Interdisciplinary Journal of Environmental and Science Education
2026, 22(4), e2622
e-ISSN: 2633-6537
https://www.ijese.com/

MODESTUM

Research Article

OPEN ACCESS

Secondary school students' engagement and conceptual understanding of chemistry concepts: Examining the association with riddle-based learning

Monday Moju [1*], Blessing Mary Adejumo [2], Jimoh Ibiyinka Shakiru [3]

[1] Department of Curriculum and Instruction, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA
[2] Department of Science and Technology Education, Faculty of Education, Obafemi Awolowo University, Ile-Ife, Osun State, NIGERIA
[3] Lagos State Government, Ikeja, Lagos State, NIGERIA
***Corresponding Author:** mmonday@vt.edu

Citation: Moju, M., Adejumo, B. M., & Shakiru, J. I. (2026). Secondary school students' engagement and conceptual understanding of chemistry concepts: Examining the association with riddle-based learning. *Interdisciplinary Journal of Environmental and Science Education, 22*(4), Article e2622. https://doi.org/10.29333/ijese/19450

ARTICLE INFO

Received: 19 Feb. 2026

Accepted: 09 Sep. 2026

ABSTRACT

Disengagement and lack of conceptual understanding of abstract chemistry concepts remain among the biggest problems faced in secondary chemistry lessons. It is even more exacerbated by the tendency to associate engagement with mere participation without considering the cognitive and emotional components of engagement and incorporating them in the learning process. To deal with the issue, the present study analyzed the effect of the application of riddle-based learning as an instructional strategy aimed at enhancing engagement and conceptual understanding of the mole concept in secondary school chemistry students. With the use of a pre-/post-test design, riddle-based instruction was employed in a sample of 34 senior secondary school chemistry students during one academic term. The data for the analysis were collected through an assessment of conceptual understanding, an engagement questionnaire, and qualitative student and teacher reflections on riddles. Results showed a statistically significant improvement in cognitive ($Z = -2.042$, $p = .041$), behavioral ($Z = -2.023$, $p = .043$), and emotional engagement ($Z = -2.072$, $p = .038$) after the intervention, with medium effect sizes ($r = .35$ to $.36$). Moreover, according to the results of paired-samples t-test, a statistically significant increase in conceptual understanding (pre-test mean [M] = 32.40, standard deviation [SD] = 14.22 to post-test M = 45.60, SD = 13.54) was observed, $t(33) = -3.17$, $p = .003$, $dz = 0.54$. Thematic analysis of qualitative reflections revealed that the use of riddles was linked to deeper thinking, increased participation and discussion, and higher levels of curiosity and enjoyment as well as frustration. Therefore, riddles could be considered a low-cost student-centered instructional strategy in chemistry lessons.

Keywords: riddle-based learning, student engagement, conceptual understanding, mole concept, chemistry education

INTRODUCTION

Student engagement is recognized as a fundamental prerequisite for productive learning and is emphasized in many national and international curriculum frameworks. Frameworks like the framework for K-12 science education developed by the National Research Council (2012), the next generation science standards (NGSS Lead States, 2013), and the project 2061 (American Association for the Advancement of Science, 1993) highlight the necessity of engaging students in active scientific practices instead of mere content acquisition. In that way, engagement is perceived as a necessary condition for developing students' conceptual understanding, scientific literacy, and transferable skills (Lawson & Lawson, 2020; Reeve et al., 2020). Nevertheless, despite all the efforts of curriculum writers, student disengagement characterized by lack of attention, motivation, and emotional connection to learning activities is one of the persistent challenges faced in secondary science classes. The disengagement results in students' lack of conceptual understanding and interest in sciences (Lawson & Lawson, 2020; Reeve et al., 2020; Sinatra et al., 2015). Hence, educational researchers pay increased attention to the role of engagement in achieving conceptual understanding and better performance in science (Bundick et al., 2014).

Engagement is viewed by researchers as a multi-dimensional construct that includes emotional, cognitive, and behavioral dimensions (Lei et al., 2018). According to Lei et al. (2018), emotional engagement represents students' interest, enjoyment, and connection to the lesson activities; cognitive engagement implies the investment of cognitive effort, strategic thinking, and persistence in comprehension of complex phenomena; and behavioral engagement is defined as participation and involvement in classroom activities. While some scholars suggest that emotional engagement serves as a precondition for cognitive and behavioral engagement in learning activities (Linnenbrink-Garcia & Pekrun, 2011; Naibert et al., 2022), other experts find that cognitive and behavioral engagement have a more direct impact on conceptual understanding (Lei et al., 2018). In chemistry in particular, the multi-dimensional view is strengthened by the call for researchers to identify what aspect of engagement they investigate and how it is measured (Lawrie, 2023) as well as validated activity-level measures of behavioral, cognitive, and emotional engagement (Naibert et al., 2022; Nayyar et al., 2024). All of the above shows that successful learning requires instructional strategies aimed at fostering all dimensions of engagement.

The association between engagement and conceptual understanding becomes obvious in with science education. Conceptual understanding goes beyond knowing the facts and includes comprehension of the underlying principles, relationships and applying knowledge in various contexts (Barlow & Brown, 2020; Çali et al., 2024; Darmofal et al., 2002; Vaiopoulou et al., 2023; Wang & Degol, 2014). For instance, in chemistry, conceptual understanding implies that students interpret chemical equations as representations of particle changes and not merely as balancing procedure. Conceptual understanding emerges when students are engaged in learning experiences cognitively, emotionally, and behaviorally. According to meta-analyses and large-scale researches, instructional strategies that promote engagement lead to bigger conceptual gains compared to traditional lecturing (Chi & Wylie, 2014; Freeman et al., 2014; Hake, 1998). Without proper engagement, students have to memorize facts that limit their capacity to apply scientific knowledge in the real life and solve the problems connected with climate change, health, and technology innovations (OECD, 2019; Sinatra et al., 2015).

Learning engagement in chemistry education is a particularly difficult task. Chemistry is a discipline characterized by abstract concepts, symbolism, and phenomena that are not observable by students (Taber, 2001; Treagust & Duit, 2008). A number of misconceptions formed on the basis of chemistry concepts, including misconceptions related to the mole concept, are not related to the deficiency of information but to students' inappropriate application of commonsense heuristics to particulate-level phenomena (Talanquer, 2006). Thus, chemistry becomes perceived as a difficult subject, which leads to decreased engagement and misconceptions (Brakhage et al., 2023; Steidtmann et al., 2022). In particular, problems in engaging students emerge at the point of the first formal contact with the discipline when initial disengagement becomes formative. Difficulties with the mole concept have been identified in studies investigating students' reasoning while solving mole problems (Pratiwi et al., 2023), underscoring the need for instructional strategies that make students' reasoning visible and discursive rather than purely computational.

Conceptual understanding in chemistry is often framed within the theory of conceptual change, which holds that learners revise or replace naive or incomplete conceptions when confronted with information their existing schemas cannot readily accommodate (Posner et al., 1982). From this perspective, effective instruction must first surface students' existing conceptions and then create the cognitive tension needed to prompt their revision (Vosniadou, 2013). Riddles, by presenting familiar language in unfamiliar or paradoxical combinations, may function as precisely this kind of anomaly-generating device, inviting students to test, discard, or refine their conceptions of abstract quantities such as the mole.

