistemological Beliefs about the Nature of Science and Their Self-Efficacy Perceptions. *Journal of Education and Practice, 8*(7), 128-137.https://files.eric.ed.gov/fulltext/EJ1137567.pdf