Deconstructing Complex Abstraction Through Context in Science Education: Comprehensive Review on Research Development, Approaches, and Articulation

Micheal Obakhavbaye, Simon Fraser University, Canada

The Barcelona Conference on Education 2024
Official Conference Proceedings

Abstract

There has been significant attention on context-based learning in science education in recent times, challenging conventional paradigms and fostering more inclusive and authentic learning experiences. However, research has shown that there are no simplified definitions of context, and without proper articulation, context becomes anything and everything. Evidence of what context is in science education has been analyzed, but not all contexts are useful for all complex science ideas and settings. Therefore, by performing a systematic literature review of empirical studies with an abstract search from three databases (Eric, Education Source and APA PsycInfo) with the filter "Context-based" and “secondary school or high school or secondary education or junior high or middle school”, a total of 284 studies were found. These studies were screened for empirical and science education research to synthesize evidence of how context is used to deconstruct traditional paradigms in secondary science education. From an initial analysis, this article identifies emergent contributions to context-based science education including context-continuum learning design, student’s meaning-making of concepts in context, and the “frame of context” articulated for specific science concepts. This review draws the connection between context articulation and fostering deeper connections between students' learning and the real world that would enhance student engagement and authentic science learning. This study makes a case for the relevant context that diffuses complex science concepts for learners. The practical implications offer insights into the frame of context that can be explored for specific complex concepts in science education.

Keywords: Complex Abstraction, Context, Science Education

iafor

The International Academic Forum
www.iafor.org

Introduction

Science education serves as a cornerstone for cultivating critical thinking, innovation, and problem-solving skills in students (Verawati & Sarjan, 2023). However, a persistent challenge within the discipline lies in its presentation such that concepts are often abstract and disconnected from real-world contexts rather than an immersion (Giamellaro, 2014; Gilbert, 2006; Sadler, 2009). This disconnection has far-reaching implications, as it impacts students' enthusiasm, motivation, and ability to engage in critical thinking, thereby limiting the transformative potential of science education (Boisselle, 2016). Remedying this situation requires a paradigm shift, involving the deconstruction of abstract concepts through context-driven learning models.

One critical concern is the tendency to treat science as a monolithic body of abstract knowledge rather than a dynamic, culturally situated, and context-sensitive discipline (Klein, 2018). Traditional pedagogical approaches often fail to engage students meaningfully, presenting science as a series of disconnected facts rather than as an iterative process of inquiry and discovery (Brookes et al., 2020; Tan & Wong, 2012). Such methods not only obscure the relevance of science to everyday life but also perpetuate inequities in learning outcomes, disproportionately affecting students from diverse cultural and socioeconomic backgrounds (Lee & Buxton, 2013). A contextual approach, by contrast, seeks to make science more inclusive and accessible by aligning instruction with the lived experiences, interests, and cultural frameworks of students (Brown et al., 2019).

Contextualized science education recognizes the importance of grounding abstract scientific principles in relatable, meaningful, and diverse settings (Garner, 2024). This approach seeks to bridge the gap between theoretical knowledge and practical application, moving students beyond rote memorization toward genuine understanding and critical engagement. Gilbert (2006) suggests that effective contextualization is based on three dimensions: physical settings, cultural justifications, and sociocultural perspectives on learning. Each dimension provides a unique lens for exploring how students interact with and internalize scientific knowledge. Physical settings anchor concepts in tangible, observable phenomena, while cultural justifications draw on societal values and beliefs to validate the relevance of science. Sociocultural perspectives emphasize collaborative learning and the role of social constructs in shaping scientific understanding. Together, these dimensions offer a holistic framework for transforming science education. Much research has proven the efficacy of contextualized science education in fostering deeper understanding and engagement (Bilican et al., 2015; Kuhn et al., 2017). Embedding scientific instructions within cultural narratives, such as indigenous knowledge systems or local norms, has been shown to enhance relevance, promoting more inclusive learning environments (Lam et al., 2020).

Problematizing Context in Science Education

The way context is viewed varies across settings, fields, and disciplines. In education, it would be difficult for learners to sufficiently organize, understand, interpret and describe concepts in a relevant way unless other implicating phenomena such as cultural setting, shared background, and prior experiences within which the learning is embedded are considered. Thus, Gilbert, (2006) indicated that context can be viewed as a frame that surrounds the focal event being examined, which in turn provides resources for its appropriate interpretation. What would be a relevant context to learners would be dependent on the activities they are engaged in at each point in time within a unit of learning. Therefore, the context of learning changes radically from one learning activity to the other and is dynamically mutable (Harris et al., 2009; Li, 2016).

Furthermore, students and teachers can become an environment for each other elevating the potential and capacity of individuals to reshape context dynamically to further their interests and agenda (Bandura, 2006). Therefore, the learning environment notion of context is a social construct, which is time-bound and sustained by continuous interactions (AlabdulRazzak et al., 2018; Bloome et al., 2009). Context-based learning emerged and built upon the older education traditions of questioning the application of school learning, it emerged as a big idea in science education (King, 2009). Researchers have argued that context-based learning bridges the gap between school learning and real life, impacting the interest of students and their understanding of science (Aydin-Ceran, 2021; Parchmann et al., 2015). Hence the invocation and articulation of context in learning is dependent on each uni of learning and multiple contexts can be invoked within a single learning unit.

Conceptual Frameworks

Situated Learning Theory.

A strand of constructivist philosophy which highlights the importance of learning through participation in a community of practice (Sadler, 2009; Sentence & Humphreys, 2018). It emphasizes that knowledge is best acquired through authentic, real-world activities that are situated within the learners' lived experiences. This approach contrasts with traditional instructional methods that abstract knowledge from its application, which often leads to surface-level understanding and a disconnect from practical relevance. By engaging in tasks that align with their current needs and future goals, learners progressively move from peripheral to full participation, gaining skills in contexts that mirror real-life situations (Aithal & Mishra, 2024).