Student-centered pedagogies have been widely promoted as effective means of addressing disengagement in science classrooms. Approaches such as inquiry-based learning, problem-solving, and collaborative activity encourage learners to construct understanding actively rather than receive information passively (Levin et al., 2009; Lin et al., 2021). Active involvement of this kind is central to genuine classroom engagement. However, science teachers have been reported to conflate behavioral compliance, such as note-taking or quiet attention, with genuine engagement, resulting in instructional designs that fail to promote meaningful understanding (Linnenbrink-Garcia & Pekrun, 2011). This gap highlights the need for pedagogical strategies that simultaneously stimulate curiosity, promote reasoning, and sustain participation in chemistry learning.

Within this context, riddle-based learning emerges as a promising yet underexplored instructional approach for promoting student engagement. Riddles are cognitively demanding tasks that present information in metaphorical, paradoxical, or puzzling forms, requiring learners to interpret clues, activate prior knowledge, and engage in analytical reasoning to arrive at solutions (Demirel & Gül, 2021; Frye et al., 2015; Luo et al., 2004). Studies across disciplines suggest that riddles foster curiosity, enjoyment, and collaborative dialogue while supporting higher-order thinking and conceptual connection. Research in mathematics education, for instance, shows that riddle-rich classrooms are associated with deeper understanding and greater student enjoyment than conventional instruction (Farnell, 2017). Similarly, studies in language arts and general science education suggest that riddles can function as low-stakes diagnostic tools, helping teachers uncover student misconceptions while encouraging learners to articulate and refine their reasoning (Mokaya & Kebaya, 2022; Wardani et al., 2019). Demirel and Gül (2021) further reported associations between riddle use and young children's language development and problem-solving capacity. Together, these findings point to the potential of riddles to support conceptual understanding by stimulating curiosity, activating prior knowledge, and engaging students in analytical reasoning as they work to resolve cognitively challenging problems.

Emerging evidence suggests that puzzle-based activities can support students' engagement and cognitive development. In mathematics education, the use of puzzles has been associated with increased interest and the development of mathematical abilities, including logical and critical thinking (Gorev et al., 2018). In computer science education, embedding riddles into instruction has been associated with improved algorithmic reasoning and increased student interest (Chaabi et al., 2025). In chemistry specifically, engagement has also been linked to instructional design choices such as context-based and simulation-supported instruction (Demelash et al., 2024). These findings indicate that riddles and related puzzle-based approaches can serve as accessible, low-cost tools for promoting cognitive challenge. Despite this potential, the systematic integration of riddles as a structured, student-centered instructional strategy in secondary chemistry education remains limited.

From a theoretical perspective, riddle-based learning aligns closely with Vygotsky's (1978) socio-cultural theory of learning, which emphasizes the role of social interaction, language, and cultural tools in the development of higher-order thinking. Learning, according to this theory, occurs within the zone of proximal development (ZPD), where learners, with guidance and collaboration, can accomplish tasks that exceed their independent capabilities. Riddles create cognitive tension by presenting challenges that are just beyond students' immediate understanding, encouraging peer discussion, teacher scaffolding, and dialogic sensemaking (Gachanja & Kebaya, 2013). Through guided exploration and the gradual withdrawal of support, learners can internalize concepts, transforming socially mediated reasoning into individual understanding (Mercer et al., 2004; Palincsar, 1998).

In chemistry classrooms, riddles may also function as semiotic tools by embedding abstract ideas within familiar language, metaphor, and symbolic representation. Such representations can reduce cognitive load, support meaning-making, and enhance retention by helping students link new concepts to existing knowledge structures (Frye et al., 2015). When strategically integrated into instruction, riddles may therefore be associated with emotional engagement through curiosity and enjoyment, cognitive engagement through reasoning and problem-solving, and behavioral engagement through discussion and collaboration.

Despite growing recognition of the importance of engagement for conceptual understanding, and despite evidence supporting riddle-based approaches in other disciplines, there is a notable lack of empirical research examining riddle-based learning in secondary chemistry contexts. Little is known about how riddles relate to different dimensions of students' engagement or how that engagement, in turn, relates to conceptual understanding of chemistry concepts. Addressing this gap is important for advancing both theory and practice in chemistry education, and for supporting students' understanding of and interest in chemistry.

Accordingly, the present study investigates riddle-based learning as a structured, student-centered instructional strategy in secondary school chemistry. Grounded in socio-cultural theory, the study examines how riddle-based instruction supports students' emotional, cognitive, and behavioral engagement, and students' conceptual understanding of the mole concept in chemistry. In doing so, the study offers insight into how playful yet cognitively demanding riddle-infused instructional approaches may support engagement and meaningful learning in chemistry education. The study addressed the following research questions:

1. How is riddle-based learning associated with students' emotional, cognitive, and behavioral engagement during chemistry instruction?
2. What is the association of riddle-based learning with secondary school students' conceptual understanding of selected chemistry concepts?

METHOD

This study used a multi-method research design that integrated qualitative and quantitative approaches to provide a holistic understanding of the research problem (Almalki, 2016; Vivek & Nanthagopan, 2021). The rationale for a multi-method design lies in its capacity to capture the complex and multifaceted nature of student engagement and conceptual understanding (Vivek & Nanthagopan, 2021). Quantitative data were used to gain insight into students' levels of conceptual understanding and dimensions of engagement, while qualitative data provided rich, contextualized accounts of students' cognitive, behavioral, and emotional experiences in the classroom. The qualitative component supported explanatory interpretation by illuminating how engagement manifested during instruction.

Context and Participants

The study was conducted in Lagos State, Nigeria, which is administratively divided into six educational districts and operates under a national curriculum supervised by the Lagos State Ministry of Education. The Nigerian education system follows a 9-3-4 structure: nine years of free and compulsory basic education, three years of senior secondary schooling, and four years of tertiary education (Fafunwa, 2018). After completing basic and senior secondary education, students may pursue either technical education or university study, depending on their interests and career goals.

Participants were students transitioning from basic education to the first year of senior secondary school (SSS1) at a public high school in Educational District VI. At this level, students begin to engage with distinct academic disciplines, including chemistry, physics, and biology, alongside commercial and arts subjects, and are expected to specialize in one of three tracks: science, commerce, or arts. Participants in this study majored in science, were offered chemistry during the first term of the 2025 academic session and had no prior exposure to riddle-based learning, making them suitable for examining its instructional relevance. The age range of participants was 12 to 14 years. Students at the point of first exposure to chemistry are often discouraged by the perception that the subject is abstract and difficult to grasp; alongside mathematics, chemistry is widely perceived as a gateway to STEM disciplines at higher levels of education (Zhao, 2022). The present study accordingly targeted students who had opted for the science track, with the specific aim of examining their engagement in chemistry. A total of 34 SSS chemistry students participated, selected as an intact class; ethical approval and informed consent were obtained prior to data collection.

