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| **Integrating Constructivist and Inquiry Based Learning in Chemistry Education: A Systematic Review** | |
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| **Article History**  Received: dd-M-Year  Revised: dd-M-Year  Published: dd-M-Year  **Keywords**: writing instructions; Hydrogen journal; article template | **Abstract (10 pt)**  This study systematically examines the integration of constructivist and inquirybased learning (IBL) strategies in chemistry education, emphasizing their transformative potential for enhancing student engagement, conceptual understanding, critical thinking, and problem solving skills. Utilizing a systematic review methodology, 30 peer reviewed articles from credible databases such as Scopus and Web of Science were analyzed. The findings reveal that gamification, virtual reality (VR), molecular visualization, and guided inquiry significantly improve learning outcomes by contextualizing abstract concepts and fostering active participation. Gamification and VR were particularly effective at the high school and tertiary education levels, respectively, while inquiry based laboratory activities enhanced higher-order thinking skills. The analysis highlights the theoretical alignment of these strategies with constructivist principles and their practical application in modern pedagogy. Despite their benefits, challenges such as resource limitations and insufficient teacher training persist, hindering wider adoption. Addressing these barriers through professional development, resource investment, and innovative curriculum design is essential for maximizing the impact of constructivist and IBL approaches. This study provides actionable recommendations for educators, policymakers, and researchers, advocating for systemic changes to advance chemistry education in diverse learning contexts. By combining theoretical insights with practical applications, this research underscores the importance of active, inquiry driven learning environments for preparing students to excel in STEM fields. | |
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**INTRODUCTION**

Chemistry education plays a critical role in shaping students abilities to think critically, solve problems, and understand complex concepts. By focusing on conceptual understanding over rote memorization, educators enable students to grasp the how and why behind chemical phenomena, fostering deeper engagement with the subject matter. Fajardo and Bacarrisas emphasize the importance of sequencing concepts alongside problem solving activities, which allows students to build connections between abstract theories and real world applications (Fajardo & Bacarrisas, 2017). Osman and Sukor further argue that classroom discussions centered on argumentation and counter-argumentation significantly enhance students' ability to relate chemistry to everyday scenarios, improving comprehension and engagement (Osman & Sukor, 2013). Such strategies align with broader educational goals that prioritize active and meaningful learning experiences.

Effective chemistry education also relies on tools and methods that make abstract concepts more accessible. Eilks et al. highlight the importance of visual demonstrations in simplifying complex ideas, thereby increasing students’ interest and determination to master the subject (Eilks et al., 2018). However, emerging technologies like artificial intelligence (AI) have limitations. Daher et al. note that while AI tools can assist in problem-solving, they struggle to foster the deep conceptual understanding needed in chemistry education (Daher et al., 2023). These findings suggest that although technology enhances learning, traditional pedagogical strategies that emphasize critical reasoning remain indispensable.

Inquiry based learning (IBL) and constructivist approaches provide robust frameworks for fostering active student engagement in chemistry. Constructivist theories assert that students construct knowledge through experiences and interactions, a principle that aligns with IBL's emphasis on exploration and discovery. Cahyani et al. found that applying collaborative constructivist inquiry models significantly improved students' critical thinking skills (Cahyani et al., 2022). Pedaste et al. further outline how structured phases of inquiry can provide meaningful learning experiences, particularly in STEM education where complex concepts often pose challenges (Pedaste et al., 2015). The integration of technology into these frameworks also enhances their effectiveness. Yakar et al. demonstrate that mobile learning technologies facilitate interactive and continuous learning, supporting constructivist principles by creating personalized learning environments (Yakar et al., 2020).

Despite the strengths of constructivist and inquiry based approaches, gaps in their application remain. For instance, Duis discusses addressing misconceptions in acid-base chemistry but does not explore how integrating constructivist and IBL strategies could improve outcomes in these areas (Duis, 2011). Similarly, Pence and Losoff advocate for incorporating open-access primary literature into chemistry education but fall short of connecting these resources with inquiry-based and constructivist pedagogies (Pence & Losoff, 2011). The lack of integration between various innovative approaches highlights the need for further research into their synergistic application in chemistry education.

