



A Review of Ethno-STEM Learning Modules in Chemical Kinetics: Bridging Cultural Relevance and Conceptual Understanding of Reaction Rates

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Abstract

This review explored how ethno-STEM learning modules help students understand reaction rates in chemical kinetics. These modules combine science with culture to make lessons more engaging and easier to relate to. We looked at how the modules were designed and used, how they supported learning, and how they mixed cultural content with science. We also compared different strategies like inquiry learning and technology use and identified common teaching problems. We focused on studies from secondary schools, vocational programs, and universities published up to mid-2024. These studies used different methods, such as interviews, surveys, and classroom experiments. We found that culture-based modules made chemistry more relevant and kept students motivated. Inquiry learning and technology also helped students understand reaction rates better. However, many of these strategies still need better ways to measure success and reach more students. Some students struggled with graphs and formulas, but active learning and visual tools helped improve their understanding. Teachers and students liked the modules because they connected chemistry to real life and local knowledge. Still, how engagement is measured varies between studies. In general, this review shows that ethno-STEM has strong potential to improve chemistry lessons by linking science and culture. But future research should be more consistent and explore how to use these methods in different types of classrooms.

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1. INTRODUCTION

Research on ethno-STEM based learning modules for chemical kinetics focusing on reaction rates has emerged as a critical area of inquiry due to the persistent challenges in chemistry education related to abstract concepts and student engagement (Khatimah & Chisbiyah, 2024; Murni et al., 2022). Over recent years, educational strategies have evolved from traditional rote learning to more culturally relevant and interactive approaches, integrating local wisdom and technology to enhance conceptual understanding (Salsabila & Rohaeti,

2024; Arroba et al., 2023). The practical significance of this research lies in addressing the widespread difficulty students face in grasping reaction kinetics, a foundational topic with applications in environmental science, industry, and pharmaceuticals (Habiddin & Page, 2023; Hayes, 2024). Studies indicate that students often hold misconceptions about reaction rates and factors affecting them, which impedes their progress in advanced chemistry topics (Habiddin & Page, 2023; Yan & Subramaniam, 2016).

The specific problem addressed is the gap between students' everyday experiences and the abstract nature of chemical kinetics, particularly reaction rates, which results in low conceptual understanding and engagement (Khatimah & Chisbiyah, 2024; Karous et al., 2017). Despite various pedagogical innovations, there remains a lack of comprehensive learning modules that effectively integrate ethnochemical knowledge with STEM principles to contextualize reaction kinetics (Salsabila & Rohaeti, 2024; Arroba et al., 2023; Murni et al., 2022). Controversies exist regarding the best instructional strategies, with some advocating for inquiry-based and culturally grounded modules, while others emphasize technology-enhanced simulations or problem-based learning (Jere & Mpeti, 2024; Cáceres-Jensen et al., 2021; Murni et al., 2022). The consequences of this gap include persistent alternative conceptions and reduced motivation among learners, which can limit their academic achievement and interest in chemistry (Habiddin & Page, 2023; Yan & Subramaniam, 2018).

The conceptual framework for this review is constructed around three key concepts: ethno-STEM integration, chemical kinetics focusing on reaction rates, and pedagogical strategies such as structured inquiry and multiple chemical representations (Khatimah & Chisbiyah, 2024; Murni et al., 2022; Schmitz & Lente, 2020). Ethno-STEM learning modules leverage cultural relevance to enhance engagement, while chemical kinetics provides the scientific content focus. Pedagogical strategies mediate the relationship between cultural context and conceptual understanding, grounded in constructivist and inquiry-based learning theories (Karous et al., 2017; Schmitz & Lente, 2020).

The integration of cultural knowledge through ethno-STEM is particularly relevant in teaching chemical kinetics, especially in explaining reaction rates, as it connects scientific principles with everyday life and local traditions. For example, in Indonesia, the process of making palm sugar involves heating and crystallizing sap, which can be explained through the kinetics of chemical reactions. Similarly, in India, the fermentation process in making chai tea involves oxidation, which provides an opportunity to discuss how factors like temperature and time influence reaction rates. In South Africa, the brewing of umqomboti beer highlights the impact of yeast concentration and temperature on fermentation, directly linking cultural practices to the study of chemical kinetics.

These examples demonstrate how incorporating local cultural practices in chemistry education can enhance conceptual understanding and engagement by making abstract scientific concepts more tangible and relatable for students (Duit, 2009; Matthews, 2015).

The purpose of this systematic review is to synthesize current research on ethno-STEM based learning modules targeting reaction rates in chemical kinetics, to identify effective pedagogical approaches and gaps in existing literature (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024). This review adds value by aligning cultural knowledge with STEM education to improve conceptual understanding and student motivation, addressing a critical gap in chemistry education research (Arroba et al., 2023; Murni et al., 2022). The review aims to inform curriculum development and instructional design for chemistry educators.

This review employs a comprehensive literature study methodology, selecting peer-reviewed articles that focus on ethno-STEM integration, chemical kinetics education, and reaction rate learning modules (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024). Analytical frameworks include thematic synthesis of pedagogical effectiveness and cultural relevance. The findings are organized to highlight module design, instructional strategies, and learning outcomes, providing a roadmap for future research and practice (Murni et al., 2022; Habiddin & Page, 2023).

This review looks at how ethno-STEM learning modules help students understand reaction rates in chemistry. These modules mix science with cultural elements to make learning more meaningful and relatable. Reaction rates can be hard to learn because they involve abstract ideas. By connecting the lessons to students' culture, teachers can help them stay engaged and understand the material better.

We explored how these learning modules are designed, how teachers use them in class, and how they affect students' learning. We also looked at what teaching methods work best, what still needs improvement, and how this approach can help shape better chemistry lessons in the future. The goal is to support both how students think and how they feel about learning chemistry. More specifically, this review:

- Describes how teachers create and use ethno-STEM modules in chemistry lessons;

- Compares teaching methods that combine science with cultural knowledge;
- Summarizes what studies say about student understanding and engagement;
- Looks at how well inquiry-based learning, digital tools, and cultural context work together;
- Identifies challenges and opportunities in connecting chemistry lessons with students' backgrounds.

2. METHODS

This study used a systematic literature review to evaluate ethno-STEM learning modules related to chemical kinetics, especially reaction rates. The article selection process followed clear and structured steps: identification, screening, eligibility assessment, and inclusion.

Steps taken include:

1. Transforming the Research Question: The main research question "Ethno-STEM based learning module for Chemical Kinetics focusing on reaction rates" was expanded into several specific queries. This ensured that various perspectives and teaching strategies could be explored.
2. Identification and Screening: A total of 726 articles were found in databases. After removing

45 duplicates, 681 titles and abstracts were screened based on relevance. Articles focusing on chemical kinetics, ethno-STEM integration, and cultural relevance in chemistry education were included. Studies that discussed teaching methods, student engagement, and conceptual understanding in relation to reaction rates were prioritized. Articles unrelated to the specific teaching of chemical kinetics or those that lacked empirical data were excluded.

3. Eligibility and Inclusion: Then, 148 full-text articles were reviewed for alignment with the inclusion criteria. From these, 50 studies were selected as key sources because they were highly relevant and methodologically sound. Studies were selected based on the following criteria: (a) peer-reviewed publications from the last 10 years, (b) discussion of ethno-STEM methods in chemistry education, (c) focus on reaction rates or related chemical concepts, and (d) empirical data supporting the effectiveness of the pedagogical strategies.

The flow of this selection process is shown in the diagram below (Figure 1).

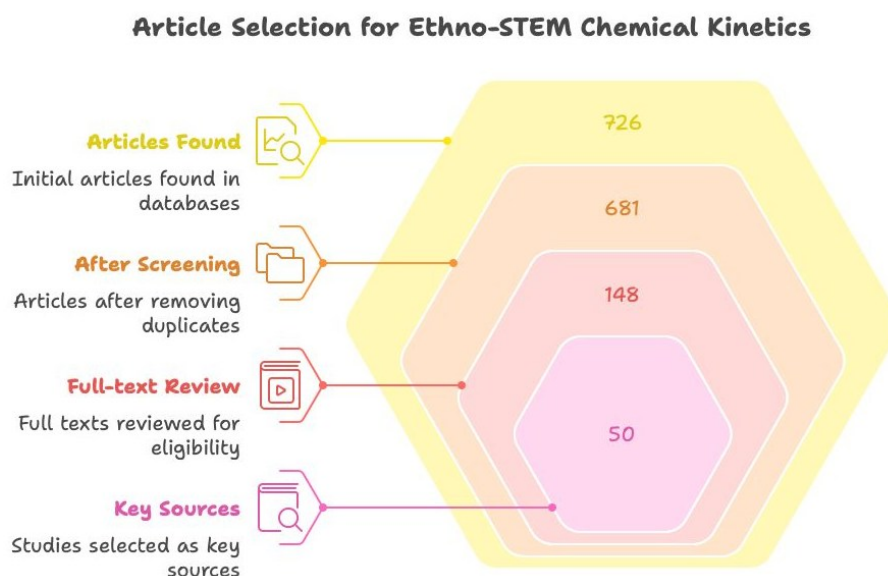


Figure 1. Flow diagram showing the article selection steps in this literature review.