Ethical Considerations

Ethical approval for the study was obtained prior to data collection from the relevant institutional and school ethics review authority, and permission to conduct the study was granted by the school administration in Educational District

Table 1. Sample of riddle-modified chemistry syllabus

Week	Topics	Learning objectives	Riddles
1	-Definition of mole -Calculation of molar mass/relative molecular mass -Percentage composition of elements in compounds	-Explain the mole concept -Locate the atomic mass of elements on the periodic table -Calculate molar mass, relative molecular mass, and number of moles of a substance	"I am a special number in chemistry, used to count particles you cannot see. Whether atoms or molecules, I'm the key. What am I?" (Anser: Mole) "I represent the mass of one mole, for atoms, elements, or compounds whole. On the periodic table you'll find me, with units in grams per mole, you see. What am I?" (Anser: Molar mass)

Table 2. Riddle-infused, inquiry-based instructional implementation procedure

Phase of teaching	What the teacher did	What the students did	Connection to theory
Engage (cognitive and emotional engagement)	The teacher grouped students and presented a riddle representing the topic (mole concept): "I am the bridge between the mass of a substance and the number of particles. Who am I?" Students were encouraged to discuss the riddle among themselves. The goal was to activate prior knowledge and help students make connections that could lead toward the answer, rather than to elicit an immediate correct response.	Students listened, recalled prior concepts (moles, particles, atoms), and attempted initial guesses within their groups, talking with one another to resolve the riddle. Through this discussion, the teacher and researcher gained insight into how the riddle activated prior knowledge and prompted behavioral engagement.	The riddle placed the task just beyond students' independent ability, sparking curiosity within a social learning environment. Because the mole concept was represented metaphorically, students had to attend closely to language to demystify its meaning, engaging students both cognitively and behaviorally in preparation for exploration.
Explore (behavioral engagement)	The teacher provided activities for students to explore the concept further and reconcile their thinking, offering hints where needed (e.g., "It is a fundamental unit in chemistry") to encourage peer discussion and collaboration around the mole concept's definition and calculation.	Students discussed in groups, shared reasoning, expressed curiosity about the riddle, and asked clarifying questions.	This phase promoted social interaction and scaffolded meaning-making, helping learners bridge prior and new knowledge within a social environment.
Elaborate/ application (cognitive engagement)	The teacher provided model examples of mole-ratio and mass-number problems, gradually withdrawing support, and asked students to formulate their own riddles based on their experience.	Students applied reasoning to solve mole-related problems, explained their answers, attempted independent calculations, and formulated riddles.	Scaffolds were withdrawn as students internalized skills, demonstrating independent mastery within the social learning environment.

VI, Lagos State. Because participants were minors (12-14 years old), written informed consent was obtained from parents or legal guardians, and student assent was obtained directly from participants before the engagement questionnaire, achievement test, and reflection instruments were administered. Students were informed that participation was voluntary, that declining to participate would not affect their standing in the class, and that their responses would be anonymized. The classroom teacher, who administered the instruments as part of regular instruction, collected the paper-based responses and forwarded scanned copies to the first author; no student names or other identifying information were retained in the analytic dataset.

Instructional Intervention

Riddle-based learning was implemented as a structured instructional strategy rather than as an isolated classroom activity. Riddles were deliberately integrated into regular chemistry lessons and aligned with the prescribed curriculum topics for the term. Each riddle was designed to introduce or reinforce key chemistry concepts by presenting them in metaphorical or problem-oriented forms that required reasoning and discussion. Riddles were generated using a generative artificial intelligence tool (ChatGPT-5) and subsequently reviewed by the classroom teacher and the researcher to verify content accuracy, curriculum alignment, and age appropriateness. This review process helped to ensure that the resulting riddles functioned as meaningful cognitive prompts rather than as entertainment devices. A sample of the riddle-modified syllabus is presented in **Table 1**.

Adapting the 5E Instructional Model for Riddle-Based Learning

Instruction was organized around the 5E instructional model (Bybee et al., 2006). Riddles were embedded in the engage and explore phases to stimulate curiosity, activate prior knowledge, and encourage collaborative learning, and in an application, phase drawn from the model's elaborate stage, in which students solved mole problems and composed riddles of their own. The explain and evaluate phases proceeded as in conventional instruction and were not modified by the intervention. The teacher scaffolded instructions to support learning within students' ZPD. Riddle-based activities were infused into the chemistry syllabus throughout the term, ensuring that students encountered them in every chemistry topic. **Table 2** presents the three riddle-adapted phases.

Instruments and Data Collection Procedures

A multi-method data collection approach was used to capture the association of riddle-based learning with students' engagement and conceptual understanding. Riddles functioned as mediating tools within students' ZPD, prompting dialogue, reflection, and collaboration. Data were collected through a student engagement survey, a pre-/post-test achievement test, and qualitative reflections from students and the classroom teacher.

Student engagement survey

To assess students' engagement, a Likert-scale survey instrument adapted from Burch et al. (2015) was administered. Items were organized around three dimensions of engagement (cognitive, behavioral, and emotional), with five items per dimension. Students rated their agreement with each item on a four-point scale (1 = strongly disagree, 4 = strongly agree). Emotional engagement items addressed interest and enjoyment; cognitive engagement items addressed effort, strategy use, and persistence; behavioral engagement items addressed participation and task involvement (Burch et al., 2015). Items underwent a validation process to ensure clarity, relevance, and alignment with the constructs under study. A pilot test was then conducted with a comparable group of students to assess reliability and usability; pilot data indicated internal consistency reliabilities of $\alpha = .78$, .84, and .88 for the cognitive, emotional, and behavioral subscales, respectively. The instrument was administered twice, at the beginning and end of the riddle-based learning intervention, to capture change in engagement over the instructional period. All 34 participants completed the survey on both occasions. The teacher collected the paper-based responses and forwarded scanned copies to the first author at the end of the intervention.

Conceptual understanding test

Students' conceptual understanding was assessed using a 50-item test combining multiple-choice and free-response questions targeting foundational knowledge of the mole concept. Each item was scored dichotomously (1 point for a fully correct response, 0 points otherwise), yielding a maximum obtainable score of 50 points; this scoring approach was intended to ensure consistency and transparency in evaluating conceptual understanding. All items were drawn from a standardized examination item bank maintained by the West African Examinations Council. The items were modified to reflect the difficulty level appropriate for the participants and administered before and after the riddle-based learning intervention. The use of multiple-choice items was considered appropriate because they allowed objective measurement across a range of understanding while facilitating statistical analysis of the resulting data (Haladyna et al., 2002).

Qualitative reflection

To complement the quantitative data, students responded to open-ended questions asking them to reflect on how the riddle activities influenced their engagement and conceptual understanding of the mole concept and their interest in chemistry. Questions were designed to elicit responses reflecting deeper thinking, conceptual clarity, and real-world connection. For example, students were asked, "When you solved chemistry-related riddles, how did it help you explain mole concepts?" Follow-up prompts encouraged elaboration on how riddles related to their understanding of the mole concept. Students wrote their reflections on paper, which the teacher collected and scanned to the first author.

Teacher reflection

In addition to the student data sources, the classroom teacher provided a one-page reflection on the relationship between riddle-based learning and students' engagement and understanding of the mole concept. This reflection was used to triangulate the data and to provide additional insight into the perceived effectiveness of riddle-based learning in chemistry.