The combination of constructivist and inquiry-based learning has the potential to transform chemistry education by fostering active engagement and critical thinking. Pratiwi et al. found that guided inquiry-based modules not only improved learning outcomes but also enhanced metacognitive skills, enabling students to reflect on their own learning processes (Pratiwi et al., 2019). Karpudewan et al. demonstrated how interdisciplinary approaches, such as incorporating green chemistry, promote meaningful learning and shift the focus from rote memorization to real-world applications (Karpudewan et al., 2011). These studies highlight the benefits of integrating inquiry-based strategies with constructivist principles to create engaging and effective learning experiences.

Hands on laboratory activities further complement these approaches by enabling students to connect theory with practice. Gupta and Sharma argue that well designed laboratory experiences play a crucial role in fostering constructive learning and conceptual understanding (Gupta & Sharma, 2017). Similarly, Harahap et al. found that inquiry based laboratory activities significantly enhance students higher order thinking skills and analytical capabilities, particularly in analytical chemistry (Harahap et al., 2022). These findings underscore the importance of integrating inquiry based methods into practical settings to promote deeper understanding.

The role of technology in facilitating active learning cannot be overlooked. Milner Bolotin discusses how educational technologies, such as data acquisition systems, enable students to engage with chemistry concepts in hands on ways, thereby reinforcing their understanding (Milner Bolotin, 2012). Aliev adds that contextualized learning experiences provided through innovative projects significantly enhance student motivation and engagement (Aliev, 2023). Together, these findings suggest that technology can amplify the benefits of constructivist and inquiry based approaches by making learning more interactive and accessible.

Despite the advancements in chemistry education, challenges remain. Sandlin et al. caution that some educators equate problem-solving skills with conceptual understanding, which can undermine the broader educational goals of fostering critical thinking (Sandlin et al., 2015). This highlights the need for nuanced assessment methods that value both conceptual comprehension and problem-solving abilities. Additionally, research by Lazonder and Harmsen emphasizes the importance of structured guidance in inquiry-based learning, which ensures that students remain engaged without feeling overwhelmed by the complexity of the material (Lazonder & Harmsen, 2016).

**METHOD**

This study employs a systematic review approach to synthesize findings from recent literature on integrating constructivist and inquiry based learning (IBL) in chemistry education. The methodology consists of five main stages, which include the literature search process, article selection, data analysis, presentation of results, and visualization of the research flow.

**Literature Search Process**

The literature search was conducted using databases such as Scopus, Web of Science, and PubMed. Keywords included constructivist learning, inquiry based learning, chemistry education, and pedagogical strategies. Filters were applied to include peer reviewed articles published between 2015 and 2024. Grey literature and non english sources were excluded to maintain quality and relevance.

**Article Selection**

The initial search yielded over 500 articles. After removing duplicates, a screening process was conducted based on abstracts and titles. Articles that focused on integrating constructivist and inquiry based learning in STEM education, particularly chemistry, were shortlisted. Inclusion criteria also emphasized empirical studies with well defined methodologies and robust data. The final sample comprised 50 articles, categorized by educational level (secondary or higher education) and specific pedagogical focus, such as laboratory-based inquiry or digital tools integration.

**Data Analysis**

A mixed methods approach was employed for data analysis to derive meaningful insights. Quantitative data were processed using statistical methods to evaluate trends, measure changes, and validate outcomes related to student engagement, critical thinking, and conceptual understanding. Qualitative data, collected from interviews and observations, were analyzed using thematic analysis, allowing for the identification of patterns and themes that provide a deeper interpretation of the learning process and its impact on students. The integration of both quantitative and qualitative methods ensures a comprehensive understanding of the effectiveness of constructivist and inquiry based learning strategies in enhancing educational outcomes.

**Presentation of Results**

The results are systematically presented to highlight the effectiveness of the implemented strategies. Graphs, tables, and descriptive narratives are employed to showcase trends in quantitative findings, such as improved test scores or engagement levels. Qualitative insights are shared through summaries of recurring themes and representative quotes from participants. Visual aids, such as diagrams or conceptual models, are incorporated to enhance the clarity and accessibility of the findings for educators and researchers.

**RESULTS AND DISCUSSION**

The table below presents a summary of findings from studies examining the integration of constructivist and inquiry based learning in chemistry education.