3. RESULT AND DISCUSSION

3.1. Descriptive Summary of the Studies

This section maps the research landscape of the literature on Ethno-STEM based learning module for Chemical Kinetics focusing on reaction rates, encompassing a diverse range of pedagogical designs, cultural integrations, and technological applications (Table 1). The studies predominantly focus on secondary and vocational education contexts, with some extending to undergraduate levels, and employ mixed methods including qualitative, quantitative, and quasi-experimental designs. The comparative analysis is relevant to the research questions as it highlights how ethno-STEM approaches influence conceptual understanding, engagement, and instructional practices in chemical kinetics education, particularly reaction rates.

This review found many studies on ethno-STEM learning modules in chemical kinetics, especially reaction rates. Most studies focused on high school and vocational students, with some at the college level. The researchers used different methods like interviews, surveys, and experiments. Many studies showed that using culture-based teaching helps students understand better. For example, combining science with local traditions or using worksheets that include local knowledge made students more motivated and helped them learn concepts more clearly.

Technology also played a big role. Some studies used computer simulations, hands-on kits, and simple experiments. For instance, small experiments using AR (augmented reality) or syringe kits made lessons more fun and easier to understand. Simulations that follow the

Predict-Observe-Explain method helped students make better sense of how reactions happen. When teachers used examples from everyday life or cultural stories, students were more engaged. These real-life examples helped students connect what they learn in class to what they see around them.

The effectiveness of ethno-STEM learning modules in teaching chemical kinetics, particularly reaction rates, varies across different educational contexts. In secondary schools, the integration of local cultural knowledge has shown to significantly increase student engagement and understanding by making abstract scientific concepts more tangible. Studies indicate that students tend to relate more effectively to learning modules that incorporate familiar cultural practices, such as traditional fermentation or cooking processes, thereby improving conceptual understanding. In contrast, in vocational education, where practical application and technical skills are paramount, ethno-STEM modules that emphasize real-world industrial practices (e.g., fermentation in brewing or palm sugar production) have proven to be more effective. These modules align well with the applied nature of vocational training, helping students see the direct relevance of chemical kinetics in their future careers. However, in both contexts, the success of these modules hinges on tailoring the content to the specific needs of the students, with secondary school students benefiting from more foundational, culturally embedded approaches, and vocational students requiring more industry-focused, skill-based learning.

1 Table 1. Descriptive Summary of Reviewed Studies on Ethno-STEM Modules in Chemical Kinetics

Study	Pedagogical Design Features	Student Conceptual Understanding	Engagement and Motivation Levels	Technology Integration	Educator and Learner Perceptions
(Akhter & Alam, 2023)	Overview of chemical kinetics concepts	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Almanza-Arjona et al., 2022)	Analogy-based learning with COVID-19 model	Fostered mathematical and computational skills	Engaged students through relevant pandemic analogy	Use of online software for modeling	Promoted deeper understanding via real-world context
(Amelia et al., 2020)	Argument-Driven Inquiry with scaffolding	Scaffolding improved scientific argumentation skills	Not explicitly measured	Inquiry-based learning with scaffolding	Scaffolding seen as beneficial for argumentation development

Study	Pedagogical Design Features	Student Conceptual Understanding	Engagement and Motivation Levels	Technology Integration	Educator and Learner Perceptions
(Arroba et al., 2023)	Practical guide combining ethnographic and scientific approaches	Improved understanding and appreciation of cultural traditions	Motivated students by linking science to culture	Plans for digitization to enhance interactivity	Teachers and students reported positive reception and relevance
(Belayneh & Belachew, 2023)	TSPCK-based instruction with conceptual teaching strategies	Enhanced academic achievement, especially for female students	Not explicitly measured	Conventional and technology-assisted methods compared	Positive perceptions of TSPCK effectiveness across genders
(Cáceres-Jensen et al., 2021)	Problem-based learning with technology-enhanced spreadsheets	Contextualized chemistry knowledge and skill development	Positive perceptions of real-world problem solving	Use of spreadsheets and digital resources	Preservice teachers valued pedagogical and technological integration
(Carragher et al., 2016)	Portable spectrophotometry for kinetics experiments	Solidified understanding of rate laws and mechanisms	Not explicitly measured	Use of inexpensive UV-visible spectrophotometers	Accessible for high school settings
(Chairam et al., 2009)	Inquiry-based active learning in Thailand	Developed qualitative and quantitative understanding	Active learning was enjoyable and effective	Not technology-focused	Shifted students from passive to active learning
(Chairam et al., 2015)	Inquiry-based learning activities for secondary students	Significant increase in understanding and reduction of misconceptions	Active, student-centered learning increased interest	Not technology-focused	Suggested cooperative learning to reduce misconceptions
(Chung & Green, 2023)	Machine learning for solvent effects on rates	Accurate prediction of solvent effects on reaction rates	Not applicable	Advanced machine learning models	Model offers rapid predictions for kinetic solvent effects
(Dejene & Belachew, 2023)	Topic-specific pedagogical content knowledge (TSPCK) instruction	Significant improvement in conceptual understanding	Not explicitly measured	Technology-assisted teaching strategies recommended	Emphasized importance of technology and pedagogy alignment
(Eghlimi et al., 2019)	Chemiluminescence demonstration with Arduino sensors	Provided cost-effective, engaging kinetics study	Increased student interest through demonstrations	Arduino-based data logging and sensors	Demonstration praised for safety and pedagogical value
(Elliott & Page, 2017)	Overview of reaction rate concepts and methods	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Festersen et al., 2018)	Digital capillary flow experiment for first order kinetics	Provided intuitive grasp of first order processes	Used real-time data projection for engagement	Electronic scale interfaced with computer	Demonstration enhanced conceptual understanding
(Gegios et al., 2017)	Greek textbook analysis and student difficulties	Identified low comprehension	Not explicitly measured	Not technology-focused	Textbook structure contributed to

Study	Pedagogical Design Features	Student Conceptual Understanding	Engagement and Motivation Levels	Technology Integration	Educator and Learner Perceptions
(Habibi et al., 2024)	Laboratory experiment on Traffic Light reaction kinetics	Enabled qualitative and quantitative kinetics analysis	Accessible to high school and university students	Use of spectrometer for absorbance measurement	student difficulties Experiment considered accessible and effective
(Habiddin & Page, 2023)	Four-tier diagnostic instrument for misconceptions	Identified numerous genuine misconceptions	Not explicitly measured	Diagnostic testing tools	Recommendations for improved teaching effectiveness
(Hayes, 2024)	Fundamental rate phenomena in metallurgy	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Heck, 2012)	Graphical system dynamics modeling software	Supported knowledge development and misconception remediation	Not explicitly measured	Computer-supported modeling software	Proposed extension to classical graphical modeling
(Jabeen & Siddiq, 2023)	Spectrophotometric kinetic study of ester hydrolysis	Determined rate constants and activation energy	Not explicitly measured	Spectrophotometric method at different temperatures	Provided sensitive and simple kinetic analysis
(Jere & Mpeta, 2024)	Computer simulations with Predict-Observe-Explain strategy	Majority achieved sound conceptual understanding	Simulations supported active learning and problem-solving	Use of computer simulations and interactive strategies	Educators encouraged to adopt simulations for better understanding
(Karus et al., 2017)	Constructivist teaching sequence with visualization tools	Developed corpuscular models and conceptual understanding	Active learning strategies employed	Use of interactive websites	Addressed misconceptions and improved understanding
(Karpudewan & Mathanasegaran, 2018)	Context-based green chemistry experiments	Better and more specific understanding of reaction effects	Positive qualitative feedback on relevance	Use of benign green chemistry experiments	Students appreciated relevance and safety of experiments
(Keeler & Wothers, 2003)	Discussion of factors influencing reaction rates	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Kerstiensa et al., 2017)	Tangible and visual representations of matter	Helped students visualize reaction progress and limiting reagents	Not explicitly measured	Use of physical shapes and pictorial tools	Visual tools enhanced conceptual clarity
(Khatimah & Chisbiyah, 2024)	Ethnochemical-STEM hybrid modules with active learning	Enhanced understanding via culturally relevant content	Increased engagement through interactive design	Limited digital tools, focus on active learning	Positive feedback on cultural relevance and practicality
(Koç et al., 2010)	Cooperative learning strategies (group investigation, jigsaw)	Improved academic achievement in kinetics	Enhanced achievement compared to traditional methods	Not technology-focused	Cooperative methods favored over traditional teaching