Data Analysis

The multi-method design allowed both quantitative and qualitative analytic approaches to examine the association of riddle-based learning with students' engagement and conceptual understanding. Students' engagement was analyzed using the Wilcoxon signed-rank test, and the achievement test was analyzed using a paired-samples t-test. Students' responses to open-ended questions on dimensions of engagement were analyzed thematically to provide deeper insight into their learning experiences.

Students' engagement

A Wilcoxon signed-rank test was conducted to examine changes in students' engagement following the riddle-based chemistry learning experience. This nonparametric approach was adopted because the Likert-scale data violated the normality assumption and the sample size was small (Mircioiu & Atkinson, 2017; Pett, 2016). The test was used to determine the difference between paired pre- and post-intervention engagement median (Mdn) scores across the three dimensions of engagement: cognitive, behavioral, and emotional. To support interpretation of practical significance alongside statistical significance, effect size r was calculated for each dimension using the standard formula $r = Z/\sqrt{N}$ (Fritz et al., 2012), where N refers to the number of observations ($N = 34$ for each dimension).

Conceptual understanding

To understand the association of riddle-based learning with students' conceptual understanding of the mole concept, a paired-samples t-test was conducted to compare pretest and posttest scores. Normality of the pretest and posttest score distributions was assessed using the Shapiro-Wilk test; results supported the assumption of normality and justified the use of the paired-samples t-test. Effect size was calculated using Cohen's d for paired samples (Cohen, 1988). Significance was set at $\alpha = .05$.

Qualitative data analysis procedure

Students' written reflections and the teacher's reflective journal were analyzed using thematic analysis (Braun & Clarke, 2006). Because the engagement construct had already been operationalized quantitatively along cognitive, behavioral, and emotional dimensions, these three dimensions were used as an a priori coding framework, consistent with a deductive approach to thematic analysis (Braun & Clarke, 2006). The first author read all reflections repeatedly for familiarization and then coded each excerpt according to the dimension(s) of engagement it reflected: statements about thinking or reasoning were coded as cognitive; statements about participation, discussion, or collaboration were coded as behavioral; and statements about curiosity, enjoyment, confidence, or frustration were coded as emotional. A subset of the data was independently coded by the second author, and any discrepancies were discussed and resolved by consensus to strengthen the trustworthiness of the coding. A fourth,

Table 3. Wilcoxon signed-rank analysis of engagement before and after riddle-based learning

Dimension	N	Median (pre/post)	Z	p	Effect size (r)
Cognitive	34	15/20	-2.042	.041	.35
Behavioral	34	14/18	-2.023	.043	.35
Emotional	34	16/19	-2.072	.038	.36

Note. $r = Z / \sqrt{N}$ (Fritz et al., 2012), where *r* values of approximately .10, .30, and .50 are conventionally interpreted as small, medium, and large effects, respectively

inductively derived category, challenges associated with riddle-based learning, was retained because it recurred saliently across both student and teacher accounts without mapping cleanly onto the three engagement dimensions. Verbatim quotations may contain grammatical errors because students' comments are reproduced as written, consistent with recommended multi-method reporting practice in education research (Creswell & Plano Clark, 2018).

FINDINGS

Chemistry is widely regarded as an abstract subject that presents considerable challenges for learners. Prior studies suggest that these challenges are related to limited student engagement, which in turn is associated with difficulty grasping chemistry concepts. This study reports findings addressing the study's two research questions:

(1) How is riddle-based learning associated with students' emotional, cognitive, and behavioral engagement during chemistry instruction?

(2) What is the association of riddle-based learning with students' conceptual understanding of selected chemistry concepts?

Findings are presented in two parts. First, survey data are analyzed to examine the association of riddle-based learning with behavioral, cognitive, and emotional engagement, supported by excerpts from students' qualitative reflections and the teacher's reflection. Second, paired-samples t-test results are presented to examine changes in students' conceptual understanding of the mole concept from pretest to posttest.

Riddle-Based Learning and Students' Engagement in Chemistry

A Wilcoxon signed-rank test was conducted for each dimension of engagement; results are presented in Table 3.

Cognitive engagement

For the cognitive dimension, the Wilcoxon signed-rank test indicated a statistically significant difference between the Mdn score before the intervention (Mdn = 15) and after the intervention (Mdn = 20), Z = -2.042, p = .041, r = .35, a medium effect. This result indicates an association of riddle-based learning with cognitive engagement in chemistry. Students' reflections corroborated this pattern:

> It makes me think deeply. For example, I am given a riddle I need to think deeply because normally riddles required thinking and reasoning and I need to think deeply to get the answer. Introduction of riddle in the topic helped me to learn how to think deeply.

> For me it makes me think very deeply about the subject and takes some time to solve and sometimes it can be so trickish.

These statements suggest that students experienced the riddles as cognitively engaging, describing deliberate effort as they worked to resolve each riddle.

Behavioral engagement

For the behavioral dimension, the Wilcoxon signed-rank test indicated a statistically significant difference between the Mdn score before the intervention (Mdn = 14) and after the intervention (Mdn = 18), Z = -2.023, p = .043, r = .35, a medium effect. This result indicates an association of riddle-based learning with behavioral engagement in chemistry. Students' reflections further corroborated this pattern:

> During the riddle sessions, I was more active in class than usual. I listened carefully, raised my hand to suggest answers, and worked with my classmates to solve the riddles because I wanted to figure out the problem before the solution was revealed.

> The riddles made me participate more in lessons. Instead of waiting for the teacher to explain everything, I tried to solve the questions myself and discussed my ideas with others. I was more focused and involved throughout the class.

This engagement was reflected in increased participation through discussion, willingness to talk, and idea-sharing as students worked collaboratively to answer the riddles, particularly during the Engage phase of the lesson. The teacher's reflection on students' engagement in the classroom echoed this observation:

> Students who were ordinarily inactive in class were very active when the riddle was introduced (teacher).

Emotional engagement

For the emotional dimension, the Wilcoxon signed-rank test indicated a statistically significant difference between the Mdn score before the intervention (Mdn = 16) and after the intervention (Mdn = 19), Z = -2.072, p = .038, r = .36, a medium effect. This result indicates that riddle-based learning was associated with emotional engagement, with students expressing excitement, curiosity, and a positive connection to the learning activity. Students' reflections corroborate this pattern:

> The riddles made the lessons enjoyable and less stressful. I felt curious and excited to participate because solving the riddle felt like a challenge rather than a test, which made chemistry more interesting for me.

Table 4. Paired-samples t-test of students' conceptual understanding of the mole concept

Test	M	SD	df	t	p	d
Pre-test	32.40	14.22	33	-3.17	.003	0.54
Post-test	45.60	13.54				

Note. N = 34; df = N-1 = 33; dz: Standardized mean difference for paired samples, computed as $t/\sqrt{N}$ (Cohen, 1988); dz is based on the SD of the difference scores

> I felt more confident and motivated during the riddle activities. Even when I was not sure of the answer, I was not afraid to try because the class atmosphere felt supportive and fun.

These results, together with the supporting excerpts, suggest that riddle-based learning was associated with greater curiosity, interest, and enjoyment of chemistry in the classroom.