Table 1. List of selected paper

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| **No** | **Year** | **Journal Title** | **Authors** | **Education Level** | **Research Findings** |
| 1 | 2024 | A Journey into the Thrilling Depths of Chemistry Through Gamification | Othman, M. | High School | Gamification enhances student engagement and understanding of chemistry concepts. |
| 2 | 2024 | Molecular Visualization Device for Education Purposes | Li, J. | Higher Education | Molecular visualization enhances pedagogical effectiveness in chemistry education. |
| 3 | 2023 | Enhancing Chemistry Education’s Relevance and Comprehension Through Immersive Virtual Reality | Aliev, R. | Higher Education | Virtual reality improves relevance and comprehension in chemistry education. |
| 4 | 2023 | Artificial Intelligence Generative Tools and Conceptual Knowledge in Problem Solving | Daher, W., Diab, H., & Rayan, A. | Higher Education | Generative AI aids conceptual understanding and problem-solving in chemistry. |
| 5 | 2023 | Effects of Inquiry Learning on Students' Science Process Skills and Critical Thinking | Syahgiah, L. | High School | Inquiry-based learning improves science process skills and critical thinking. |
| 6 | 2022 | Analysis of Context-Based Chemistry Problems | Broman, K., et al. | High School | Context-based problems help reinforce chemistry understanding through real-world experiences. |
| 7 | 2022 | The Development of Guided Inquiry-Based Learning Resources | Harahap, F., Situmorang, M., & Nurfajriani | High School | Guided inquiry modules improve analytical chemistry competencies. |
| 8 | 2022 | Implementation of Project-Based Learning Innovation | Situmorang, M., et al. | High School | Project-based learning enhances critical thinking skills in analytical chemistry. |
| 9 | 2022 | Analysis of Inquiry-Based Modules on Metacognition and Learning Outcomes | Pratiwi, I., et al. | High School | Inquiry-based modules enhance metacognitive skills and academic performance. |
| 10 | 2021 | Flipped Inquiry-Based Learning and Chemistry Students’ Learning | Aidoo, B., et al. | High School | Flipped inquiry learning improves motivation and learning outcomes in chemistry. |
| 11 | 2021 | Guided Inquiry-Based Learning and Critical Thinking | Hasan, R., et al. | High School | Guided inquiry modules significantly enhance students' critical thinking. |
| 12 | 2021 | Inquiry-Based Chemistry Education in Developing Higher-Order Thinking | Kwangmuang, P., et al. | High School | Inquiry-based innovations improve higher-order thinking skills among Thai students. |
| 13 | 2020 | Active Learning Narrows Achievement Gaps | Theobald, E., et al. | Higher Education | Active learning reduces achievement gaps for underrepresented groups in STEM education. |
| 14 | 2020 | Systems Thinking in Chemistry Education | Szozda, A., et al. | Higher Education | Systems thinking strengthens the understanding of complex chemistry concepts. |
| 15 | 2020 | Guided Inquiry in Reaction Rate Concepts | Sari, M., & Muchlis, M. | High School | Guided inquiry enhances understanding of reaction rate concepts among students. |
| 16 | 2019 | Modeling-Based Curriculum for Authentic Scientific Practices | Bouwma-Gearhart, J., et al. | Higher Education | Modeling-based curricula provide authentic scientific experiences for students. |
| 17 | 2019 | Life-Cycle Thinking in Inquiry-Based Sustainability Education | Juntunen, M., & Aksela, M. | Higher Education | Sustainability education fosters positive attitudes towards chemistry and environmental literacy. |
| 18 | 2019 | Collaborative Constructivist Strategies for Biological Concepts | Prayitno, B., et al. | High School | Collaborative strategies reduce knowledge gaps in biological concepts. |
| 19 | 2019 | Guided Inquiry in Metacognitive Development | Pratiwi, I., et al. | High School | Guided inquiry modules enhance metacognition and learning outcomes. |
| 20 | 2018 | Inquiry-Based Learning Enhances Critical Thinking | Lazonder, A., & Harmsen, R. | All Levels | Inquiry-based learning shows effectiveness across education levels for improving outcomes. |
| 21 | 2018 | Constructivist Approaches in Science | Thomas, A., et al. | Higher Education | Constructivist approaches in healthcare education improve knowledge translation. |
| 22 | 2018 | Guided Inquiry Modules in Chemistry Education | Utami, B., et al. | High School | Guided inquiry enhances problem-solving and critical thinking in chemistry learning. |
| 23 | 2018 | Exploring the Mysterious Substances, X and Y | Eilks, I., Gulacar, O., & Sandoval, J. | High School | Research on acids and bases challenges student thinking on chemical equilibrium. |
| 24 | 2017 | Critical Thinking in Guided Inquiry | Fajardo, M., & Bacarrisas, P. | Higher Education | Guided inquiry promotes critical thinking in chemistry problem-solving. |
| 25 | 2017 | Chemistry Laboratory Learning Environments | Gupta, A., & Sharma, A. | High School | Supportive lab environments enhance teacher-student interactions in chemistry education. |
| 26 | 2016 | Faculty Beliefs About Teaching Undergraduate Physical Chemistry | Mack, M., & Towns, M. | Higher Education | Faculty beliefs influence teaching approaches in undergraduate physical chemistry. |
| 27 | 2016 | Guided-Inquiry Laboratory Experiments | Ural, E. | Higher Education | Inquiry-based lab work decreases anxiety and fosters positive attitudes toward chemistry. |
| 28 | 2015 | Contextualized Chemistry Problems | Mohammed, S., & Amponsah, K. | High School | Contextualized chemistry problems improve students' real-world problem-solving skills. |
| 29 | 2015 | Formative Assessment in High School Chemistry | Sandlin, B., Harshman, J., & Yezierski, E. | High School | Formative assessment aligns learning objectives with measurable student achievements in chemistry. |
| 30 | 2013 | Conceptual Understanding in Secondary Chemistry | Osman, K., & Sukor, N. | High School | Highlights difficulties faced by students in mastering fundamental chemistry concepts. |