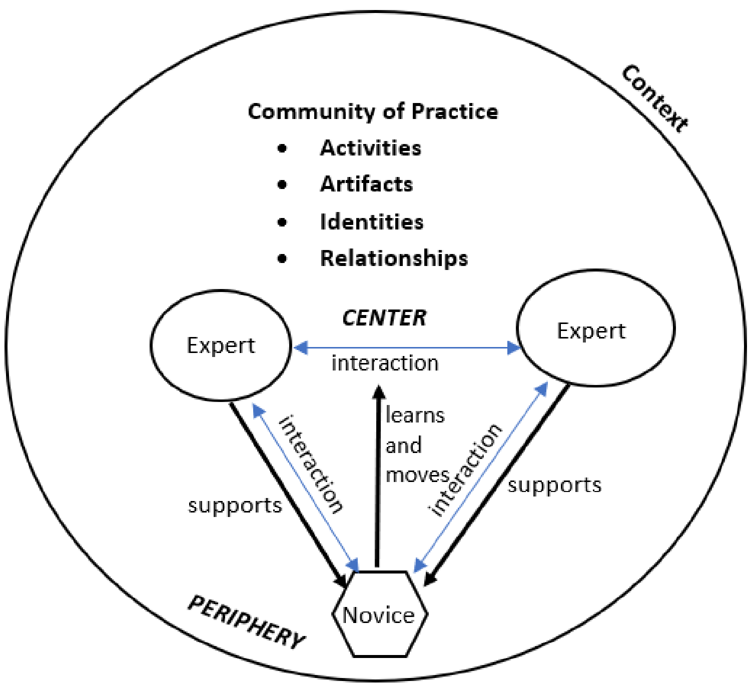

Figure 1: Situated Learning Model
Source: Mina Herrera, S.P. (2022)

Situated learning involves "legitimate peripheral participation," where learners initially engage in simple, meaningful tasks before gradually moving toward more complex, expert-level practices (DeGirolamo et al., 2024). This progression mirrors the natural learning process in real-world communities of practice. For example, in science education, students could begin by observing ecological data collection before participating in fieldwork. By situating learning within real-world activities, students experience the relevance of abstract scientific principles and connect them to tangible outcomes. A crucial aspect of the theory is its emphasis on social interaction. Learning occurs through collaboration with peers, mentors, and experts, fostering the co-construction of knowledge (van Schaik, 2020). Furthermore, the physical and cultural environment plays a pivotal role in situated learning, science classrooms designed to mimic laboratories, field sites, or other relatable settings create immersive experiences that reflect real-world applications (Swargiary, 2024). Such environments also allow learners to explore sociocultural influences on scientific practices, enhancing their ability to navigate diverse professional landscapes.

Gilbert (2006) Four Models of Context.

Gilbert’s (2006) Four Models of Context provides a foundational framework for addressing the complexities of abstractions, especially in science education. These models highlight different approaches to embedding context in learning, offering strategies to make scientific knowledge accessible and relevant to learners.

Model 1: Context as the Direct Application of Concepts- considers context as a tool for illustrating pre-taught concepts. Just as introducing chemical equations and subsequently applying them to neutralize acid spills gives students a direct link between theory and practice. However, this approach often positions context as supplementary rather than integral, which may limit its ability to support deeper conceptual engagement.

Model 2: Context as Reciprocity Between Concepts and Applications- emphasizes the dynamic interplay between scientific ideas and their practical applications. This reciprocal relationship helps students refine their understanding by exploring how abstract concepts influence real-world problems and vice versa. However, care is to be taken to prevent cognitive overload when students juggle both theoretical and applied aspects simultaneously (Song et al., 2023).

Model 3: Context as Provided by Personal Mental Activity- recognizes the role of individual cognition in shaping context. By allowing students to draw on personal experiences, this model promotes a deeper connection to abstract scientific concepts. For example, a student might relate biological adaptations to personal observations in nature. While powerful, this model requires learners to be self-directed, which may challenge those needing structured guidance.

Model 4: Context as the Social Circumstances- integrates scientific learning into broader societal issues, making abstract concepts meaningful through cultural and environmental connections. Topics like climate change or public health serve as socially relevant contexts, promoting collaborative exploration and critical thinking. This model stresses the societal importance of science but demands significant effort in aligning content with real-world challenges.

This research intends to explore how context-driven frameworks can address the challenges posed by traditional science instruction, promoting deeper understanding and equity in learning.

Research Questions.

1. What contextual articulation is considered important to science subjects?
2. How is context articulated in the learning design?
3. What emergent design principles can be derived from the context-continuum model to support authentic science learning in secondary schools?

Methods

Procedure

This review is part of an ongoing research and thus it does not claim exhaustivity. The study adopted a systematic review of the literature method as described by (Booth et al., 2021). After the formulation of the research questions and objectives, the search parameters were defined, although the search parameter will still need to be adjusted to account for grey literature following the outcome of the review and the progress of the main research. Next, databases were selected and the literature search was initiated. This was followed by the development of the inclusion and exclusion criteria which served as the guide for screening the literature obtained through the database search. All relevant literature was carefully screened, and a data extraction form was carefully developed to allow for the comparison of the data from the articles. Lastly, the data obtained after being deemed to be of quality were synthesized to provide answers to the research questions.

Databases and Search Parameters

Three databases including Eric, Education Source, and APA PsycInfo were searched systematically, using the following search parameters "Context-based" and “secondary school or high school or secondary education or junior high or middle school”. To publications obtained were then screened through the inclusion and exclusion criteria.

Inclusion Criteria

1. The study must be an empirical study
2. The study must be in the science field
3. The study must be peer-reviewed
4. Students must be the participants

Exclusion Criteria

1. Non-English articles are excluded
2. Theoretical/conceptual papers are excluded

Data Analysis

The data obtained was structured into seven categories, which were inductively deduced from the studies reviewed. These studies were screened for empirical and science education research to synthesise evidence of how context is used to deconstruct traditional paradigms in secondary science education. The procedure was discussed with multiple researchers to eliminate bias. The following categories were identified: Domain dominance, prescriptive context-based learning, relevance and real-world connection, learner-driven contextual environment, exploring students' personal and career aspirations in design, multiple knowledge presentation and representation, and context-continuum learning design.

Search and Selection of Results

Figure 2 presents a summary of the entire search process in the form of a PRISMA diagram. After the search process, 2373 articles were identified from the 3 databases used, and 2089 articles were further removed through the set filters, leaving 284 articles to be screened. Following the screening, 187 articles were excluded based on abstract and title, with 95 being assessed for eligibility. 26 articles were included in the review after screening against the eligibility criteria.