Study	Pedagogical Design Features	Student Conceptual Understanding	Engagement and Motivation Levels	Technology Integration	Educator and Learner Perceptions
(Marzabal et al., 2018)	Experiment selection criteria for intuitive conceptions	Proposed criteria to address learning difficulties	Not explicitly measured	Not technology-focused	Suggested teaching strategies for conceptual evolution
(Murni et al., 2022)	Structured inquiry-based module with chemical representations	Not detailed in abstract	Not detailed	Not detailed	Not detailed
(Nascimento et al., 2018)	Stochastic model for kinetics and thermodynamics	Simulated kinetic profiles and catalytic effects	Not applicable	Computational Monte Carlo methods	Model aligned with theoretical physical chemistry
(Nursafitri et al., n.d.)	5E learning cycle with analogy	Significant differences in conceptual understanding	Not explicitly measured	Not technology-focused	Learning cycle with analogy improved understanding
(Oriakhi, n.d.)	Explanation of kinetics and reaction rates	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Rushton et al., 2014)	Model-based reasoning for rate laws	Facilitated understanding of rate laws and mechanisms	Not explicitly measured	Graphical and mathematical analysis tools	Emphasized model-based pedagogy for kinetics
(Salsabila & Rohaeti, 2024)	Inquiry-based E-worksheet integrating local wisdom	High validity and practical use improved understanding	Students actively participated and appreciated indigenous knowledge	E-worksheet with Flip PDF software	Teachers and students rated module highly practical and readable
(Schmitz & Lente, 2020)	Clear presentation of fundamental kinetics concepts	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Seethaler et al., 2018)	Textbook analysis of rates of change concepts	Identified variability and missing conceptual links	Not applicable	Not applicable	Revealed gaps in textbook treatment of kinetics concepts
(Setu et al., 2022)	Pair-test assessment in active learning	Improved performance in paired assessments	Increased motivation and pleasant experiences	Not technology-focused	Mixed perceptions due to partner disagreements and time constraints
(Situmorang, 2014)	Innovative module integrating lab, field, and interactive media	Improved student achievement and independent learning	Motivated students towards self-directed learning	Interactive electronic learning media	Module considered effective and motivating by students
(Supasorn & Promarak, 2015)	5E inquiry with analogy learning approach	Medium normalized gain in conceptual understanding	Effective in enhancing and retaining understanding	Not technology-focused	Demonstrated effectiveness of inquiry and analogy combined

Study	Pedagogical Design Features	Student Conceptual Understanding	Engagement and Motivation Levels	Technology Integration	Educator and Learner Perceptions
(Supasorn et al., 2021)	Portable syringe-gal kit for gas-generating reactions	Facilitated easy investigation of reaction rates	Not explicitly measured	Low-cost, portable experimental kit	Practical and accessible for classroom use
(Supasorn et al., 2022)	5E inquiry approach with small-scale experiments and AR visualization	Medium gain in conceptual understanding	Students found activities entertaining and effective	Augmented reality and hands-on experiments	Positive student feedback on learning experience
(Syamsiana et al., 2018)	POE (Predict-Observe-Explain) strategy	Effective in improving learning outcomes on reaction factors	Student-centered activities promoted engagement	Not technology-focused	Strategy effective for knowledge improvement
(Upadhyay, n.d.)	Comprehensive kinetics and reaction dynamics text	Not applicable (conceptual review)	Not applicable	Not applicable	Not applicable
(Yan & Subramaniam, 2016)	Diagnostic appraisal of grade 12 understanding	Documented 23 alternative conceptions	Not explicitly measured	Diagnostic instrument with 3-tier format	Highlighted differences in misconceptions by achievement level
(Yan & Subramaniam, 2018)	Multi-tier diagnostic test on reaction kinetics	Uncovered 25 alternative conceptions, mostly graph-related	Not explicitly measured	Diagnostic instrument with 4-tier format	Demonstrated utility of multi-tier diagnostics for misconceptions
(Zewail-Foote et al., 2019)	KinTek Explorer kinetic modeling software	Facilitated intuitive understanding of multistep kinetics	Not explicitly measured	Use of kinetic modeling software	Software aided comprehension of complex kinetics
(Zhu et al., 2005)	Kinetics of aqueous phase reactions	Experimental kinetics data for atmospheric chemistry	Not applicable	Laser flash photolysis and UV-visible absorption	Provided precise rate coefficients for reactions

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However, many students still had trouble with graphs or understanding how reaction rates work. Some tools, like four-level quizzes and using models, helped fix these problems by showing what students misunderstood and helping teachers guide them. Most teachers and students liked these modules. They found them useful, practical, and interesting. Still, there were some issues, like limited access to technology and challenges when students had to work in pairs or groups. Overall, the review shows that combining culture, good teaching strategies, and technology can make chemistry lessons better. It helps students understand more and stay interested in learning. Overall, the review shows that combining culture, good teaching strategies, and

technology can make chemistry lessons better. It helps students understand more and stay interested in learning.

Pedagogical Design Features:

- Over 20 studies employed inquiry-based, active learning, or culturally integrated pedagogies to enhance chemical kinetics instruction, emphasizing constructivist and student-centered approaches (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023).
- Several studies incorporated analogies, argument-driven inquiry, and cooperative learning strategies to address conceptual difficulties and foster scientific

reasoning (Amelia et al., 2020; Nursafitri et al., n.d.; Koç et al., 2010).

- Ethno-STEM integration was achieved through modules embedding local wisdom, cultural knowledge, and indigenous practices, enhancing relevance and inclusivity (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023).

Student Conceptual Understanding:

- Approximately 15 studies reported measurable improvements in students' conceptual understanding of reaction rates and kinetics, often using pre/post-tests or diagnostic instruments (Jere & Mpeta, 2024; Dejene & Belachew, 2023; Supasorn et al., 2022; Supasorn & Promarak, 2015).
- Diagnostic studies revealed persistent misconceptions and alternative conceptions, particularly related to graphical interpretation and rate laws, highlighting the need for targeted interventions (Habiddin & Page, 2023; Yan & Subramaniam, 2016; Yan & Subramaniam, 2018).
- Contextualized and problem-based learning approaches contributed to deeper understanding and retention of chemical kinetics concepts (Cáceres-Jensen et al., 2021; Karpudewan & Mathanasegaran, 2018; Almanza-Arjona et al., 2022).

Engagement and Motivation Levels:

- Ethno-STEM and inquiry-based modules generally increased student engagement and motivation by connecting chemistry to cultural contexts and real-world problems (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023).
- Active learning strategies, including pair-testing and cooperative learning, enhanced motivation and participation, though some challenges such as partner disagreements were noted (Setu et al., 2022; Koç et al., 2010).
- Use of interactive and tangible tools, such as AR visualization and chemiluminescence demonstrations, further stimulated student interest (Supasorn et al., 2022; Eghlimi et al., 2019).

Technology Integration:

- Digital tools ranged from simple e-worksheets and spreadsheets to advanced simulations, augmented

reality, and kinetic modeling software, supporting diverse learning needs (Salsabila & Rohaeti, 2024; Jere & Mpeta, 2024; Cáceres-Jensen et al., 2021; Zewail-Foote et al., 2019).

- Low-cost and portable experimental kits enabled practical hands-on learning in resource-limited settings (Supasorn et al., 2021; Carraher et al., 2016).
- Some studies planned or recommended digitization and software use to expand accessibility and interactivity (Arroba et al., 2023; Heck, 2012).

Educator and Learner Perceptions:

- Feedback generally indicated positive perceptions of ethno-STEM modules' cultural relevance, practicality, and instructional support (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023).
- Teachers and students valued modules that facilitated active participation and linked chemistry to familiar cultural or environmental contexts (Cáceres-Jensen et al., 2021; Chairam et al., 2009).
- Some studies highlighted the need for scaffolding and instructional support to overcome student difficulties in argumentation and conceptualization (Amelia et al., 2020; Habiddin & Page, 2023).