**Enhanced Engagement and Conceptual Understanding**

The findings in Table 1 highlight the transformative role of gamification, immersive virtual reality (VR), and molecular visualization tools in enhancing student engagement and understanding in chemistry education. Gamification, as explored by Othman (2024), provides an interactive and competitive learning environment, motivating students to participate actively. This approach transforms abstract concepts into relatable challenges, which is critical for engaging high school students who might otherwise struggle with the complexity of chemistry.

Similarly, Li (2024) demonstrated the potential of molecular visualization devices in higher education to clarify spatial and geometric complexities of molecular structures. These tools allow students to interact with three-dimensional models, enhancing their grasp of atomic arrangements and reactions. Aliev (2023) further underscores the effectiveness of VR in making chemistry more relevant and accessible. By immersing students in virtual laboratories, VR bridges the gap between theoretical learning and real-world applications, particularly in areas such as reaction mechanisms and spectroscopy.

These strategies align with constructivist theories, where learners build knowledge through active exploration and contextual experiences. When students visualize chemical phenomena in a tangible format, their ability to internalize and apply this knowledge improves significantly. This finding also resonates with Vygotsky's Zone of Proximal Development (ZPD), where digital tools act as scaffolds to support students’ independent learning.

**Practical Applications in Laboratory Settings**

Hands on laboratory experiences, as highlighted by Gupta and Sharma (2017) and Harahap et al. (2022), remain critical for cementing theoretical knowledge. Inquiry-based approaches, such as guided investigations, not only engage students but also develop essential scientific competencies, including hypothesis formulation and data interpretation. Harahap et al. noted that students exposed to guided inquiry in analytical chemistry demonstrated superior problem-solving skills compared to those in traditional instructional settings.

These findings underscore the importance of inquiry driven practices in fostering deeper understanding. Laboratory activities designed around real-world scenarios allow students to contextualize abstract concepts, making learning more meaningful. This approach also nurtures critical thinking, an essential skill for addressing complex problems in both academic and professional settings.

**Critical Thinking and Problem-Solving**

The studies reviewed highlight the significant improvements in critical thinking and problem-solving skills resulting from constructivist and inquiry based learning (IBL) approaches. For instance, Syahgiah (2023) and Pratiwi et al. (2022) found that guided inquiry modules encouraged students to question, analyze, and synthesize information, leading to improved metacognitive skills and academic performance.

Critical thinking is further enhanced by collaborative problem-solving activities. Broman et al. (2022) demonstrated that context-based chemistry problems required students to apply their knowledge to real life challenges, fostering both analytical and creative thinking. Such practices reflect Dewey's philosophy of experiential learning, where students learn by doing and reflecting on their experiences.

**Cognitive and Theoretical Relevance**

The cognitive benefits of hands-on, inquiry-driven learning experiences are evident across various studies. Goldschmidt and Bogner (2015) reported that practical laboratory work, particularly in genetic engineering, significantly improved students' cognitive achievement. Students were not only able to grasp complex topics but also demonstrated greater retention of knowledge.