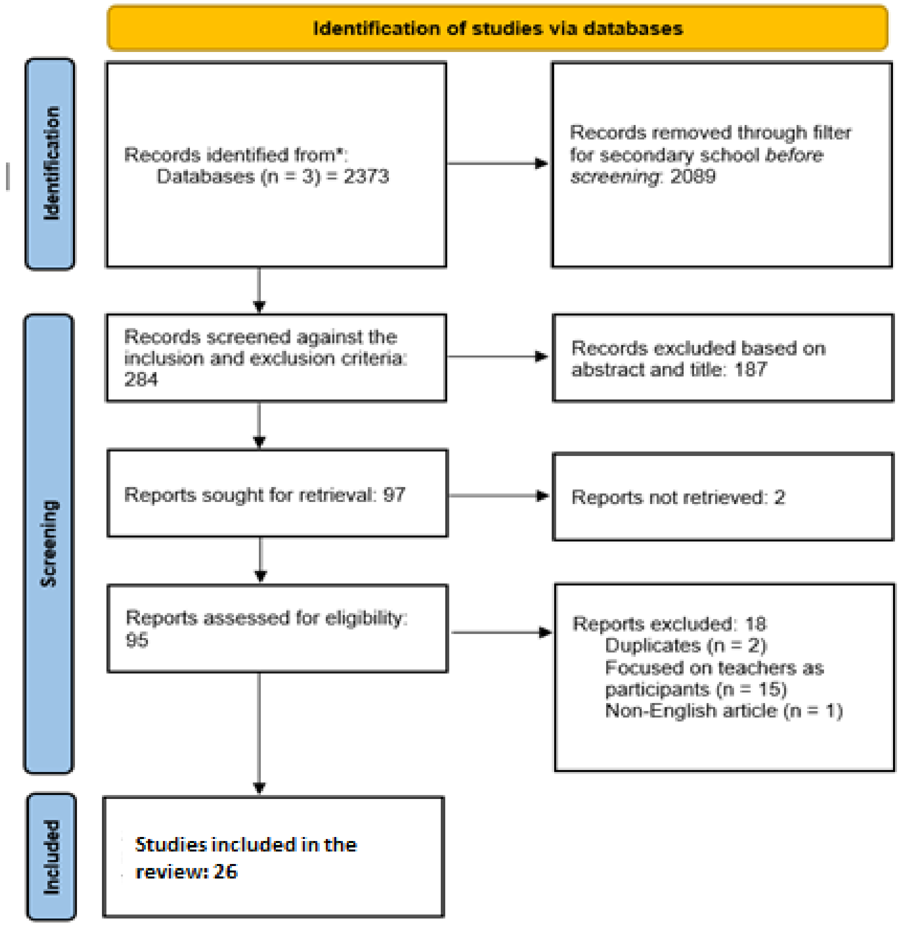

Figure 2: PRISMA Framework

Findings

Table 1 presents an overview of the studies that investigated Complex Abstraction Through Context in Science Education.

Table 1: Studies That Investigated Complex Abstraction

Author/Year	**Discipline**	**Participants**	**Epistemology/ Theoretical Perspective**	**Activities / Context Articulated**	**Research Design**
Afrah Assi & Anat Cohen (2024)	Chemistry	32 students	Constructivism	Pre-class activities flipped learning	Exploratory Case study
Shirly Avargil & Ran Piorko (2022)	Chemistry / Biotechnology	370 Students	Constructivism	Engaged with molecular structures	Comparative Study
Eralp BAHÇIVAN (2014)	Physics	30 students; 5 Teachers	Social Constructivism	Observed during typical physics lessons	Qualitative case study design
Medine Baran & A.Kadir Maskan (2016)	Science – Multidisciplinary	5325 high school students	Constructivism	Used news reports and multimedia sources	Quantitative survey
Basso et al. (2018)	Chemistry	500 students participated over six years	Constructivism	A week-long crime scene investigation activity involving students in experiments across various chemistry branches	Survey
Chen et al. (2019)	Mechanical engineering and CNC machine tool operations	40 male students	Positivist	VR-based CNC milling machine training using either sequence-based or context-based teaching designs, including individual and integrative exercises	Experimental design
Cigdemoglu & Geban (2015)	Chemistry	175 students	Constructivism	Lessons structured around real-world applications of chemical reactions and energy concepts.	Quasi-experimental design
de Putter-Smits et al. (2012)	Biology, Chemistry, Physics	Teachers: 25 Students: 840	Constructivism	Teachers designed and implemented context-based curriculum materials across multiple science subjects (biology, chemistry, physics.	Comparative Study
Demelash et al. (2024)	Chemistry.	Students: 229	Social Constructivism	Simulations of chemistry concepts, Group discussions, student presentations, and Q&A sessions	Quasi-experimental design
Demircioğlu et al. (2009)	High school chemistry, with a specific emphasis on teaching the Periodic Table of Elements.	Students: 80 Teachers: 2	Constructivism	The instructional approach incorporates storylines	Quasi-experimental design

Dhlamini (2016)	Mathematics, specifically focusing on financial mathematics	57 learners	Cognitive	The study used context-based problem-solving instruction (CBPSI)	Pre-experimental design
Parchmann, I., Gräsel, C., Baer, A., Nentwig, P., Demuth, R., & Ralle, B. (2006)	Chemistry	N/A – Germany	Constructivism.	Students engaged in planning and conducting investigations tied to real-life contexts.	Case Study
Dori, Y. J., Avargil, S., Kohen, Z., & Saar, L. (2018)	Chemistry	428 – Israel	Gilbert's Models 2 and 4; Metacognition	Participants read adapted scientific articles on selected chemistry topics. The students were then involved in textual explanations, visual representation and self-monitoring tasks.	Quasi-experimental design
Habig, S., Blankenburg, J., van Vorst, H., Fechner, S., Parchmann, I., & Sumfleth, E. (2018)	Chemistry	1253	Person-Object Theory of Interest (Krapp, 1999), RIASEC Model (Holland, 1997), Context-Based Learning Theory	Students read context-based texts describing topics like polluted drinking water and volcanoes. They then Rated the texts for familiarity.	Quasi-experimental design
Podschuweit, S., & Bernholt, S. (2017)	Physics	32 students.	Constructivist, leveraging diSessa's Knowledge-in-Pieces theory and Coordination Class Theory	Pre-test to assess baseline knowledge. Experimental tasks were conducted in pairs within a laboratory setting Post-test to evaluate learning gains and transferability.	Experiment
Ummels, M. H. J., Kamp, M. J. A., De Kroon, H., & Boersma, K. Th. (2015).	Biology	21 students from a 10th-grade class in a semi-rural Dutch school	cultural-historical activity theory, influenced by Vygotsky's constructivist principles	Role Play: Students acted out family members debating the pros and cons of meat consumption.	Design-based research
Kang, J., Keinonen, T., Simon, S., Rannikmäe, M., Soobard, R., & Direito, I. (2018)	STEM Education	574 students	Stuckey et al.'s (2013) three-dimensional model of relevance; Hidi and Renninger's (2006) interest development model; Context-Based Learning (CBL)	Students read 25 career-related scenarios covering topics like energy, health, and environmental issues. The scenarios were developed to reflect individual, societal, and vocational dimensions of relevance.	Cross-sectional design