3.2. Critical Analysis and Synthesis

The reviewed literature on ethno-STEM based learning modules for chemical kinetics reveals a growing emphasis on integrating cultural relevance with scientific pedagogy to enhance student engagement and conceptual understanding. Many studies demonstrate the potential of inquiry-based, technology-enhanced, and culturally contextualized approaches to address the abstract nature of reaction rates. However, challenges remain in consistently measuring learning outcomes, addressing persistent misconceptions, and ensuring scalability and adaptability across diverse educational contexts. The methodologies employed vary widely, from qualitative case studies to quasi-experimental designs, which affects the generalizability of findings. Overall, the synthesis highlights both promising strategies and critical gaps that future research must address to optimize ethno-STEM integration in chemical kinetics education, as outlined in **Table 2**, which summarizes key strengths and weaknesses in current implementation practices.

Table 2. Critical Aspects in the Implementation of Ethno-STEM Modules: Strengths and Weaknesses

Aspect	Strengths	Weaknesses
Integration of Cultural Knowledge with STEM Concepts	Several studies effectively incorporate local wisdom and ethnochemical knowledge into chemical kinetics learning modules, enhancing cultural relevance and student motivation. For example, inquiry-based e-worksheets enriched with local wisdom from Brebes, Central Java, demonstrated high validity and practicality, fostering active participation and appreciation for indigenous knowledge (Salsabila & Rohaeti, 2024). Similarly, practical guides integrating seven local cultural aspects promoted constructivist learning and critical thinking (Arroba et al., 2023). These approaches align well with the objective of benchmarking pedagogical strategies that merge cultural knowledge with STEM concepts.	Despite these successes, many implementations remain localized and context-specific, limiting broader applicability. The depth of cultural integration varies, and some studies lack rigorous evaluation of how cultural elements directly impact conceptual understanding or engagement beyond anecdotal evidence (Arroba et al., 2023). There is also limited discussion on how to systematically adapt these modules for diverse cultural settings or scale them effectively.
Effectiveness of Inquiry-Based and Technology-Supported Pedagogies	Inquiry-based learning combined with technology, such as computer simulations and augmented reality, has shown to improve conceptual understanding of reaction rates. For instance, computer simulations supported by the Predict-Observe-Explain strategy helped learners achieve sound understanding in most conceptual categories (Jere & Mpetta, 2024). The use of augmented reality and small-scale experiments also facilitated shifts from misconceptions to more accurate mental models (Supasorn et al., 2022). These findings support the objective of comparing inquiry-based and technology-enhanced tools within ethno-STEM frameworks.	Many studies rely on small sample sizes or case study designs, which constrain the robustness and generalizability of conclusions (Jere & Mpetta, 2024) (Supasorn et al., 2022). Additionally, some learners still exhibited partial or no understanding in complex areas, indicating that technology alone may not fully address conceptual difficulties. The integration of technology with cultural content is often underexplored, leaving a gap in understanding how these elements synergize.
Addressing Misconceptions and Conceptual Difficulties	Research identifies numerous misconceptions in chemical kinetics, such as difficulties with graphical interpretation and rate laws (Habiddin & Page, 2023) (Yan & Subramaniam, 2018). Ethno-STEM approaches that incorporate active learning and visualization tools, including tangible representations of matter and analogy-based learning, have been effective in mitigating some misconceptions (Kerstiensa et al., 2017) (Supasorn & Promarak, 2015). The use of scaffolding in argument-driven inquiry models further supports scientific reasoning and argumentation skills (Amelia et al., 2020). These strategies align with the objective of identifying and addressing common conceptual challenges.	Despite these interventions, misconceptions persist, especially in areas requiring higher-order reasoning or mathematical interpretation (Habiddin & Page, 2023). Some studies report that traditional teaching methods still dominate, limiting the reach of innovative approaches (Karous et al., 2017). Moreover, diagnostic tools vary in sensitivity and scope, and few studies longitudinally assess the durability of conceptual change.
Student Engagement and Affective Outcomes	Ethno-STEM modules that connect chemistry concepts to students' cultural backgrounds have been reported to increase engagement and motivation. For example, pair-test assessments and problem-based learning with real environmental contexts enhanced student motivation and collaborative skills (Setu et al., 2022) (Cáceres-Jensen et al., 2021). Vocational high school studies emphasize the importance of interactive module design and active learning strategies in fostering engagement (Khatimah & Chisbiyah, 2024). These findings support the	Engagement measures are often self-reported or qualitative, lacking standardized quantitative metrics, which challenges the objective assessment of affective outcomes (Khatimah & Chisbiyah, 2024) (Setu et al., 2022). Additionally, some students experience challenges with group dynamics or time constraints in collaborative assessments (Setu et al., 2022). There is limited exploration of how engagement translates into long-term academic achievement or interest in STEM careers.

Aspect	Strengths	Weaknesses
Pedagogical Content Knowledge and Instructional Design	objective of synthesizing empirical evidence on engagement outcomes. Topic-specific pedagogical content knowledge (TSPCK) based instruction has been shown to improve both conceptual understanding and academic achievement in chemical kinetics (Dejene & Belachew, 2023) (Belayneh & Belachew, 2023). Representation-based and conceptual teaching strategies are particularly effective, with evidence suggesting gender-related differences favoring female students in learning gains (Belayneh & Belachew, 2023). These findings contribute to understanding effective instructional designs within ethno-STEM frameworks.	The majority of TSPCK studies focus on conventional classroom settings without explicit integration of cultural elements, limiting their direct applicability to ethno-STEM modules (Dejene & Belachew, 2023) (Belayneh & Belachew, 2023). Furthermore, the interaction effects between pedagogical strategies and cultural contextualization remain underexplored. The reliance on pretest-posttest designs may not capture deeper cognitive or affective changes.
Use of Real-World and Contextualized Learning Modules	Modules contextualized in real-world problems, such as sustainable chemistry of herbicides and environmental pollution, have demonstrated success in developing contextualized chemistry knowledge and scientific skills (Cáceres-Jensen et al., 2021). These approaches align with the goal of bridging abstract chemical kinetics concepts with tangible societal issues, enhancing relevance and student skill development.	While promising, these modules often require advanced resources, such as digital tools and spreadsheets, which may not be accessible in all educational contexts (Cáceres-Jensen et al., 2021). The scalability and adaptability of such modules to secondary or vocational education levels are not well documented. Additionally, the impact on conceptual understanding versus skill acquisition is not always clearly differentiated.
Methodological Rigor and Research Design	The body of research includes diverse methodologies, from qualitative case studies and R&D models to quasi-experimental designs and mixed methods (Salsabila & Rohaeti, 2024) (Dejene & Belachew, 2023) (Belayneh & Belachew, 2023). This diversity allows for rich insights into different facets of ethno-STEM learning modules and their effects on chemical kinetics education.	However, many studies suffer from small sample sizes, limited control groups, or lack of longitudinal data, which restricts the strength of causal inferences (Jere & Mpeteta, 2024) (Supasorn et al., 2022). There is also variability in assessment tools and outcome measures, complicating cross-study comparisons. Few studies employ randomized controlled trials or large-scale implementations, limiting evidence for widespread adoption.

Many studies showed that combining chemistry with local culture helped students understand better. For example, worksheets using traditional knowledge from Brebes, Indonesia made learning more meaningful and increased student participation (Salsabila & Rohaeti, 2024). These modules helped students connect chemistry to daily life. However, most were designed for specific areas, so they may not work the same way in different places. Also, not all studies clearly showed how cultural content improved learning (Arroba et al., 2023).

Learning methods that use technology, like simulations and small experiments, helped students learn about reaction rates (Jere & Mpeteta, 2024; Supasorn et al., 2022). Tools such as augmented reality and Predict-Observe-Explain activities made lessons more interactive

and helped students build better understanding. But many of these studies had small groups, so it's hard to say if the results apply everywhere. Plus, we still don't know how well technology works when combined with cultural learning (Habiddin & Page, 2023).

Students still often struggle with reaction rate graphs and formulas (Yan & Subramaniam, 2018). Some tools like drawings, models, and quizzes helped teachers find and fix these misunderstandings. Still, students need stronger thinking and math skills to really understand the topic. In many schools, old teaching styles are still common, making it harder to use better methods. Also, because most studies only lasted a short time, it's difficult to know if the changes really last.