Riddle-Based Learning and Students' Conceptual Understanding of the Mole Concept

To examine the association of riddle-based learning with students' conceptual understanding, a paired-samples t-test was conducted; results are presented in Table 4.

The paired-samples t-test indicated a statistically significant difference between pre-test (mean [M] = 32.40, standard deviation [SD] = 14.22) and posttest conceptual understanding scores (M = 45.60, SD = 13.54), $t(33) = -3.17$, $p = .003$, dz = 0.54, representing a medium effect size. This result indicates a statistically significant increase in conceptual understanding scores over the intervention period. Excerpts from students' reflections further corroborate this pattern. Students described the riddles as prompting deep thought about the mole concept and supporting their ability to solve chemistry problems:

> It helps me in solving problems because if I'm given a question to solve, I think before solving the problem, so it has helped me to learn how to think very well.

> For me it makes me think very deep about the subject and takes some time to solve and sometimes it can be so trickish. It also gives me a better understanding.

> The riddles help me understand the topic better than I imagine it to be ... riddles help me to think and reason about the topic very well and understand it more.

The deep thought prompted by the riddles also appeared to help students make connections to prior knowledge related to new topics. One student explained:

> The riddle helps me understand the topic because it refers to topics taught in class, and when you think back you remember things taught in class and understand it better…For me it makes me go back to the subject that has been taught for a long time.

Beyond drawing on prior knowledge, students indicated that the riddles helped them explain chemistry concepts in their own words rather than focus solely on producing a technically correct answer:

> Adding riddles helps me explain topics in my own words better. It was a whole lot easier for me to explain to the class the way I understood it instead of thinking about the right word.

Taken together, the quantitative results and the pattern of student reflections suggest that riddle-based learning was associated with students' engagement with chemistry concepts, giving them the opportunity to reflect on the topic, connect it to prior experience, and explain it in their own words.

Challenges Associated with Riddle-Based Learning

The thematic analysis of the data further revealed challenges associated with implementing riddle-based instruction. Despite the associations reported above, students' and the teacher's reflections indicated that riddle-based learning was also associated with difficulties, including overthinking and spending considerable time on a single riddle. The following excerpts illustrate these difficulties:

> My challenge is that I will have to think about the things that I am not supposed to think. For me it takes a lot of time to solve riddles ... and all those thinking sometimes gives me headache.

> The answer to the riddles is sometimes challenging because it needs critical thinking and understanding to solve the answer.

> Solving riddles is not actually a challenge to me, but a means of exercising my brain by critically thinking to find the answers.

As a result, some students expressed a preference for direct instruction over riddle-based tasks:

> I don't know if I face any challenges because I hate riddles even if I try them in chemistry class it is because I was forced but I prefer straight teaching without the use of riddle ... [the straight teaching] makes me love chemistry more, but where there is riddle, I hate or dislike that topic more.

The teacher's reflection likewise indicated that integrating riddles into chemistry instruction presented a genuine challenge for some students:

> Students face different challenges according to their [learning] differences. Some like the sound of riddles in the class as it really spikes their curiosity, some enjoy it as a method of bringing excitement to the class, many understand a line or two in some given riddles but find it difficult to connect all points, some students hate the sound of it as they don't like the idea of making their brain work or think too much. I think the use of riddles in chemistry to them is like forcing them to sit in a long-hour mathematics class. In one of my student's feedback on the use of riddles in teaching chemistry, and I quote: it's always giving me a headache (teacher).

The teacher also noted that the deliberately tricky wording used in some riddles could work against comprehension:

> The tricky words used in formulating riddles can lead students to focus on irrelevant details rather than the core concepts, which in turn can make students misread or overanalyze the riddles, causing them to miss the intended concept (teacher).

These accounts suggest that riddles can be cognitively demanding in ways that are not uniformly productive, and that adequate teacher support is likely needed to help students move from a state of cognitive dissonance toward comfort and competence in resolving riddle problems.

DISCUSSION

This study examined the association of riddle-based learning with students' engagement and conceptual understanding in chemistry. The findings suggest that riddles, used as instructional prompts, are associated with students' behavioral, emotional, and cognitive engagement, and that gains in conceptual understanding were observed over the same period. Although integrating riddles also introduced challenges for some students, the pattern of results points to the potential of riddle-based learning as one approach to the long-standing problem of disengagement with abstract chemistry concepts. These findings are interpreted through the lens of Vygotsky's (1978) socio-cultural theory, which holds that learning is a socially mediated process shaped by interaction, language, and cultural tools. From this perspective, riddle-based learning may function as a mediational tool that supports students' cognitive activity within social contexts, enabling them to co-construct meaning through dialogue, shared problem-solving, and guided participation.

Riddles as Catalysts for Engagement and Conceptual Understanding

Consistent with the quantitative results, students' reflections indicated that riddles prompted "deep thinking" and sustained mental effort, both core indicators of cognitive engagement (Doolittle, 1995; Fredricks et al., 2004). This pattern aligns with a broader body of research suggesting that intellectually playful tasks, such as riddles, gamified instruction, and puzzles, are associated with deeper cognitive investment because they require learners to analyze, infer, and reason rather than passively recall information (Coelho et al., 2026; Fontes et al., 2024). It is also consistent with research indicating that learning activities introducing cognitive challenge without an immediate solution path can foster productive struggle in ways that support conceptual change and longer-term understanding (Kapur, 2016; Schonberg, 2025). The increased cognitive engagement observed here also reflects students' active use of language to make sense of chemistry concepts, consistent with Vygotsky's (1978) view that thought develops through speech and social interaction; students' reports that riddles made them "think deeply" and "reason" suggest that riddles externalized thinking that students later internalized as individual understanding.

Behavioral engagement also increased, with students reporting greater participation, attentiveness, and collaborative problem-solving during riddle-based lessons. This finding is consistent with prior research suggesting that riddles and problem-based prompts encourage active classroom behaviors, particularly discussion and peer interaction (Prince, 2004), and with the general pattern that students who perceive a task as an intriguing challenge, rather than a routine exercise, are more likely to take initiative and persist. In chemistry specifically, interactive strategies that emphasize sense-making have been associated with greater willingness to participate and articulate ideas publicly (Cooper et al., 2018). This pattern resonates with Vygotsky's (1978) concept of the ZPD, the distance between what learners can do independently and what they can accomplish with guidance from more capable peers or instructors. During the riddle-based activities, students collaboratively explored possible solutions, shared partial understanding, and refined ideas through discussion, positioning the riddles within students' ZPD by offering challenges that were initially difficult but solvable through social mediation and scaffolded instruction. The teacher's observation that previously inactive students became more involved when riddles were introduced is consistent with this interpretation: shared intellectual responsibility, from a socio-cultural perspective, can draw students into participation who might otherwise remain passive, by creating a shared problem space that allows students to contribute ideas without fear of immediate evaluation.