Effects of Scrum methodology on students' critical scientific literacy: the case of Green Chemistry	Chemistry	198 students	Vision III in Science Education. ered learning	Students were introduced to the socio-scientific issue: of choosing the greener synthesis of adipic acid. They analyzed two synthesis routes (using cyclohexanol or cyclohexene) and applied the principles of Green Chemistry.	Quasi-experimental design
van Vorst, H., & Aydogmus, H. (2021)	Chemistry	228	expectancy-value model of achievement motivation	Students worked individually on chosen tasks, involving identical chemical activities such as writing reaction equations.	cross-sectional survey design
Karsli Baydere, F. (2021)	Chemistry	38 (exp 20, control 18)	social constructivism	Students predicted outcomes related to real-life contexts (e.g., properties of polar and grizzly bears in cold environments).	Quasi-experimental design
Löffler, P., Pozas, M., & Kauertz, A. (2018)	Physics	178	Constructivist Framework; modeling theory	Students worked on a problem-solving task with varying contextualization, complexity, and transparency levels.	Experimental Design
Cabello, V. M., Moreira, P. M., & Griñó Morales, P. (2021)	Earth Science	22 (Chile)	sociocultural theory	Students engaged in an 18-hour learning using earthquakes and Tectonic Plate Theory (TPT) in which they drew explanations, engaged in group puzzles, and watched a video about earthquakes.	Exploratory (descriptive)
Fabien Güth, & Vorst, H. van. (2024)					
Edelsztein, V. C., Tarzi, O. I., & Galagovsky, L. (2020)	Chemistry	95 (Buenos Aires)	Sustainable Conscious Cognitive Learning Model (MACCS)	Students engaged in group discussion to explore diversity in responses to their prior knowledge	Quasi-experimental design
Eugenio-Gozalbo, M., Ramos-Truchero, G., Suárez-López, R., Andaluz Romanillos, M. S., & Rees, S. (2022)	Interdisciplinary	55 (40 exp, 15 control)	socio-constructivist perspective; Experiential learning and sustainable education	Students engage in data interpretation using real-world data on seasonal food and agricultural practices.	Quasi-experimental design

Teshager, G., Bishaw, A., & Dagnew, A. (2021)	Interdisciplinary	360-Ethiopia	pragmatism and heavily influenced by John Dewey's experiential learning theory.	Teachers identify and integrate real-life contexts into teaching. Regulation, Teachers adapt curriculum materials to align with local contexts available	cross-sectional survey design

Domain Dominance

Three studies (Basso et al., 2018; de Putter-Smits et al., 2012; Dori et al., 2018) identified that chemistry emerges as the dominant domain in context-based learning (CBL) studies. The focus ranges from forensic chemistry activities to curriculum design and integrating scientific articles, showcasing its adaptability in real-world and academic contexts. Teachers developed context-based materials in biology, chemistry, and physics, with chemistry being most emphasized for its rich application potential. Forensic chemistry was also indicated to offer an engaging real-world connection in a six-year study.

Prescriptive Context-Based Learning

Studies by (Bahçivan, 2014; Chen et al., 2019; Demircioğlu et al., 2009) emphasized that context-based learning was implemented as a structured activity "done to" students rather than collaboratively designed, often limiting their autonomy and participation. Storyline-based teaching of the periodic table according to Demircioğlu et al. (2009) engaged students but remained prescriptive, focusing on content delivery. While Bahçivan, (2014) pointed out that physics lessons followed traditional approaches without laboratory activities, with students playing passive roles.

Relevance and Real-World Connection

Using real-world contexts to explain abstract scientific concepts enhances comprehension and engagement. Studies (Baran and Maskan, 2016; Cigdemoglu & Geban, 2015; Demelash et al., 2024) show students connect academic knowledge with everyday life through practical applications. News and multimedia sources bridged scientific concepts with real-world issues for high school students as reported by Baran and Maskan, (2016), Videos, simulations, and experiments contextualized chemical reactions and energy concepts among students in Cigdemoglu and Geban's, (2015) study. Also, in Demelash and colleagues (2024)'s study, real-world experiments and simulations helped students connect abstract Chemistry topics to their practical applications.

Learner-Driven Contextual Environment

Studies (Cabello, et al., 2021; Podschuweit and Bernholt, 2017; Ummels et al., 2015) affirm that inquiry-based and collaborative approaches empower learners to take control of their learning, promoting curiosity, teamwork, and problem-solving skills. In Cabello and colleagues (2021), earth science students engaged in group puzzles and video-based inquiry to explore tectonic plates, while biology students debated real-world issues like meat consumption through role-playing exercises, fostering critical thinking and collaboration in Ummels and colleagues, (2015)'s study. Physics experiments in pairs were reported to encourage inquiry and knowledge transfer through hands-on tasks (Podschuweit & Bernholt, 2017).

Exploring Students' Personal and Career Aspirations in Design

Contextual learning designs that align with students' career goals and personal motivations improve engagement and learning behaviours by connecting academic content to their aspirations were observed in (Habig et al., 2018; Kang et al., 2018; van Vorst & Aydogmus, 2021). In Kang and colleagues, (2018), career-related scenarios across STEM subjects linked academic concepts to societal and vocational relevance. Chemistry students related familiar context-based texts to career-oriented issues such as environmental challenges in Habig and colleagues' (2018) study. Also, tasks integrating real-life motivations, like writing chemical reaction equations according to van Vorst and Aydogmus, (2021) linked content to students' goals.

Multiple Knowledge Presentation and Representation

Diverse forms of knowledge presentation, such as symbolic, macroscopic, and visual representations, along with collaborative projects, enhance students' comprehension and engagement in CBL environments as evidenced by (Cigdemoglu & Geban, 2015; Dori et al., 2018; Edelsztein et al., 2020).

Edelsztein and colleagues (2020) reported that chemistry students used group discussions and projects to explore diversity in conceptual understanding, and Gilbert's models incorporated textual, visual, and symbolic representations to explain Chemistry topics in Dori, et al., (2018)'s study. In Cigdemoglu and Geban, (2015) multimedia tools, videos, and experiments supported multi-representational learning of Chemistry topics.

Context-Continuum Learning Design

The following studies (Chen et al., 2019; Demelash et al., 2024; Karsli Baydere, 2021; Teshager et al., 2021) identified that context-continuum learning combines everyday experiences and flexible transitions between physical and virtual learning environments for integrative learning.

Teshager and colleagues (2021) and Karsli Baydere, (2021) identified that in the living-Learning Continuum, curriculum materials adapted to students' local contexts enhanced relevance and understanding, and chemistry students connected principles like polar bears' adaptations to real-life examples.

For Physical-Virtual Continuum, VR-based training bridged virtual and physical operations, offering interactive experiences in CNC operations in Chen and colleagues' (2019)'s study, and Demelash and fellows (2024) reported that chemistry simulations integrated with real-world experiments provided seamless transitions between virtual and physical contexts their study report.