Ethno-STEM lessons made students more interested, especially when connected to real life or their culture (Setu et al., 2022; Cáceres-Jensen et al., 2021). Group tasks and problem-solving helped students stay active in class. But most studies used student surveys to measure engagement, which may not always show true interest. Group work also had some problems, like uneven participation or limited time. Future studies should use better tools to measure motivation and explore whether these methods help students stay interested in science for the long term (Dejene & Belachew, 2023; Belayneh & Belachew, 2023).

reveals several prominent themes as shown in **Table 3**. Major themes include culturally contextualized and inquiry-based pedagogies that enhance student engagement and conceptual understanding, as well as the integration of technology and interactive tools such as simulations and augmented reality for teaching kinetics. A substantial focus is also placed on students' misconceptions and conceptual difficulties, with various diagnostic and scaffolded instructional strategies addressing these challenges. Emerging themes highlight the role of socio-scientific and sustainable chemistry contexts, alongside the development of pedagogical content knowledge specific to chemical kinetics.

3.1. Thematic Review of Literature

The literature on ethno-STEM based learning modules for chemical kinetics focusing on reaction rates

Table 3. Key Themes Identified in the Literature on Ethno-STEM for Reaction Rates

Theme	Appears In	Theme Description
Culturally Contextualized Ethno-STEM Pedagogies	7/50 Papers	Ethno-STEM approaches integrate local cultural knowledge and indigenous wisdom into chemical kinetics instruction, fostering relevance and engagement. Studies report enhanced student motivation and understanding when modules incorporate ethnochemical content, local analogies, or cultural perspectives, bridging abstract chemistry concepts with students' lived experiences (Khatimah & Chisbiyah, 2024) (Salsabila & Rohaeti, 2024) (Arroba et al., 2023) (Almanza-Arjona et al., 2022). These approaches often employ constructivist and inquiry-based strategies that respect cultural diversity and support inclusive learning environments.
Inquiry-Based and Active Learning Strategies	9/50 Papers	Inquiry-based learning, including 5E models and Argument-Driven Inquiry (ADI), is widely used to improve students' conceptual understanding of reaction rates by engaging them in experimentation, questioning, and reasoning processes. Evidence suggests significant gains in conceptual knowledge and scientific argumentation skills when students participate actively in designing experiments and analyzing data (Salsabila & Rohaeti, 2024) (Amelia et al., 2020) (Syamsiana et al., 2018) (Nursafitri et al., n.d.) (Supasorn & Promarak, 2015) (Chairam et al., 2015). These strategies also help reduce misconceptions by encouraging exploration and peer discussion.
Technology-Enhanced Learning Tools and Simulations	8/50 Papers	Technology integration through computer simulations, augmented reality, e-worksheets, and kinetic modeling software enhances visualization and comprehension of complex kinetics concepts. Tools such as computer simulations combined with Predict-Observe-Explain strategies and AR visualizations improve learners' understanding of dynamic processes at molecular and macroscopic levels (Jere & Mpeti, 2024) (Murni et al., 2022) (Eghlimi et al., 2019) (Carragher et al., 2016) (Habibi et al., 2024) (Heck, 2012) (Zewail-Foote et al., 2019). Technology supports interactive and flexible learning, making abstract phenomena more tangible.
Students' Misconceptions and Conceptual Difficulties	7/50 Papers	Research consistently identifies common misconceptions in chemical kinetics related to reaction rates, rate laws, and molecular interpretations. Diagnostic instruments reveal alternative conceptions due to mathematical challenges, difficulty interpreting graphs, and abstract representations (Habiddin & Page, 2023) (Yan & Subramaniam, 2016) (Yan & Subramaniam, 2018) (Karous et al., 2017). Addressing these misconceptions requires targeted pedagogical content knowledge, scaffolded instruction, and diagnostic assessment to tailor teaching effectively (Marzabal et al., 2018).
Pedagogical Content Knowledge and Instructional Design	6/50 Papers	Emphasis on topic-specific pedagogical content knowledge (TSPCK) informs the design of instructional strategies that improve students' conceptual understanding and academic achievement in kinetics. Comparative studies find that representation-based and conceptual teaching strategies outperform traditional methods, enhancing

Theme	Appears In	Theme Description
Use of Real-World and Sustainable Contexts	4/50 Papers	students' learning gains (Dejene & Belachew, 2023) (Belayneh & Belachew, 2023) (Marzabal et al., 2018) (Koç et al., 2010). Incorporating multiple representations and aligning teaching with students' cognitive levels are key factors.
Hands-On and Low-Cost Experimental Approaches	4/50 Papers	Embedding chemical kinetics concepts within real-world contexts such as environmental chemistry, sustainable herbicide kinetics, and socio-scientific issues supports meaningful learning. Problem-based learning with digital tools and spreadsheet modeling engages preservice teachers and students in authentic applications, fostering sustainability skills and contextual knowledge (Cáceres-Jensen et al., 2021) (Karpudewan & Mathanasegaran, 2018) (Almanza-Arjona et al., 2022) (Chairam et al., 2009). This contextualization strengthens affective outcomes and STEM competencies.
Visualization and Analogical Representations	3/50 Papers	Development and use of accessible experimental kits and small-scale apparatus, such as syringe-vial gas collection and chemiluminescence demonstrations, facilitate hands-on learning of reaction rates in resource-limited settings. These practical tools enable quantitative data collection and observation of kinetics phenomena without expensive equipment (Supasorn et al., 2021) (Eghlimi et al., 2019) (Chung & Green, 2023) (Jabeen & Siddiq, 2023). Such approaches increase student participation and conceptual clarity.
Assessment Innovations and Collaborative Learning	2/50 Papers	Visualization techniques using tangible models, analogies, and graphical representations help students grasp abstract kinetics concepts like concentration changes over time and reaction mechanisms. Analogical teaching and use of elementary shapes to represent atoms support mental model development and deeper understanding (Kerstiensa et al., 2017) (Nursafitri et al., n.d.) (Schmitz & Lente, 2020). This theme intersects with inquiry strategies to scaffold learning.
Challenges in Curriculum Alignment and Textbook Content	2/50 Papers	Innovative assessment methods, such as pair-testing and multi-tier diagnostic tools, show promise in improving students' motivation and performance in kinetics. Collaborative assessments facilitate peer learning and reduce anxiety, while diagnostic tests uncover nuanced alternative conceptions for targeted intervention (Setu et al., 2022) (Yan & Subramaniam, 2018). These assessment approaches complement active learning frameworks.
		Analyses reveal that existing textbooks and curricula often inadequately address kinetics concepts, lacking integration of submicroscopic models and connections to students' experiences. This gap contributes to persistent difficulties and low comprehension levels among secondary students (Karous et al., 2017) (Gegios et al., 2017). Calls for curriculum reform emphasize relevance, conceptual depth, and research-based content alignment.

This review found several main themes in how ethno-STEM is used to teach chemical kinetics. One important theme is connecting chemistry lessons to local culture. By using stories, traditions, and examples from students' own lives, these lessons felt more meaningful and easier to understand (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024). Students showed more interest and better understanding when culture was part of the learning. Simple strategies like using local analogies or everyday situations helped bridge abstract science with daily experiences.

Another theme is the use of active learning. Students learned better when they were involved in experiments and discussions, especially through methods like the 5E model and Argument-Driven Inquiry (Amelia et al., 2020; Supasorn & Promarak, 2015). These

methods helped students think more deeply and fix common misunderstandings. Technology also supported learning—tools like simulations, augmented reality, and digital worksheets made hard ideas easier to see and practice (Jere & Mpeta, 2024; Zewail-Foote et al., 2019). Hands-on experiments using simple materials, like syringe kits or small setups, helped students learn even in schools with fewer resources (Eghlimi et al., 2019).

The review also found that students struggled with graphs and formulas about reaction rates. Tools like quizzes and visual models helped teachers spot and fix these problems (Yan & Subramaniam, 2018). Lessons that used real-world topics—like farming or pollution—made chemistry more useful and helped students build skills they could apply outside school (Cáceres-Jensen et al., 2021). Group work and new assessment methods,

like pair testing, made learning more active, although some textbooks still don't match students' needs or experiences (Setu et al., 2022; Karous et al., 2017).

3.3. Chronological Review of Literature

The literature on ethno-STEM based learning modules for chemical kinetics, especially those focusing on reaction rates, has come a long way—from tackling basic conceptual struggles to introducing creative teaching strategies that blend cultural knowledge with

modern tech. Early studies zoomed in on student misconceptions and aimed to boost understanding using inquiry-based and hands-on learning. As time went on, researchers shifted toward more culturally grounded modules, interactive simulations, and local wisdom to keep students engaged and improve outcomes. This shift shows a clear move from old-school approaches to more inclusive and tech-savvy methods in chemistry education, as mapped out in **Table 4**.