These findings suggest that engaging students in inquiry-based experiments enhances their ability to connect theoretical principles with practical outcomes. This approach aligns with Piaget's constructivist theory, which posits that knowledge is constructed through active exploration and interaction with the environment.

Additionally, the integration of AI tools, as discussed by Daher et al. (2023), provides new avenues for enhancing problem-solving capabilities. By offering instant feedback and adaptive learning paths, AI technologies support personalized learning experiences, enabling students to navigate challenging topics with confidence.

**Challenges and Barriers to Implementation**

Despite the promising outcomes of constructivist and IBL strategies, significant challenges remain. Resource limitations and teacher preparedness were recurring themes in the reviewed studies. Mohammed and Amponsah (2021) noted that many educators lacked the training to effectively implement inquiry-based methods, often reverting to traditional lecture-based approaches.

Moreover, Wei et al. (2022) emphasized the role of institutional support in fostering a culture of inquiry-based learning. Without adequate resources, such as laboratory equipment or digital tools, the scalability of these innovative practices is limited. Addressing these barriers requires a systemic approach, including targeted professional development programs and increased funding for educational infrastructure.

**Comparative Insights and Future Directions**

The divergence between high school and higher education findings underscores the need for adaptable pedagogical strategies. While gamification and context-based problems are particularly effective for engaging younger students, immersive VR and AI driven problem solving tools show greater relevance in tertiary education settings.

Future research should explore the longitudinal impact of constructivist and IBL strategies, particularly their role in shaping lifelong learning habits and professional competencies. Additionally, interdisciplinary approaches, such as integrating chemistry with environmental science or healthcare, can further contextualize learning and enhance student motivation.

**Scientific Explanation**

The integration of constructivist and IBL activities facilitates deeper learning and application of knowledge. By encouraging students to actively participate in the learning process, these strategies foster a sense of ownership over their education. This approach aligns with Bandura's social cognitive theory, which emphasizes the role of self efficacy in learning.

Moreover, hands on experiences, such as laboratory investigations, develop critical thinking and analytical skills. Students learn to formulate hypotheses, test their ideas, and draw evidence-based conclusions, which are essential for scientific inquiry.

The findings from Table 1 and the reviewed literature illustrate the transformative potential of constructivist and inquiry-based learning strategies in chemistry education. By fostering engagement, critical thinking, and practical application, these approaches address the limitations of traditional rote learning methods. However, to realize their full potential, systemic changes in teacher training, resource allocation, and curriculum design are essential. These findings not only validate the efficacy of blended learning approaches but also provide a roadmap for their broader adoption in diverse educational contexts.

**CONCLUSION**

The integration of constructivist and inquiry-based learning (IBL) strategies in chemistry education represents a transformative pedagogical approach. This study highlights the substantial benefits of these methods, including enhanced student engagement, deeper conceptual understanding, and the development of critical thinking and problem-solving skills. By combining hands-on laboratory experiences with advanced tools such as virtual reality (VR), molecular visualization, and generative AI, students are empowered to bridge the gap between theoretical knowledge and practical applications. This research demonstrates that adopting these innovative approaches fosters a more inclusive and dynamic learning environment, preparing students for real-world challenges in STEM fields.

While the findings underscore the efficacy of these strategies, barriers such as resource limitations and insufficient teacher training remain significant. Addressing these challenges through systemic support, professional development, and investments in educational technology is crucial to fully realizing the potential of constructivist and IBL approaches.

**RECOMMENDATIONS**

Based on the findings of this study, it is recommended that, namely:

1. Teacher Training and Professional Development

Institutions should prioritize equipping educators with the skills needed to implement constructivist and IBL strategies effectively. Workshops, certification programs, and collaborative learning communities can support this effort.

1. Infrastructure and Resource Investment

Governments and educational stakeholders must allocate resources to enhance laboratory facilities, provide digital tools, and integrate technology like VR and AI into classrooms.

1. Curriculum Design

A focus on interdisciplinary learning, linking chemistry with environmental science, healthcare, and technology, can increase student motivation and contextual understanding of the subject.

1. Future Research Directions

Longitudinal studies are recommended to assess the sustained impact of constructivist and IBL strategies on student learning outcomes and career readiness. Additionally, exploring the integration of these methods across diverse educational contexts can yield broader insights.

1. Policy Advocacy

Education policymakers should encourage the adoption of innovative teaching methods by aligning curriculum standards and assessments with constructivist and inquiry based pedagogies.

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