Discussion

Deconstructing complex abstraction through context in science education will require an exploration of how context-driven frameworks can address the challenges posed by traditional science instruction. This section is structured into 3 following the research questions:

What Contextual Articulation is Considered Important to Science Subjects

Chemistry emerges as a major domain for context-based learning (CBL), largely due to its apparent connection to real-world phenomena. Studies like Basso and colleagues (2018) illustrate how forensic chemistry captivates students through crime scene investigations, blending academic content with engaging scenarios. Similarly, de Putter-Smits and colleagues (2012) underscore the flexibility of chemistry to adapt to diverse contexts, positioning it as a dominant subject in CBL. These findings align with broader literature emphasizing the importance of chemistry in bridging scientific knowledge with societal relevance (Georgiou & Kyza, 2023; Hardy et al., 2021). However, while chemistry offers an array of real-world applications, other domains such as physics and biology often struggle to achieve similar contextual applications, as evidenced by Bahçıvan (2014), where traditional physics teaching limited student autonomy and engagement.

The integration of multimedia tools and simulations, as seen in Cigdemoglu and Geban (2015) and Demelash and colleagues (2024), provides another perspective on contextual articulation. By combining virtual and physical experiments, these studies highlight the power of multi-representational learning in demystifying complex abstractions. This approach is supported by studies emphasizing the value of interactive environments in promoting deep learning and the transferability of knowledge (Nykyporets & Ibrahimova, 2023). However, other studies argue that over-reliance on technology without direct hands-on experiences may dilute the authenticity of learning contexts (George et al., 2024; Srikanth, 2024).

Interdisciplinary approaches are also indicated to be essential in contextual articulation according to the results of this review. Ummels and colleagues (2015) employed role-play in biology to address societal issues, fostering critical thinking and collaboration. Similarly, Kang and colleagues (2018) leveraged career-related scenarios in STEM to align academic content with students' aspirations. These studies demonstrate how interdisciplinary and career-oriented contexts can heighten relevance and motivation, a view corroborated by broader research on inquiry-based learning.

Other studies however critiqued the prescriptive nature of CBL, where activities are imposed on students, as noted in Demircioğlu and colleagues (2009). The prioritization of learner-driven contexts thus becomes essential, ensuring that students actively construct meaning from their experiences (Pastini & Lilasari, 2023). While chemistry remains a leading domain in contextual articulation, other disciplines must not be left out but challenged to innovate to achieve comparable contextual depth.

How Context is Articulated in the Learning Design

Context articulation in learning design encompasses integrating real-world scenarios, interdisciplinary perspectives, and adaptive tools to enhance student's engagement and comprehension. The results of this study highlight how learning environments are constructed to connect abstract scientific ideas to relatable contexts. For instance, Chen and colleagues (2019) illustrate the use of (Virtual reality) VR-based environments to simulate CNC milling tasks, offering students the opportunity to practice detailed exercises across multiple stages.

This approach highlights the potential of virtual tools to bridge theoretical concepts and technical skills, a strategy supported by literature emphasizing the effectiveness of immersive technologies in skill-based learning (Pradhan, 2024; Sugiarto et al., 2024). However, such technology-based designs face critiques regarding accessibility, especially in resource-constrained schools, where the high cost of VR systems could limit widespread adoption (Kamat & Nasnodkar, 2019).

Similarly, Demelash and colleagues (2024) integrated real-world experiments with simulations, creating a dual-context learning environment where abstract chemistry concepts were made tangible through hands-on activities. This approach also reflects the notion that hybrid designs, combining physical and virtual elements, can foster deeper understanding and engagement (Hickey et al., 2020).

In addition, collaborative and inquiry-based contexts are prominently featured in the learning designs of many studies. Ummels and colleagues (2015) engaged students in role-play, where they debated societal issues such as meat consumption. This strategy, which promotes critical thinking and collaboration, aligns with inquiry-based pedagogies that place students at the centre of the learning process (Gholam, 2019). Likewise, in Cabello and colleagues (2021), students engaged in group puzzles and watched videos to investigate tectonic plate theory, blending interactive and visual learning methods. While such designs promote active participation, they also require careful facilitation to prevent uneven group dynamics, where some students dominate discussions while others remain passive (Lakey, 2020).

Another dimension of contextual articulation is integrating career-relevant scenarios into the learning design, as observed by Kang and colleagues (2018) and Habig and fellows (2018). Kang and colleagues (2018) presented 25 career-related STEM scenarios to align academic content with vocational relevance, echoing the ideas that underscore the motivational power of career-contextualized education (Bogush, 2016). Similarly, Habig and colleagues used familiar context-based texts, such as those related to environmental challenges, to demonstrate how students can link abstract science concepts to their aspirations. This approach addresses critiques that traditional curricula often fail to reflect students’ lived experiences (Scott & Husain, 2021).

Prescriptive designs, however, offer a contrasting view to these learner-centered approaches. Bahçıvan (2014) noted that physics lessons often relegated students to passive roles, with minimal laboratory interaction, while Demircioğlu and colleagues (2009) employed storyline-based instruction that, while engaging, underscored rigid learning pathways. These findings reflect broader concerns about the effectiveness of top-down instructional designs, which have been critiqued for limiting students’ creativity and learning process (Ciani et al., 2008). By contrast, co-constructed learning designs offer a more flexible approach, enabling students to shape their educational experiences actively.

What Emergent Design Principles Can Be Derived From the Context-Continuum Model to Support Authentic Science Learning in Secondary Schools

The context-continuum model provides a versatile framework for science education by incorporating students' everyday experiences with flexible, diverse learning environments (Dimitrov et al., 2014). This duality between real-life and virtual contexts promotes meaningful connections, deeper learning engagements, and improved conceptual understanding in science education. An emergent design principle identified is leveraging students' lived experiences to build scientifically relevant knowledge, as seen in Teshager and colleagues (2021) and Karsli Baydere (2021). Teshager and colleagues (2021) highlighted how localized curriculum adaptations aligned with students' cultural and social contexts enhanced the relevance of abstract scientific principles. Similarly, Karsli Baydere's (2021) study demonstrates the effectiveness of incorporating relatable examples, such as "polar bear adaptations to cold", to make complex biological and chemical concepts more tangible. This resonates with the Living-Learning Continuum, which emphasizes grounding science in familiar contexts to make abstract ideas accessible (Barber, 2023). However, excessively localized designs may risk reducing the universality of scientific principles, limiting students' exposure to global scientific issues (Muraile, 2019).