Table 4. Research Timeline: Year Range, Focus, and Description

Year Range	Research Direction	Description
2003–2010	Foundational Kinetics Concepts and Cooperative Learning	Initial studies focused on fundamental reaction kinetics concepts, factors affecting reaction rates, and cooperative learning techniques to improve academic achievement. Research emphasized collision theory, rate laws, and active learning strategies such as group investigation and jigsaw to address students' difficulties in grasping chemical kinetics.
2012–2015	Inquiry-Based Learning and Visual/Tangible Tools	This period saw the development and assessment of inquiry-based learning models, such as 5E learning cycles and POE strategies, alongside the introduction of tangible and visual representations to aid comprehension. Efforts aimed to enhance conceptual understanding and address misconceptions by integrating analogies, small-scale experiments, and interactive computer simulations.
2016–2018	Diagnostic Assessments and Contextualized Experiments	Researchers developed multi-tier diagnostic tools to uncover alternative conceptions and misconceptions in chemical kinetics. The use of context-based green chemistry experiments, digital modeling, and system dynamics software became prominent to connect abstract concepts with real-world applications, enhancing scientific reasoning and argumentation skills.
2019–2020	Technology-Enhanced and Argument-Driven Inquiry	Focus shifted towards employing advanced technologies like kinetic modeling software and chemiluminescence demonstrations to support learning. Argument-driven inquiry models with scaffolding were introduced to foster scientific argumentation and reasoning, addressing confidence issues while promoting deeper conceptual understanding.
2021–2022	Problem-Based and Pair Assessment Approaches	Learning modules integrated sustainable chemistry contexts and problem-based learning to develop sustainability skills and digital competencies. Pair-test assessments were explored as active learning strategies to improve performance and motivation, while research highlighted the role of culturally relevant experiments and small-scale interactive kits.
2023–2024	Ethno-STEM Integration and Cultural Contextualization	Recent studies emphasize the design and implementation of ethno-STEM based modules incorporating local wisdom, cultural knowledge, and augmented reality to enhance engagement and conceptual understanding in chemical kinetics. Comparisons of pedagogical content knowledge-based instruction modes and computer simulations underline the effectiveness of culturally contextualized and technology-supported learning tools in diverse educational settings.

3.4. Agreement and Divergence Across Studies

There is broad consensus across studies that ethno-STEM and inquiry-based approaches, especially those integrating cultural knowledge, significantly enhance student engagement and conceptual understanding in chemical kinetics. Many studies highlight the effectiveness of contextually relevant, interactive, and technology-enhanced modules in promoting deeper learning and motivation. However,

there are divergences (**Table 5**) regarding the relative impact of specific pedagogical strategies (e.g., scaffolding in ADI models vs. pair testing) and the extent to which technology integration alone drives improved conceptual gains. Differences in educational contexts (vocational, secondary, higher education), sample sizes, and assessment tools contribute to varying conclusions about best practices and long-term impacts.

Table 5. Comparison Criterion Studies in Agreement Studies in Divergence Potential Explanations

Comparison Criterion	Studies in Agreement	Studies in Divergence	Potential Explanations
Pedagogical Design Features	Most studies agree that integrating cultural knowledge with inquiry-based or ethno-STEM pedagogies enhances relevance and student engagement in chemical kinetics learning (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023). Use of analogies, scaffolding, and contextual modules is supported (Amelia et al., 2020; Nursafitri et al., n.d.; Supasorn & Promarak, 2015).	Some studies emphasize problem-based learning and digital tools (e.g., spreadsheets) as key, whereas others prioritize hands-on small-scale experiments or graphical modeling, creating divergence in favored design (Cáceres-Jensen et al., 2021; Supasorn et al., 2022; Heck, 2012).	Variation in institutional settings (vocational, secondary, undergraduate) and resource availability influence pedagogical choices and priorities.
Student Conceptual Understanding	There is agreement that ethno-STEM and inquiry-based strategies lead to measurable improvements in conceptual understanding of reaction rates and kinetics (Salsabila & Rohaeti, 2024; Dejene & Belachew, 2023; Supasorn et al., 2022; Supasorn & Promarak, 2015; Chairam et al., 2015). Computer simulations and visualization tools also enhance understanding (Jere & Mpeta, 2024; Kerstiensa et al., 2017).	Some studies indicate partial or mixed gains, with persistent misconceptions and difficulties remaining despite interventions, suggesting incomplete conceptual change (Habiddin & Page, 2023; Yan & Subramaniam, 2016; Yan & Subramaniam, 2018). Others show greater impact from teacher-driven topic-specific PCK instruction (Dejene & Belachew, 2023; Belayneh & Belachew, 2023).	Differences in duration of intervention, assessment rigor, and prior student knowledge impact outcomes; also, methodological differences (qualitative vs. quantitative) contribute.
Engagement and Motivation Levels	Cultural relevance and interactive, student-centered learning positively influence motivation and engagement, as reported consistently (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Chairam et al., 2015). Pair-tests and cooperative learning increase student interest (Setu et al., 2022; Koç et al., 2010).	Some authors note challenges in sustained motivation due to complexity of kinetics or time constraints, and mixed results on group vs. individual assessments highlight variability (Setu et al., 2022).	Differences in student demographics, class size, and instructional time affect engagement; cultural integration may be more motivating in certain contexts.
Technology Integration	Consensus that technology (e.g., e-worksheets, computer simulations, augmented reality, spectrophotometry, kinetic modeling software) supports conceptual learning and engagement (Salsabila & Rohaeti, 2024; Arroba et al., 2023; Jere & Mpeta, 2024; Carraher et al., 2016; Habibi et al., 2024; Zewail-Foote et al., 2019).	Divergence arises in the extent of technology use; some studies emphasize low-cost, simple tools (e.g., syringe-vial kits) over high-tech simulation for accessibility (Supasorn et al., 2022; Supasorn et al., 2021; Eghlimi et al., 2019). Others note technology alone is insufficient without pedagogical scaffolding (Amelia et al., 2020).	Resource availability, teacher training, and students' technological literacy influence the adoption and effectiveness of technology tools.
Educator and Learner Perceptions	Positive perceptions of culturally contextualized modules and inquiry-based learning are widely reported, with teachers and students valuing relevance and usability (Khatimah & Chisbiyah, 2024; Arroba et al., 2023; Cáceres-Jensen et al., 2021; Chairam et al., 2015).	Some studies highlight challenges such as students' lack of confidence in argumentation or disagreement in group assessments, indicating mixed perceptions (Setu et al., 2022; Amelia et al., 2020).	Differences in teacher experience, student cultural backgrounds, and the novelty of ethno-STEM approaches affect acceptance and perceived utility.

3.5. Theoretical and Practical Implications

Theoretical Implications:

- The integration of ethno-STEM approaches in chemical kinetics education supports constructivist learning theories by linking students' cultural backgrounds with scientific concepts, thereby enhancing conceptual understanding and motivation.

This aligns with findings that culturally contextualized modules promote critical thinking and meaningful engagement with abstract chemistry topics (Khatimah & Chisbiyah, 2024; Arroba et al., 2023; Karous et al., 2017).

- Inquiry-based learning frameworks, particularly structured inquiry and 5E models, have been shown

to effectively scaffold students' mental models and conceptual grasp of reaction rates, supporting educational theories that emphasize active learning and guided discovery in complex scientific domains (Murni et al., 2022; Supasorn & Promarak, 2015; Chairam et al., 2015).