Emotional engagement showed a similar pattern, with some students describing the riddle-based lessons as more enjoyable and motivating than traditional instruction. These responses are consistent with research suggesting that playful intellectual activity promotes curiosity and positive affect, which can in turn support attention, subject interest, and learning (Hidi & Renninger, 2006; Pekrun et al., 2011). From a socio-cultural perspective, students' reports of curiosity and enjoyment suggest that the riddles reframed chemistry learning as a socially supported intellectual challenge rather than an individual performance task; the supportive classroom discourse surrounding riddle-solving appeared to foster a sense of belonging and confidence that socio-cultural theorists consider important for sustained participation in learning communities. Students' ability to explain concepts "in their own words" is also consistent with the process of internalization Vygotsky (1978) described, whereby socially mediated language gradually becomes internal speech supporting independent reasoning.

The study also found a statistically significant increase in students' conceptual understanding following the intervention, a pattern consistent with research indicating that learning tasks requiring explanation, reasoning, and connection to prior knowledge support meaningful learning in science (Chi & Wylie, 2014; Vosniadou, 2013). Students' reflections suggested that riddles helped them activate prior knowledge and reason through chemical ideas and explain concepts in their own words. Related patterns have been reported in studies using riddles, analogies, or conceptual puzzles to support understanding in chemistry and physics, with associated gains in conceptual clarity and problem-solving performance (Adzape et al., 2020; Huang et al., 2020; Lathwesan & Belova, 2021). Collectively, these findings are consistent with the view that riddle-based learning functions as a form of cognitively activating instruction associated with engagement and conceptual understanding, positioning students as active sense-makers who bridge abstract chemical concepts and their existing cognitive frameworks.

Challenges Associated with Riddle-Based Learning

Alongside its apparent benefits, riddle-based learning was also associated with notable challenges, a pattern that itself aligns with socio-cultural theory: students who experienced frustration or cognitive overload may have encountered tasks that exceeded their ZPD because scaffolding was insufficient for their needs. Some learners reported overthinking, cognitive fatigue, frustration, and even dislike for riddles, particularly when riddles were perceived as excessively demanding or time-consuming. These experiences are consistent with cognitive load theory, which suggests that tasks requiring high levels of reasoning can overwhelm learners when scaffolding is inadequate (Sweller et al., 2011); when riddles contain complex or misleading language, students may focus on irrelevant details rather than core concepts, increasing extraneous cognitive load. This pattern is consistent with prior cautions in the science education literature that, while productive struggle can support learning, unstructured or poorly supported challenge can instead lead to disengagement, especially among students with lower prior knowledge or confidence (Kapur, 2016; Kirschner et al., 2006). The teacher's reflection illustrates this tension, noting that some students struggled to connect ideas within riddles or resisted the approach because they associated it with excessive mental effort, a pattern consistent with prior findings that students accustomed to teacher-centered instruction may initially resist inquiry-oriented approaches requiring sustained thinking (Brown et al., 2012). Together, these findings suggest that riddles are most effective when thoughtfully designed and strategically facilitated, with teachers playing a critical role in moderating cognitive demand, clarifying task goals, and supporting students as they move from initial confusion toward understanding (Belland et al., 2017; Hmelo-Silver et al., 2007).

CONCLUSION

This study examined the association of riddle-based learning with students' engagement and conceptual understanding in chemistry. Guided by socio-cultural theory, it sought to understand how riddles functioned as instructional tools in relation to students' cognitive, behavioral, and emotional participation in learning, as well as their understanding of an abstract chemistry concept.

The findings indicate that riddle-based learning was associated with all three dimensions of student engagement. Students demonstrated greater cognitive effort through deep thinking and reasoning, greater behavioral participation through discussion and collaboration, and heightened emotional engagement characterized by curiosity, enjoyment, and confidence. In addition, the observed improvement in students' conceptual understanding suggests that riddles were associated with meaningful learning, encouraging students to draw on prior knowledge, reflect on ideas, and explain concepts in their own words. These outcomes point to the value of riddles as cognitively activating tasks that may help move students beyond passive reception of information toward active sense-making.

Interpreted through Vygotsky's (1978) socio-cultural theory, these findings suggest that riddles functioned as mediational tools supporting learning through social interaction and shared problem-solving. The collaborative nature of riddle-solving positioned students within their ZPD, allowing them to co-construct understanding with peers and teacher support. The dialogic classroom interactions observed during riddle-based lessons appeared to support the internalization of scientific concepts, consistent with the view that learning is both a social and a cognitive process.

Because the study relied on a single-group, pre-post design without a comparison group, these conclusions should be read as evidence of association rather than causation. Within that limitation, the study offers preliminary evidence that riddle-based learning can function as a socio-cultural instructional strategy in chemistry education when thoughtfully implemented. By supporting engagement, conceptual understanding, and social interaction, riddles appear to offer a promising, low-cost strategy for addressing some of the challenges associated with learning abstract chemistry concepts, provided that they are aligned with students' developmental needs and supported through intentional teacher scaffolding.

Implications for Practice

These findings suggest that riddle-based learning may be a useful tool for supporting students' engagement and conceptual understanding in chemistry classrooms. By drawing on metaphor, dialogue, and problem-solving, riddles offer an accessible pathway into scientific thinking that does not require specialized materials or technology, an important consideration in resource-constrained classrooms. Riddles appear most effective when teachers intentionally support students' movement from confusion to understanding, ensuring that challenges remain within what students can reasonably process, given appropriate scaffolding. Used in this way, riddles may function as tools for social meaning-making that support both engagement and conceptual understanding. The study adds to a growing body of work advocating creative, inquiry-oriented strategies in chemistry teaching, and is broadly consistent with the view that cognitive development is socially mediated and culturally shaped. As such, riddle-based learning holds promise not only to support students' conceptual understanding but also to inform how science is taught and experienced in the classroom.

Limitations and Directions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, and most importantly, the study used a single-group pre-/post-test design without a comparison or control group. While this design was appropriate given the ethical and logistical constraints of intervening in an intact classroom, it does not support causal inference about the specific effect of riddle-based learning. Several threats to internal validity cannot be ruled out: maturation, in that students' natural cognitive development or growing familiarity with course content over the term may partly account for the observed gains; instructor effects, in that the classroom teacher's general enthusiasm, skill, or attention, rather than the riddles specifically, may have contributed to the results; and testing or practice effects, in that scores may have improved partly because students had already encountered the pretest items. Accordingly, all findings reported here should be interpreted as associations between riddle-based learning and engagement and conceptual understanding, rather than as evidence of a causal effect.

Second, the sample was small (N = 34) and drawn from a single intact classroom in one school within one educational district in Lagos State, which limits statistical power and the generalizability of the findings to other schools, regions, or educational systems. Third, engagement and reflection data relied on students' self-reports, which may be subject to social desirability bias, particularly given that the classroom teacher was involved in both instruction and data collection.

Future research should replicate this study using a comparison or control-group design, ideally with random assignment at the classroom level, to strengthen causal inference regarding the specific effect of riddle-based learning. Longitudinal designs tracking engagement and conceptual understanding across a full academic year, or across multiple chemistry topics beyond the mole concept, would help clarify whether the associations observed here persist over time and generalize across content areas. Future work should also examine how different levels and forms of teacher scaffolding moderate whether riddles produce productive cognitive challenge rather than disengagement or frustration, given the difficulties evident in the data.