The Physical-Virtual Continuum, another aspect of the model, introduces immersive, technology-enhanced environments to facilitate integrative learning. Chen and colleagues (2019) exemplify this with a VR-based training system for CNC operations, enabling students to practice technical skills interactively. Similarly, Demelash and colleagues (2024) integrate real-world chemistry experiments with simulations, allowing seamless transitions between virtual and physical environments. These designs align with existing literature advocating for hybrid learning environments that cater to diverse learning preferences and foster engagement through multimodal representation (Dikilitas & Fructuoso, 2023; O'Ceallaigh et al., 2023). However, challenges such as accessibility gaps, technological reliability, and teacher readiness remain significant barriers to widespread implementation (Alvarez, 2020). Collaborative inquiry is another important design principle. Cabello and colleagues (2021) in their study engaged students in group activities, such as puzzles and discussions, to explore tectonic plate theory. These tasks encouraged active participation, problem-solving, and peer learning, supporting previous evidence that collaborative inquiry promotes critical thinking and deeper understanding among students (Yu et al., 2024). A shortcoming however is that poorly facilitated group dynamics can hinder the intended learning outcomes, with some students dominating tasks while others disengage (Juvonen et al., 2019).

The integration of contextually relevant career and societal issues is also another key design principle derived from the context-continuum model. In Kang and colleagues (2018), career-related STEM scenarios bridged the gap between students' aspirations and academic content, creating a strong motivational framework for learning. Similarly, Habig and colleagues (2018) employed environmental challenges to connect chemistry concepts to real-world contexts, emphasizing the societal relevance of science. Also, effective context-continuum designs, such as those in Teshager and colleagues (2021) and Demelash and fellows (2024), highlight the need for environments that accommodate diverse learners and transitions between real-world and virtual settings. However, achieving such adaptability demands significant teacher preparation, resource availability, and curriculum alignment.

Limitations

This systematic review has provided critical insights into the deconstruction of complex abstraction through context in science education. It identified areas like domain dominance, prescriptive context-based learning, relevance and real-world connection, learner-driven contextual environment, exploring students' personal and career aspirations in design, multiple knowledge presentation and representation and context-continuum learning design that are vital to achieving abstract deconstruction. However, this review being a part of an ongoing research, the authors do not claim the area identified is exhaustive. Bias of any form is also an anticipated limitation, especially for systematic reviews, however, this was remedied by adhering rigorously to the research methodology and ensuring that the selected articles underwent an in-depth peer review process.

Implications for Practice

The outcome of this review stresses significant insights that can be applied to address abstract scientific concepts in schools. A major implication is the necessity of bridging abstract content with students' lived experiences. Teachers, school administrators and curriculum developers should actively integrate localized contexts that reflect students' cultural and social realities, as demonstrated in Teshager and colleagues (2021) and Karsli Baydere (2021). This approach not only enhances assimilation but also encourages students to see science as directly applicable to their lives, hence promoting engagement and motivation. The use of hybrid environments, combining physical and virtual learning spaces is also another essential implication. Chen and colleagues (2019) and Demelash and fellows (2024) reveal the value of blending real-world experiments with simulations to create seamless transitions between theoretical understanding and practical application. This suggests that schools must invest in technological tools and teacher training to implement effective hybrid models, although accessibility challenges must be addressed to ensure equity. Inquiry-based and collaborative learning models are pivotal for empowering students to take ownership of their learning processes. Evidence from Ummels and colleagues (2015) and Cabello and fellows (2021) highlights how role-playing, group discussions and problem-solving activities promote critical thinking, teamwork, and deeper learning. Teachers should adopt these strategies while ensuring facilitation methods that prevent passive participation or dominance by specific individuals in group settings.

Conclusion

To meet the many challenges of abstraction in science education, the design of context-based learning must be anchored in principles that promote relevance, engagement, and adaptability. Central to this is the Context-Continuum Learning Design, which emphasizes the seamless integration of real-world experiences with both physical and virtual learning environments. By allowing students to navigate between tangible and digital contexts, this approach supports a deeper understanding of abstract scientific concepts while catering to diverse learning preferences and needs. Equally important are Socio-cultural Justifications, which ground science education in the cultural, social, and economic realities of students. Contextualizing science through culturally relevant examples ensures that abstract concepts are accessible and meaningful, fostering inclusivity and validating the lived experiences of all learners. This transforms science from an abstract discipline into a dynamic and relatable field that resonates with students' backgrounds and communities. Another essential component is Student Agency, which shifts the focus from prescriptive, teacher-centred methods to learner-driven approaches. By empowering students to actively participate in their learning, through inquiry-based exploration and collaborative problem-solving, science education can become a space for creativity, critical thinking, and self-direction. This fosters a sense of ownership and engagement, enabling students to connect more meaningfully with the subject matter. Further, a connection to real life and the real world remains critical in demystifying abstract scientific concepts. By linking lessons to everyday experiences, societal challenges, and potential career pathways, teachers can inspire students to see the practical value and implications of science in their lives. This not only enhances motivation but also prepares students to apply their knowledge to real-world problems and global challenges.

References

Aithal, P. S., & Mishra, N. (2024). Integrated Framework for Experiential Learning: Approaches & Impacts. *International Journal of Case Studies in Business, IT and Education (IJCSBE)*, *8*(1), 145-173.

Alabdul Razzak, M., Al-Kwifi, O. S., & Ahmed, Z. U. (2018). Rapid alignment of resources and capabilities in time-bound networks: A theoretical proposition. *Global Journal of Flexible Systems Management*, *19*(4), 273-287.

Alvarez Jr, A. V. (2020). Learning from the Problems and Challenges in Blended Learning: Basis for Faculty Development and Program Enhancement. *Asian Journal of Distance Education*, *15*(2), 112-132.

Assi, A., & Cohen, A. (2024). Context-based learning in flipped middle school chemistry class. *International Journal of Science Education*, *46*(6), 570-589.

Avargil, S., & Piorko, R. (2022). High school students' understanding of molecular representations in a context-based multi-model chemistry learning approach. *International Journal of Science Education*, *44*(11), 1738-1766.

Bahçıvan, E. (2014). Consistency among Turkish students' different worlds: A case study focusing on responses to science. *Journal of Turkish Science Education*, *11*(1), 101-114.

Bandura, A. (2006). Toward a psychology of human agency. *Perspectives on psychological science*, *1*(2), pp.164-180.

Baran, M., Maskan, A. K., Baran, M., Türkan, A., & Yetisir, M. I. (2016). Examining High School Students' Attitudes towards Context Based Learning Approach with Respect to Some Variables. *International Journal of Environmental and Science Education*, *11*(5), 851-865.

Barber, J. P. (2023). *Facilitating the integration of learning: Five research-based practices to help college students connect learning across disciplines and lived experience*. Taylor & Francis.

Basso, A., Chiorri, C., Bracco, F., Carnasciali, M. M., Alloisio, M., & Grotti, M. (2018). Improving the interest of high-school students toward chemistry by crime scene investigation. *Chemistry Education Research and Practice*, *19*(2), 558-566.