- The use of multiple chemical representations and tangible visualizations addresses common misconceptions by facilitating the connection between macroscopic observations and submicroscopic processes, reinforcing dual coding and multimedia learning theories in chemistry education (Murni et al., 2022; Kerstensa et al., 2017; Karous et al., 2017).
- Topic-specific pedagogical content knowledge (TSPCK) enhances students' conceptual understanding and academic achievement in chemical kinetics, confirming the theoretical importance of specialized instructional strategies tailored to the nuances of chemical kinetics content (Dejene & Belachew, 2023; Belayneh & Belachew, 2023).
- The identification of persistent misconceptions through multi-tier diagnostic instruments underscores the need for instructional designs that explicitly target students' intuitive but incorrect conceptions, supporting constructivist and diagnostic teaching models (Habiddin & Page, 2023) (Yan & Subramaniam, 2016) (Yan & Subramaniam, 2018).
- The application of model-based reasoning and mathematical modeling in teaching reaction kinetics aligns with cognitive theories advocating for the integration of conceptual and quantitative reasoning to deepen understanding of rate laws and mechanisms (Rushton et al., 2014) (Almanza-Arjona et al., 2022).
- computer simulations, and augmented reality, indicates that educational institutions should invest in developing and integrating these resources to improve learning outcomes in chemical kinetics (Salsabila & Rohaeti, 2024; Jere & Mpeteta, 2024; Murni et al., 2022).
- The use of low-cost, portable experimental kits and digital data acquisition methods facilitates hands-on learning and accessibility, making chemical kinetics more approachable in diverse educational settings, including resource-limited environments (Supasorn et al., 2022; Supasorn et al., 2021; Festersen et al., 2018).
- Problem-based and cooperative learning strategies, including pair-testing and group investigations, have practical benefits in enhancing student achievement and motivation, recommending their adoption in classroom assessment and instructional design (Setu et al., 2022) (Koç et al., 2010).
- The incorporation of scaffolding within argument-driven inquiry models supports the development of scientific argumentation skills, which are critical for students' deeper understanding and should be integrated into chemistry pedagogy (Amelia et al., 2020).
- The advancement of machine learning models to predict solvent effects on reaction rates offers promising applications for industry and research by enabling rapid and accurate kinetic predictions, which can inform chemical process design and optimization (Chung & Green, 2023).

Practical Implications:

- Ethno-STEM learning modules that incorporate local cultural knowledge and indigenous wisdom can increase student engagement and relevance of chemistry education, suggesting curriculum developers and educators should prioritize culturally responsive pedagogies in chemical kinetics instruction (Khatimah & Chisbiyah, 2024; Salsabila & Rohaeti, 2024; Arroba et al., 2023).
 - The demonstrated effectiveness of inquiry-based and technology-enhanced tools, such as e-worksheets, computer simulations, and augmented reality, indicates that educational institutions should invest in developing and integrating these resources to improve learning outcomes in chemical kinetics (Salsabila & Rohaeti, 2024; Jere & Mpeteta, 2024; Murni et al., 2022).
- The findings from this study suggest that ethno-STEM modules can be directly applied in the classroom by integrating local cultural knowledge into the teaching of chemistry, particularly in the topic of chemical kinetics. For example, teachers can use practical, culturally relevant examples from daily life, such as traditional fermentation processes or sugar production, to explain concepts of reaction rates. This allows students to more easily connect abstract scientific concepts with their own experiences. However, challenges that teachers may face include limitations in resources and access to the technology needed for technology-enhanced modules, such as computer simulations or augmented reality (AR). Additionally, teachers need a strong understanding of how to effectively integrate cultural elements with scientific principles, ensuring that it not only enhances

conceptual understanding but also maintains student relevance and engagement. Teaching that incorporates local culture also requires adjustments to accommodate the cultural diversity within the classroom, which may influence how the material is delivered to align with students' backgrounds

3.6. Limitations of the Literature

Although research on ethno-STEM learning modules in chemical kinetics continues to grow, significant limitations remain, as outlined in **Table 6**. Many studies rely on small samples or case study methods, which limit the generalizability of findings (Jere & Mpet, 2024). Geographic and cultural bias is also common, with most research focused on specific local contexts,

reducing its relevance for broader educational settings (Khatimah & Chisbiyah, 2024). Few studies assess long-term learning retention or engagement, and many use qualitative or self-reported data without control groups, weakening the strength of conclusions (Salsabila & Rohaeti, 2024). Moreover, most focus on a single pedagogical approach—typically inquiry-based—without comparing it to other models. Important learner variables such as gender, socioeconomic status, and prior knowledge are often overlooked, limiting inclusivity. While some studies incorporate technology, few evaluate its accessibility or effectiveness within the ethno-STEM context. Overall, these limitations point to the need for more rigorous, inclusive, and scalable research designs in future ethno-STEM studies.

Table 6. Key Limitations in Ethno-STEM Research on Chemical Kinetics Education

Area of Limitation	Description of Limitation	Papers which have limitation
Small Sample Sizes	Several studies rely on limited participant numbers or case study approaches, which restricts the generalizability of findings and reduces external validity. Small samples may not capture the diversity of learner experiences or educational contexts.	(Jere & Mpet, 2024) (Supasorn et al., 2022)
Geographic and Cultural Bias	Most research is concentrated in specific regions or cultural contexts, limiting the applicability of findings across diverse populations. This geographic bias affects the external validity and may overlook culturally specific challenges or benefits of ethno-STEM approaches.	(Khatimah & Chisbiyah, 2024) (Salsabila & Rohaeti, 2024) (Arroba et al., 2023) (Chairam et al., 2009)
Limited Longitudinal Data	Few studies provide long-term follow-up to assess retention or sustained impact of ethno-STEM modules on conceptual understanding and engagement. This limits understanding of the durability of learning gains and affective outcomes over time.	(Supasorn & Promarak, 2015) (Supasorn et al., 2022)
Methodological Constraints	Predominance of qualitative or quasi-experimental designs without randomized control limits causal inference. Additionally, reliance on self-reported data or expert evaluations may introduce bias and affect the robustness of conclusions regarding module effectiveness.	(Salsabila & Rohaeti, 2024) (Belayneh & Belachew, 2023) (Amelia et al., 2020)
Narrow Focus on Specific Pedagogies	Many studies focus on particular instructional strategies (e.g., inquiry-based, POE, ADI) without comparative analyses across diverse pedagogical approaches, limiting comprehensive understanding of which methods best integrate ethno-STEM in chemical kinetics education.	(Salsabila & Rohaeti, 2024) (Murni et al., 2022) (Syamsiana et al., 2018) (Amelia et al., 2020)
Insufficient Attention to Learner Diversity	Few investigations consider variables such as gender, socioeconomic status, or prior knowledge, which may influence learning outcomes and engagement. This omission restricts the ability to tailor ethno-STEM modules to diverse learner needs and contexts.	(Murni et al., 2022) (Belayneh & Belachew, 2023) (Yan & Subramaniam, 2018)
Lack of Technology Integration Analysis	While some studies incorporate technology-enhanced learning tools, there is limited systematic evaluation of their usability, accessibility, and impact within ethno-STEM frameworks, constraining understanding of technology's role in enhancing chemical kinetics learning.	(Salsabila & Rohaeti, 2024) (Cáceres-Jensen et al., 2021) (Zewail-Foote et al., 2019)
Limited Empirical Evidence on Misconceptions	Although misconceptions in chemical kinetics are acknowledged, empirical studies addressing how ethno-STEM modules specifically	(Habiddin & Page, 2023) (Karous et al., 2017) (Yan & Subramaniam, 2018)

Area of Limitation	Description of Limitation	Papers which have limitation
Overemphasis on Secondary and Vocational Contexts	remediate these misconceptions remain scarce, weakening evidence for targeted conceptual change strategies. The literature predominantly targets secondary and vocational education, with fewer studies exploring ethno-STEM module effectiveness at tertiary or informal education levels, limiting insights into broader educational applicability and scalability.	(Khatimah & Chisbiyah, 2024) (Cáceres-Jensen et al., 2021) (Chairam et al., 2015)

3.7. Gaps and Future Research Directions

Table 7 highlights ten key research gaps in ethno-STEM education for teaching reaction rates, including limited cross-cultural implementation, weak integration of technology with cultural content, and a lack of long-term studies to assess sustained impact. Most modules remain local in scope and have not been tested widely, while tools like AR and simulations are underutilized in enhancing cultural relevance (Supasorn et al., 2022; Jere & Mpeta, 2024). Persistent misconceptions, particularly about graphs and rate laws,

also remain insufficiently addressed through structured interventions (Habiddin & Page, 2023). The table further emphasizes the need for standardized affective assessments, attention to gender and socioeconomic factors, and targeted teacher training to ensure successful ethno-STEM implementation. By identifying high-priority areas such as scalability and teacher preparedness, Table 7 serves as a critical roadmap for curriculum development and future research that aims to create more inclusive and impactful science education.