Author contributions: MM: conceptualization, data curation, formal analysis; **BMA:** writing – review & editing; **JIS:** formal analysis. All authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors confirm that this study was conducted in full compliance with the ethical standards of the American Psychological Association. Ethical approval was obtained prior to data collection, informed consent was secured from all participants and their guardians, participation was voluntary, and all data were anonymized to protect participants' identities. The authors confirm that all processes were carried out in accordance with all applicable rules and guidelines with the Virginia Tech IRB approval number 24-1179. All participants consented to participate in the study.

AI statement: In the preparation of this manuscript, ChatGPT version 5.0 was utilized to enhance language quality, specifically for grammatical corrections, and for generation of riddles. Subsequently, the generated riddles were reviewed by the chemistry teachers and the first author.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Adzape, J. N., Otor, E. E., & Akpoghol, T. V. (2020). Effects of chemistry-based puzzles on senior secondary school students' interest in chemical periodicity. *Education and Linguistics Research, 6*(2), 88-100. https://doi.org/10.5296/elr.v6i2.17836

Almalki, S. (2016). Integrating quantitative and qualitative data in mixed methods research—Challenges and benefits. *Journal of Education and Learning, 5*(3), 288-296. https://doi.org/10.5539/jel.v5n3p288

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. Oxford University Press.

Barlow, A., & Brown, S. (2020). Correlations between modes of student cognitive engagement and instructional practices in undergraduate STEM courses. *International Journal of STEM Education, 7*, Article 18. https://doi.org/10.1186/s40594-020-00214-7

Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing results from empirical research on computer-based scaffolding in STEM education. *Review of Educational Research, 87*(2), 309-344. https://doi.org/10.3102/0034654316670999

Brakhage, H., Gröschner, A., Gläser-Zikuda, M., & Hagenauer, G. (2023). Fostering students' situational interest in physics: Results from a classroom-based intervention study. *Research in Science Education, 53*(5), 993-1008. https://doi.org/10.1007/s11165-023-10120-x

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Brown, P., Abell, S., Demir, A., & Schmidt, F. (2012). College science teachers' views of classroom inquiry. *Science Education, 96*(2), 213-248. https://doi.org/10.1002/sce.20151

Bundick, M. J., Quaglia, R. J., Corso, M. J., & Haywood, D. E. (2014). Promoting student engagement in the classroom. *Teachers College Record, 116*(4), 1-34. https://doi.org/10.1177/016146811411600411

Burch, G. F., Heller, N. A., Burch, J. J., Freed, R., & Steed, S. A. (2015). Student engagement: Developing a conceptual framework and survey instrument. *Journal of Education for Business, 90*(4), 224-229. https://doi.org/10.1080/08832323.2015.1019821

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness*. Biological Sciences Curriculum Study. https://bscs.org/reports/the-bscs-5e-instructional-model-origins-and-effectiveness/

Çali, M., Lazimi, L., & Ippoliti, B. M. L. (2024). Relationship between student engagement and academic performance. *International Journal of Evaluation and Research in Education, 13*(4), 2211-2218. https://doi.org/10.11591/ijere.v13i4.28710

Chaabi, H., Azmani, A., & Dodero, J. M. (2025). Bridging computational thinking research and practice of pre-service and in-service teachers. *Humanities and Social Sciences Communications, 12*, Article 666. https://doi.org/10.1057/s41599-025-04895-9

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219-243. https://doi.org/10.1080/00461520.2014.965823

Coelho, F., Rando, B., Aparício, D., Pontífice-Sousa, P., Gonçalves, D., & Abreu, A. M. (2026). The impact of educational gamification on cognition, emotions, and motivation: A randomized controlled trial. *Journal of Computers in Education, 13*(2), 537-584. https://doi.org/10.1007/s40692-025-00366-x

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Cooper, K. M., Downing, V. R., & Brownell, S. E. (2018). The influence of active learning practices on student anxiety in large-enrollment college science classrooms. *International Journal of STEM Education, 5*, Article 23. https://doi.org/10.1186/s40594-018-0123-6

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE.

Darmofal, D. L., Soderholm, D. H., & Brodeur, D. R. (2002). Using concept maps and concept questions to enhance conceptual understanding. In *Proceedings of the 2002 Frontiers in Education Conference* (pp. 1159-1164). IEEE. https://doi.org/10.1109/FIE.2002.1157954

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), Article em0189. https://doi.org/10.29333/pr/14146

Demirel, B., & Gül, E. D. (2021). The effect of riddles on problem-solving skills of 57-66 months old children. *Cukurova University Faculty of Education Journal, 50*(2), 721-748. https://doi.org/10.14812/cuefd.943800

Doolittle, J. H. (1995). Using riddles and interactive computer games to teach problem-solving skills. *Teaching of Psychology, 22*(1), 33-36. https://doi.org/10.1207/s15328023top2201_10

Fafunwa, A. B. (2018). *History of education in Nigeria*. Routledge. https://doi.org/10.4324/9780429454905

Farnell, E. (2017). Puzzle pedagogy: A use of riddles in mathematics education. *PRIMUS: Problems, Resources, and Issues in Mathematics Undergraduate Studies, 27*(2), 202-211. https://doi.org/10.1080/10511970.2016.1195465

Fontes, M. M., Morgado, L., Pestana, P. D., & Cravino, J. P. (2024). Viewing puzzles as two-faced: Theoretical and practical implications for puzzle-based learning. *Thinking Skills and Creativity, 52*, Article 101470. https://doi.org/10.1016/j.tsc.2024.101470

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59-109. https://doi.org/10.3102/00346543074001059

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *PNAS, 111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Fritz, C. O., Morris, P. E., & Richler, J. J. (2012). Effect size estimates: Current use, calculations, and interpretation. *Journal of Experimental Psychology: General, 141*(1), 2-18. https://doi.org/10.1037/a0024338

Frye, E. M., Bradbury, L. U., & Gross, L. A. (2015). Teaching students to compose informational poetic riddles to further scientific understanding. *The Reading Teacher, 69*(4), 435-445. https://doi.org/10.1002/trtr.1355

Gachanja, W. M., & Kebaya, C. (2013). Pedagogical aspects of riddles: A critical examination of Abagusii riddles. *International Journal of Humanities and Social Science, 3*, 293-298. https://ijhss.thebrpi.org/journal/index/1616

Gorev, P., Telegina, N. V., Karavanova, L., & Feshina, S. (2018). Puzzles as a didactic tool for development of mathematical abilities of junior schoolchildren in basic and additional mathematical education. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(10), 178-185. https://doi.org/10.29333/ejmste/93675

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74. https://doi.org/10.1119/1.18809

Haladyna, T. M., Downing, S. M., & Rodriguez, M. C. (2002). A review of multiple-choice item-writing guidelines for classroom assessment. *Applied Measurement in Education, 15*(3), 309-333. https://doi.org/10.1207/S15324818AME1503_5

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111-127. https://doi.org/10.1207/s15326985ep4102_4

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based learning. *Educational Psychologist, 42*(2), 99-107. https://doi.org/10.1080/00461520701263368

Huang, S.-Y., Kuo, Y.-H., & Chen, H.-C. (2020). Applying digital escape rooms infused with science teaching in elementary school: Learning performance, learning motivation, and problem-solving ability. *Thinking Skills and Creativity, 37*, Article 100681. https://doi.org/10.1016/j.tsc.2020.100681