Baydere, F. K. (2021). Effects of a context-based approach with prediction–observation–explanation on conceptual understanding of the states of matter, heat and temperature. *Chemistry Education Research and Practice*, *22*(3), 640-652.

Bilican, K., Cakiroglu, J., & Oztekin, C. (2015). How Contextualized Learning Settings Enhance Meaningful Nature of Science Understanding. *Science Education International*, *26*(4), 463-487.

Bloome, D., Beierle, M., Grigorenko, M., & Goldman, S. (2009). Learning over time: Uses of intercontextuality, collective memories, and classroom chronotopes in the construction of learning opportunities in a ninth-grade language arts classroom. *Language and education*, *23*(4), 313-334.

Bogush, M. L. (2016). *The Perspectives of Core Academic Middle School Teachers regarding Career Education under Different School Settings* (Doctoral dissertation, University of South Florida).

Boisselle, L. N. (2016). Decolonizing science and science education in a postcolonial space (Trinidad, a developing Caribbean nation, illustrates). *Sage Open*, *6*(1), 2158244016635257.

Booth, A., James, M. S., Clowes, M., & Sutton, A. (2021). Systematic approaches to a successful literature review.

Brookes, D. T., Ektina, E., & Planinsic, G. (2020). Implementing an epistemologically authentic approach to student-centered inquiry learning. *Physical Review Physics Education Research*, *16*(2), 020148.

Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2019). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. *Urban Education*, *54*(6), 775-803.

Cabello, V. M., Moreira, P. M., & Griñó Morales, P. (2021). Elementary students' reasoning in drawn explanations based on a scientific theory. *Education Sciences*, *11*(10), 581.

Chen, L. W., Tsai, J. P., Kao, Y. C., & Wu, Y. X. (2019). Investigating the learning performances between sequence-and context-based teaching designs for virtual reality (VR)-based machine tool operation training. *Computer Applications in Engineering Education*, *27*(5), 1043-1063.

Ciani, K. D., Summers, J. J., & Easter, M. A. (2008). A "top-down" analysis of high school teacher motivation. *Contemporary Educational Psychology*, *33*(4), 533-560.

Cigdemoglu, C., & Geban, O. (2015). Context-based lessons with 5E model to promote conceptual understanding of chemical reactions and energy concepts. *Journal of Baltic Science Education*, *14*(4), 435.

de Putter-Smits, L. G., Taconis, R., Jochems, W., & Van Driel, J. (2012). An analysis of teaching competence in science teachers involved in the design of context-based curriculum materials. *International journal of science education*, *34*(5), 701-721.

DeGirolamo, S., Pedersen, C. R., Corneliussen, J., Anders Kjærgaard, & Pattyn, N. (2024). Learning Environment. Routledge EBooks, 201–225. https://doi.org/10.4324/9781003378969-13

Demelash, M., Andargie, D., & Belachew, W. (2024). Enhancing Secondary School Students' Engagement in Chemistry through 7E Context-Based Instructional Strategy Supported with Simulation. *Pedagogical Research, 9*(2).

Demircioğlu, H., Demircioğlu, G., & Çalik, M. (2009). Investigating the effectiveness of storylines embedded within a context-based approach: the case for the Periodic Table. *Chemistry Education Research and Practice*, *10*(3), 241-249.

Dhlamini, J. J. (2016). Enhancing Learners' Problem Solving Performance in Mathematics: A Cognitive Load Perspective. *European Journal of STEM Education*, *1*(1), 27-36.

Dikilitas, K., & Fructuoso, I. N. (2023). Conceptual framework for flexible learning design: The Context of flipped classroom. *Conceptual framework for flexible learning design: The Context of flipped classroom. https://doi. org/10.31265/usps*, *267*.

Dimitrov, N., Dawson, D. L., Olsen, K., & Meadows, K. N. (2014). Developing the intercultural competence of graduate students. *Canadian Journal of Higher Education*, *44*(3), 86.

Dori, Y. J., Avargil, S., Kohen, Z., & Saar, L. (2018). Context-based learning and metacognitive prompts for enhancing scientific text comprehension. *International Journal of Science Education*, *40*(10), 1198-1220.

Eugenio-Gozalbo, M., Ramos-Truchero, G., Suárez-López, R., Andaluz Romanillos, M. S., & Rees, S. (2022). Introducing food sustainability in formal education: a teaching-learning sequence contextualized in the garden for secondary school students. *Education Sciences*, *12*(3), 168.

Garner, A. V. (2024). The Nature of Analyzing and Interpreting Data in 6-12 Science Education.

George, A. S., Baskar, T., & Srikaanth, P. B. (2024). The Erosion of Cognitive Skills in the Technological Age: How Reliance on Technology Impacts Critical Thinking, Problem-Solving, and Creativity.

Georgiou, Y., & Kyza, E. A. (2023). Fostering chemistry students' scientific literacy for responsible citizenship through socio-scientific inquiry-based learning (SSIBL). *Sustainability*, *15*(8), 6442.

Gholam, A. P. (2019). Inquiry-based learning: Student teachers' challenges and perceptions. *Journal of Inquiry and Action in Education*, *10*(2), 6.

Giamellaro, M. (2014). Primary contextualization of science learning through immersion in content-rich settings. *International Journal of Science Education*, *36*(17), 2848-2871.

Gilbert, J. K. (2006). On the nature of "context" in chemical education. *International journal of science education*, *28*(9), 957-976.

Güth, F., & van Vorst, H. (2024). To choose or not to choose? Effects of choice in authentic context-based learning environments. *European Journal of Psychology of Education*, 1-31.

Habig, S., Blankenburg, J., van Vorst, H., Fechner, S., Parchmann, I., & Sumfleth, E. (2018). Context characteristics and their effects on students' situational interest in chemistry. *International Journal of Science Education*, *40*(10), 1154-1175.

Hardy, J. G., Sdepanian, S., Stowell, A. F., Aljohani, A. D., Allen, M. J., Anwar, A., ... & Wright, K. L. (2021). Potential for chemistry in multidisciplinary, interdisciplinary, and transdisciplinary teaching activities in higher education. *Journal of Chemical Education*, *98*(4), 1124-1145.

Harris, J., Mishra, P., & Koehler, M. (2009). Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed. *Journal of research on technology in education*, *41*(4), 393-416.

Hickey, D. T., Chartrand, G. T., & Andrews, C. D. (2020). Expansive framing as pragmatic theory for online and hybrid instructional design. *Educational Technology Research and Development*, *68*(2), 751-782.

Juvonen, J., Lessard, L. M., Rastogi, R., Schacter, H. L., & Smith, D. S. (2019). Promoting social inclusion in educational settings: Challenges and opportunities. *Educational Psychologist*, *54*(4), 250-270.