Table 7. Identified Research Gaps and Future Directions in Ethno-STEM Chemical Kinetics Education

Gap Area	Description	Future Research Directions	Justification	Research Priority
Scalability and Adaptability of Ethno-STEM Modules	Current ethno-STEM modules are often localized with limited evidence on adaptability across diverse cultural and educational contexts.	Conduct multi-site studies to adapt and test ethno-STEM modules in varied cultural and educational settings, developing frameworks for systematic cultural integration and scalability.	Localized success limits broader applicability; systematic adaptation is needed to generalize benefits and support diverse learners (Khatimah & Chisbiyah, 2024; Arroba et al., 2023).	High
Integration of Technology with Cultural Content	Limited research explores how technology-enhanced tools synergize with cultural knowledge in ethno-STEM chemical kinetics modules.	Investigate design principles and effectiveness of technology tools (e.g., AR, simulations) explicitly integrated with ethnochemical content to enhance conceptual understanding and engagement.	Technology and cultural content are often treated separately; their integration could amplify learning outcomes but remains underexplored (Arroba et al., 2023; Jere & Mpeta, 2024; Supasorn et al., 2022).	High
Longitudinal Impact on Conceptual Change and Engagement	Few studies assess the durability of conceptual understanding and sustained engagement following ethno-STEM interventions.	Implement longitudinal studies tracking students' conceptual retention, motivation, and STEM interest over multiple academic terms after ethno-STEM module exposure.	Understanding long-term effects is critical for validating the lasting impact of culturally contextualized pedagogy (Salsabila & Rohaeti, 2024; Supasorn & Promarak, 2015).	High
Addressing Persistent Misconceptions in Chemical Kinetics	Despite interventions, misconceptions, especially in graphical interpretation and rate laws, persist among learners.	Develop targeted instructional strategies combining diagnostic tools with scaffolded inquiry and visualization tailored to common misconceptions identified via multi-tier diagnostics.	Persistent misconceptions hinder deep understanding; tailored interventions informed by diagnostics can improve conceptual clarity (Habiddin & Page, 2023; Yan & Subramaniam, 2016; Yan & Subramaniam, 2018).	High
Quantitative Measurement of Affective Outcomes	Engagement and motivation are often measured qualitatively or	Design and validate quantitative instruments to measure affective outcomes	Reliable affective measures are needed to objectively assess and optimize the emotional and	Medium

Gap Area	Description	Future Research Directions	Justification	Research Priority
Gender and Socioeconomic Influences on Learning Gains	via self-report, lacking standardized quantitative metrics. Limited exploration exists on how gender and socioeconomic status interact with ethno-STEM pedagogies in chemical kinetics.	(engagement, motivation) in ethno-STEM chemical kinetics learning, correlating these with cognitive gains. Conduct disaggregated analyses of learning outcomes and engagement by gender and socioeconomic background within ethno-STEM interventions to identify differential effects and equity issues.	motivational impact of ethno-STEM modules (Khatimah & Chisbiyah, 2024; Setu et al., 2022). Evidence suggests gender differences in achievement; understanding these factors can guide inclusive module design (Belayneh & Belachew, 2023; Murni et al., 2022).	Medium
Teacher Preparedness and Pedagogical Content Knowledge (PCK) in Ethno-STEM	Most PCK studies focus on conventional settings without explicit cultural integration, limiting ethno-STEM applicability.	Develop and evaluate professional development programs that build teachers' ethno-STEM specific PCK, including cultural knowledge integration and technology use in chemical kinetics instruction.	Teacher readiness is crucial for effective ethno-STEM implementation; tailored PCK development is under-addressed (Dejene & Belachew, 2023; Belayneh & Belachew, 2023).	High
Resource Accessibility and Low-Cost Technology Integration	Advanced digital tools and experiments may not be accessible in resource-limited educational contexts.	Design and test low-cost, portable, and culturally relevant experimental kits and digital tools for chemical kinetics that support ethno-STEM learning in under-resourced schools.	Accessibility barriers limit equitable implementation; affordable tools can democratize ethno-STEM learning (Supasorn et al., 2021; Eghlimi et al., 2019; Carraher et al., 2016).	High
Synergistic Effects of Cooperative Learning and Ethno-STEM Approaches	Cooperative learning enhances motivation but its integration with ethno-STEM modules is insufficiently studied.	Investigate the combined effects of cooperative learning strategies and ethno-STEM modules on conceptual understanding, engagement, and social skills in chemical kinetics education.	Combining social learning with cultural relevance may yield stronger educational outcomes but remains underexplored (Setu et al., 2022; Koç et al., 2010).	Medium
Standardization and Validation of Assessment Tools	Variability in assessment instruments complicates cross-study comparisons and evaluation of ethno-STEM effectiveness.	Develop standardized, validated assessment tools for conceptual understanding and engagement specific to ethno-STEM chemical kinetics modules to enable consistent evaluation.	Standardized tools are essential for rigorous evaluation and comparison of pedagogical effectiveness across studies (Habiddin & Page, 2023; Yan & Subramaniam, 2018).	Medium

4. CONCLUSION

The collective body of research on ethno-STEM based learning modules for chemical kinetics, particularly focusing on reaction rates, highlights the beneficial role of integrating cultural knowledge within STEM education to enhance both conceptual understanding and student engagement. Pedagogical approaches that embed local wisdom, indigenous practices, and ethnochemical knowledge have demonstrated increased student motivation by making chemistry more relatable and meaningful. Such culturally contextualized modules foster inclusivity and encourage active participation, bridging

the abstract nature of chemical kinetics with learners' cultural and social realities. Inquiry-based and active learning strategies, when combined with cultural content, further support deeper cognitive engagement and critical thinking, suggesting that cultural integration is a powerful lever for improving learning outcomes.

Technology-enhanced pedagogies also play a crucial role in addressing the complexities of chemical kinetics. The use of computer simulations, augmented reality, interactive visualizations, and affordable experimental kits provides dynamic, hands-on experiences that clarify abstract concepts like reaction

rates and mechanisms. These tools support multiple representations and foster scientific reasoning, although the synergy between technological and cultural elements remains underexplored. While technology facilitates conceptual gains, it alone is insufficient to eradicate persistent misconceptions, especially those related to graphical interpretations and mathematical reasoning in kinetics. Complementary scaffolding and targeted pedagogical content knowledge are essential to overcoming these difficulties.

Diagnostic instruments consistently reveal that misconceptions in chemical kinetics are widespread and resilient, particularly in areas involving rate laws, graphical data interpretation, and reaction mechanisms. Ethno-STEM approaches that include analogies, tangible models, and argument-driven inquiry can mitigate some of these challenges by contextualizing learning and promoting scientific argumentation skills. However, the durability of conceptual change and the scalability of such interventions across diverse educational settings require further investigation.

Student affective outcomes are positively influenced by culturally relevant and inquiry-based modules, with increased motivation and engagement reported across secondary and vocational education contexts. Cooperative and problem-based learning strategies enhance collaboration and real-world applicability, though challenges such as group dynamics and assessment logistics persist. Educator and learner perceptions underscore the value of culturally grounded, interactive modules that align with students' experiences, yet highlight a need for more systematic support and teacher professional development.

Overall, while the literature affirms the promise of ethno-STEM integration combined with inquiry and technology to improve learning in chemical kinetics, gaps remain in rigorous, large-scale evaluations and the development of adaptable models for diverse populations. Future research should aim to deepen understanding of how cultural and technological factors intersect to sustain conceptual gains and engagement, thereby informing curriculum innovations that effectively align chemical kinetics education with students' cultural backgrounds and STEM competencies.

Future research should focus on the scalability of ethno-STEM modules across diverse educational contexts to maximize their effectiveness in enhancing

student engagement and conceptual understanding in chemical kinetics. This can be achieved by conducting multi-site studies that adapt and test these modules in varied cultural settings, ensuring inclusivity and relevance in science education. Additionally, exploring the integration of technology with cultural knowledge can further enhance the effectiveness of ethno-STEM modules in promoting student engagement and understanding in chemical kinetics. Research should also consider the long-term impacts of these culturally integrated modules on students' ongoing interest in STEM fields, particularly in relation to their future academic and career choices. Moreover, addressing persistent misconceptions in chemical kinetics through targeted interventions will be crucial for improving students' conceptual understanding and fostering a deeper interest in STEM disciplines. Ethno-STEM modules have the potential to transform chemistry education by making abstract concepts more accessible and engaging, ultimately fostering a deeper appreciation for both science and cultural heritage. To achieve this, educators must prioritize the development of culturally responsive pedagogies that resonate with students' backgrounds and experiences, thereby enhancing the relevance of chemical kinetics in their learning journey. In conclusion, the integration of ethno-STEM approaches in chemical kinetics education not only improves conceptual understanding but also fosters a sense of belonging and relevance among diverse student populations.

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