Kapur, M. (2016). Examining productive failure, productive success, unproductive failure, and unproductive success. *Educational Psychologist, 51*(2), 289-299. https://doi.org/10.1080/00461520.2016.1155457

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86. https://doi.org/10.1207/s15326985ep4102_1

Lathwesan, C., & Belova, N. (2021). Escape rooms in STEM teaching and learning—Prospective field or declining trend? A literature review. *Education Sciences, 11*(6), Article 308. https://doi.org/10.3390/educsci11060308

Lawrie, G. (2023). Engaging with engagement in learning chemistry: A guiding note about a multidimensional construct. *Chemistry Education Research and Practice, 24*(3), 791-792. https://doi.org/10.1039/D3RP90006A

Lawson, H. A., & Lawson, M. A. (2020). Student engagement and disengagement as a collective action problem. *Education Sciences, 10*(8), Article 212. https://doi.org/10.3390/educsci10080212

Lei, H., Cui, Y., & Zhou, W. (2018). Relationships between student engagement and academic achievement: A meta-analysis. *Social Behavior and Personality: An International Journal, 46*(3), 517-528. https://doi.org/10.2224/sbp.7054

Levin, D. M., Hammer, D., & Coffey, J. E. (2009). Novice teachers' attention to student thinking. *Journal of Teacher Education, 60*(2), 142-152. https://doi.org/10.1177/0022487108330245

Lin, J., Li, Q., Sun, H., Huang, Z., & Zheng, G. (2021). Chinese secondary school students' reading engagement profiles: Associations with reading comprehension. *Reading and Writing, 34*(9), 2257-2287. https://doi.org/10.1007/s11145-021-10139-4

Linnenbrink-Garcia, L., & Pekrun, R. (2011). Students' emotions and academic engagement: Introduction to the special issue. *Contemporary Educational Psychology, 36*(1), 1-3. https://doi.org/10.1016/j.cedpsych.2010.11.004

Luo, J., Wu, J., & Luo, Y. (2004). "Aha!" effects in a guessing riddle task: An event-related potential study. *Human Brain Mapping, 21*(2), 121-129. https://doi.org/10.1002/hbm.20030

Mercer, N., Dawes, L., Wegerif, R., & Sams, C. (2004). Reasoning as a scientist: Ways of helping children to use language to learn science. *British Educational Research Journal, 30*(3), 359-377. https://doi.org/10.1080/01411920410001689689

Mircioiu, C., & Atkinson, J. (2017). A comparison of parametric and non-parametric methods applied to a Likert scale. *Pharmacy, 5*(2), Article 26. https://doi.org/10.3390/pharmacy5020026

Mokaya, G. K., & Kebaya, C. (2022). Integrating riddles as instructional resource in the competency-based curriculum for early years education in Kenya. *Research Journal in Advanced Humanities, 3*(1). https://doi.org/10.58256/rjah.v3i1.760

Naibert, N., Vaughan, E. B., Lamberson, K. M., & Barbera, J. (2022). Exploring student perceptions of behavioral, cognitive, and emotional engagement at the activity level in general chemistry. *Journal of Chemical Education, 99*(3), 1358-1367. https://doi.org/10.1021/acs.jchemed.1c01051

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Nayyar, P., Dougherty, B. A., & Lewis, S. E. (2024). Evaluation of the activity engagement survey (AcES) for use with clicker questions. *Journal of Chemical Education, 101*(11), 4624-4632. https://doi.org/10.1021/acs.jchemed.4c00848

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

OECD. (2019). *Education at a glance 2019: OECD indicators*. OECD Publishing. https://doi.org/10.1787/f8d7880d-en

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology, 49*(1), 345-375. https://doi.org/10.1146/annurev.psych.49.1.345

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The achievement emotions questionnaire (AEQ). *Contemporary Educational Psychology, 36*, 36-48. https://doi.org/10.1016/j.cedpsych.2010.10.002

Pett, M. (2016). *Nonparametric statistics for health care research*. SAGE. https://doi.org/10.4135/9781071878705

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227. https://doi.org/10.1002/sce.3730660207

Pratiwi, J., Rasmawan, R., Erlina, E., Enawaty, E., & Ulfah, M. (2023). Profile of critical thinking skills of chemistry education students in solving problems related to the concept of mole. *Jurnal Pendidikan Sains Indonesia, 11*(3), 559-573. https://doi.org/10.24815/jpsi.v11i3.30372

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Reeve, J., Cheon, S. H., & Jang, H. (2020). A teacher-focused intervention to enhance students' classroom engagement. In A. Reschly, & S. Christenson (Eds.), *Handbook of student engagement interventions* (pp. 87-102). Academic Press. https://doi.org/10.1016/B978-0-12-813413-9.00007-3

Schonberg, C. (2025). Spaced learning supports productive struggles in an online learning platform. *Technology, Knowledge and Learning, 30*(4), 345-361. https://doi.org/10.1007/s10758-025-09914-x

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist, 50*(1), 1-13. https://doi.org/10.1080/00461520.2014.1002924

Steidtmann, L., Kleickmann, T., & Steffensky, M. (2022). Declining interest in science in lower secondary school classes: Quasi-experimental and longitudinal evidence on the role of teaching and teaching quality. *Journal of Research in Science Teaching, 60*(1), 164-195. https://doi.org/10.1002/tea.21794

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer. https://doi.org/10.1007/978-1-4419-8126-4

Taber, K. S. (2001). Constructing chemical concepts in the classroom? *Chemistry Education Research and Practice, 2*(1), 43-51. https://doi.org/10.1039/B0RP90029J

Talanquer, V. (2006). Commonsense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education, 83*(5), 811-816. https://doi.org/10.1021/ed083p811

Treagust, D. F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(2), 297-328. https://doi.org/10.1007/s11422-008-9090-4

Vaiopoulou, J., Tsikalas, T., Stamovlasis, D., & Papageorgiou, G. (2023). Conceptual understanding in science learning and the role of four psychometric variables: A person-centered approach. *Frontiers in Psychology, 14*. https://doi.org/10.3389/fpsyg.2023.1204868

Vivek, R., & Nanthagopan, Y. (2021). Review and comparison of multi-method and mixed method application in research studies. *European Journal of Management Issues, 29*(4), 200-208. https://doi.org/10.15421/192119

Vosniadou, S. (2013). *International handbook of research on conceptual change*. Routledge. https://doi.org/10.4324/9780203154472

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wang, M., & Degol, J. (2014). Staying engaged: Knowledge and research needs in student engagement. *Child Development Perspectives, 8*(3), 137-143. https://doi.org/10.1111/cdep.12073

Wardani, D. K., Martono, T., Pratomo, L. C., Rusydi, D. S., & Kusuma, D. H. (2019). Online learning in higher education to encourage critical thinking skills in the 21st century. International *Journal of Educational Research Review, 4*(2), 146-153. https://doi.org/10.24331/ijere.517973

Zhao, M. (2022). Summer science academy in chemistry as a gateway to STEM for matriculating first-generation and other underrepresented students. *Journal of Chemical Education, 99*(2), 759-767. https://doi.org/10.1021/acs.jchemed.1c00950