Kamat, Y., & Nasnodkar, S. (2019). A survey on the barriers and facilitators to edtech adoption in rural schools in developing countries. *International Journal of Intelligent Automation and Computing*, *2*(1), 32-51.

Kang, J., Keinonen, T., Simon, S., Rannikmäe, M., Soobard, R., & Direito, I. (2019). Scenario evaluation with relevance and interest (SERI): Development and validation of a scenario measurement tool for context-based learning. *International Journal of Science and Mathematics Education*, *17*, 1317-1338.

Klein, J. T. (2018). "Advancing" Interdisciplinary Studies: The Boundary Work of Integrating, Complexifying, and Professionalizing. *Issues in Interdisciplinary Studies*, *36*(2), 45-67.

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.

Lakey, G. (2020). *Facilitating group learning: Strategies for success with diverse learners*. PM Press.

Lam, D. P., Hinz, E., Lang, D. J., Tengö, M., von Wehrden, H., & Martín-López, B. (2020). Indigenous and local knowledge in sustainability transformations research: a literature review. *Ecology & Society*, *25*(1).

Lave, J. & E. Wenger. (1991). Situated Learning: Legitimate Peripheral Participation. Cambridge, England: Cambridge University Press. Doi: 10.1017/ CBO9780511815355.

Lee, O., & Buxton, C. A. (2013). Teacher professional development to improve science and literacy achievement of English language learners. *Theory Into Practice, 52*(2), 110-117.

Li, Z. (2016). Rethinking the relationship between learner, learning contexts, and technology: a critique and exploration of Archer's morphogenetic approach. *Learning, Media and Technology*, *41*(3), 501-520.

Löffler, P., Pozas, M., & Kauertz, A. (2018). How do students coordinate context-based information and elements of their own knowledge? An analysis of students' context-based problem-solving in thermodynamics. *International Journal of Science Education*, *40*(16), 1935-1956.

Mina Herrera, S., P. (2022). Theoretical Models for Teaching and Research. PressBooks. https://opentext.wsu.edu/theoreticalmodelsforteachingandresearch/chapter/situated-learning-theory/

Muraille, E. (2019). Ethical control of innovation in a globalized and liberal world: Is good science still science?. *Endeavour*, *43*(4), 100709.

Nykyporets, S. S., & Ibrahimova, L. V. (2023). An empirical analysis of active and interactive pedagogical strategies in the context of distance learning environments: a comparative study. *Innovations in the Education of the Future: Integration of Humanities, Technical and Natural Sciences: International collective monograph. Chap. 22: 393-410.*

O'Ceallaigh, T. J., Connolly, C., & Brien, E. O. (2023). Hyflex Pedagogies: Nurturing teacher presence in multi-modal learning spaces post pandemic. *Routledge Open Research*, *2*(2), 2.

Parchmann, I., Broman, K., Busker, M., & Rudnik, J. (2015). Context-Based Teaching and Learning on School and University Level. *Chemistry education: Best practices, opportunities and trends*, 259-278.

Parchmann, I., Gräsel, C., Baer, A., Nentwig, P., Demuth, R., & Ralle, B. (2006). "Chemie im Kontext": A symbiotic implementation of a context-based teaching and learning approach. *International journal of science education*, *28*(9), 1041-1062.

Pastini, N. W., & Lilasari, L. N. T. (2023). Empowering EFL students: A review of student-centred learning effectiveness and impact. *Journal of Applied Studies in Language*, *7*(2), 246-259.

Podschuweit, S., & Bernholt, S. (2018). Composition-effects of context-based learning opportunities on students' understanding of energy. *Research in Science Education*, *48*, 717-752.

Pradhan, R. (2024). Emphasizing concept and skill-based learning: a comprehensive review. *New Trends Of Teaching, Learning And Technology, 1*, 285.

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in science Education*, *45*(1), 1-42.

Scott, T., & Husain, F. N. (2021). Textbook reliance: Traditional curriculum dependence is symptomatic of a larger educational problem. *Journal of Educational Issues*, *7*(1), 233-248.

Sentance, S., & Humphreys, S. (2018). Understanding professional learning for Computing teachers from the perspective of situated learning. *Computer Science Education*, *28*(4), 345-370.

Song, C., Shin, S. Y., & Shin, K. S. (2023). Optimizing foreign language learning in virtual reality: a comprehensive theoretical framework based on constructivism and cognitive load theory (VR-CCL). *Applied Sciences*, *13*(23), 12557.

Srikanth, M. (2024). *Exploring the Perceptions and Experiences of E-Learning in Consultancy Organizations: A qualitative study with a focus on the Indian context* (Doctoral dissertation, University of Essex).

Sugiarto, J., Widjanarko, W., & Rosidi, M. I. (2024). Innovations in technology-based learning to enhance 21st century competencies. *Indonesian Journal of Education (INJOE)*, *4*(3), 1002-1010.

Swargiary, K. (2024). *Redefining Reality: My Vision for an Education Rooted in Real-World Experiences*. ERA, US.

Tan, A. L., & Wong, H. M. (2012). 'Didn't Get Expected Answer, Rectify It.': Teaching science content in an elementary science classroom using hands-on activities. *International Journal of Science Education*, *34*(2), 197-222.

Teshager, G., Bishaw, A., & Dagnew, A. (2021). Context-based teaching and learning practices in upper primary science classrooms in East Gojjam Administrative Zone, Ethiopia. *Cogent Education*, *8*(1), 1940635.

Ummels, M. H. J., Kamp, M. J. A., De Kroon, H., & Boersma, K. T. (2015). Designing and evaluating a context-based lesson sequence promoting conceptual coherence in biology. *Journal of Biological Education*, *49*(1), 38-52.

van Schaik, P. (2020). *Utilizing, co-constructing and sharing knowledge in collaborative teacher learning*. Universiteit van Amsterdam.

van Vorst, H., & Aydogmus, H. (2021). One context fits all?–analysing students' context choice and their reasons for choosing a context-based task in chemistry education. *International Journal of Science Education*, *43*(8), 1250-1272.

Verawati, N. N. S. P., & Sarjan, M. (2023). The Philosophy of Critical Thinking in Problem-Based Science Learning. *Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, *11*(4), 992-1001.

Vogelzang, J., Admiraal, W. F., & van Driel, J. H. (2020). Effects of Scrum methodology on students' critical scientific literacy: the case of Green Chemistry. *Chemistry Education Research and Practice*, *21*(3), 940-952.

Yu, S., Jantharajit, N., & Srikhao, S. (2024). Collaborative Inquiry-Based Instructional Model to Enhance Mathematical Analytical Thinking and Reasoning Skills for Fourth-Grade Students. *Asian Journal of Education and Training*, *10*(1), 10-17.