JPPIPA 11(5) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Content Validity Analysis of a Virtual Reality Based Two-Tier Multiple Choice Assessment Instrument with Ethnochemistry to Early Detect Misconceptions in Reaction Rate Topics

Arin Ika Ningtyas[1], Sri Yamtinah[1*], Sulistyo Saputro[1], Ari Syahidul Shidiq[1], Sudarmin[2], Sri Rahayu[3]

[1]Chemistry Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia.
[2]Chemistry Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Semarang, Indonesia.
[3]Chemistry Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, Indonesia.

Received: January 16, 2025
Revised: March 20, 2025
Accepted: May 25, 2025
Published: May 31, 2025

Corresponding Author:
Sri Yamtinah
jengtina@staff.uns.ac.id

DOI: 10.29303/jppipa.v11i5.11429

Abstract: This study aimed to develop a detection instrument for reaction rate misconceptions in prospective chemistry teachers. A Two-Tier Multiple Choice (TTMC) test with ethnochemistry content and a virtual reality (VR) storyboard were designed as assessment tools. The research followed the ADDIE model within a research and development framework. Content validity was evaluated by material and media experts through a Focus Group Discussion (FGD), with 10 TTMC questions assessed for content, language, and presentation using the Aiken formula on a 1-4 rating scale. The TTMC instrument demonstrated strong content validity, with Aiken values ranging from 0.81 to 1.00. The VR storyboard also showed content validity, with Aiken values between 0.76 and 1.00, which is above the minimum acceptable limit. These results indicate that the TTMC test and VR storyboard are valid tools for detecting misconceptions in reaction rate material, offering valuable insights for chemistry education, particularly in teacher training programs.

Keywords: Content validity; Ethnochemistry; Reaction rate; Two Tier Multiple Choice (TTMC); Virtual reality based assessment

Introduction

Learning is a process of transferring knowledge from educators to learners within a dynamic environment supported by learning resources. In chemistry education, students frequently encounter difficulties due to the abstract and complex nature of the subject. These challenges are further compounded by the fact that chemistry is directly related to representation approaches at three different levels, namely, macroscopic (can be seen directly and tangibly), submicroscopic (cannot be seen directly, such as the arrangement of interacting atoms, molecules, and ions), and symbolic (chemical equations, element symbols, formulas, reaction mechanisms) (Reiser et al., 2022). Students fail to connect real-world observations with molecular reasoning without properly integrating these levels, perpetuating misconceptions (Barke et al., 2009). Topics such as reaction rates are especially challenging, often resulting in misconceptions that hinder conceptual understanding and lead to low academic performance (Soeharto & Csapó, 2021).

Several studies have identified misconceptions about reaction rates (Jusniar et al., 2020). These misconceptions are prevalent in secondary education and persist at the undergraduate level. They often arise when students rely on rote memorization rather than a deep understanding of underlying scientific principles (Romine et al., 2016). Despite previous studies documenting misconceptions in reaction rate topics,

How to Cite:
Ningtyas, A. I., Yamtinah, S., Saputro, S., Shidiq, A. S., Sudarmin, & Rahayu, S. (2025). Content Validity Analysis of a Virtual Reality Based Two-Tier Multiple Choice Assessment Instrument with Ethnochemistry to Early Detect Misconceptions in Reaction Rate Topics. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 960–969. https://doi.org/10.29303/jppipa.v11i5.11429

particularly among high school students, research focusing on university students remains limited. Misconceptions in chemistry learning are one of the main challenges that can hinder students' understanding of important concepts (Oktaviana et al., 2024). Misconceptions are typically defined as misunderstandings of real-world phenomena that deviate from scientific explanations. These misconceptions negatively impact subsequent chemistry learning by introducing incorrect concepts, which inhibit the acquisition of scientifically accepted ideas and disrupt the learning process (Yamtinah et al., 2023).

An additional challenge is the inadequacy of traditional assessment tools in diagnosing misconceptions. Two-Tier Multiple Choice (TTMC) instruments offer a promising solution. Designed to assess both knowledge and reasoning, TTMC instruments are more effective in identifying misconceptions than conventional formats (Vishnumolakala et al., 2017). However, further innovation is needed to make abstract chemical concepts more accessible. TTMC has validity with moderate interpretation and high reliability; it is feasible and meets the criteria as a good result question with content validity (CV) of 1.00, and it has an average test reliability of 0.92, which is classified as very high (Shidiq et al., 2014). The advantage of TTMC compared to conventional choice forms is that the percentage of students guessing answers is only 4%. In contrast, conventional multiple-choice makes students guess answers up to 20% (Tüysüz, 2009).

To overcome the existing problems, this research will develop a two-tier multiple-choice instrument integrated with virtual reality (VR). Integrating VR technology into a two-tier multiple-choice assessment instrument can be innovative. VR supports teaching and learning activities that can visualize abstract chemical material that must be close to 3 levels of representation in macroscopic, submicroscopic, and symbolic forms (Warman et al., 2023). In addition, VR is also associated with ethnochemistry, which is one branch of science that will study chemistry based on a cultural perspective (Arif et al., 2021). Learning ethnochemistry is important and can be a bridge in towards good science learning as study of learning in schools (Sarwi et al., 2023).

Virtual Reality, or computer-simulated environment, is a technology that can condition users to interact with an environment simulated by a computer (virtual environment) (Novianty et al., 2020). Virtual Reality (VR) is a simulation similar to the real world. The use of this technology creates a simulated environment that can be explored in 360 degree (Safiatuddin & Asnawi, 2023). Thus, VR can help learners build better understanding and reduce the risk of misconceptions.

The development of this ethnochemistry-based VR-integrated two-tier multiple-choice assessment instrument is expected to be able to serve as an early detection of misconceptions more accurately, improve concept understanding, and strengthen student engagement through more interactive and contextualized learning, both in terms of local culture and global social issues (Paristiowati et al., 2019; Rodriguez et al., 2020). This study focused on validating both the VR storyboard and the TTMC instrument through expert evaluation and the Aiken Index (Mohamad et al., 2015). Thus, this sftudy introduces a novel approach by developing a Two-Tier Multiple Choice (TTMC) instrument integrated with ethnochemistry content and supported by a virtual reality (VR) storyboard. Integrating VR technology with ethnochemistry context in misconception detection is an innovative aspect that has not been extensively explored in prior research. This combination offers a more immersive and contextually meaningful assessment experience, potentially increasing diagnostic accuracy and learner engagement.

This study aims to develop a VR-based assessment tool integrating ethnochemistry to detect misconceptions in reaction rate topics. Despite prior efforts to address chemistry misconceptions, instruments combining VR and ethnochemistry are limited. The study addresses two main questions: What is the content validity of the VR-integrated Two-Tier Multiple Choice (TTMC) instrument with ethnochemistry content?; and What is the content validity of the VR storyboard developed in this study? This study aims to provide a valid assessment instrument that can bridge ethnochemistry and innovative approaches in chemistry education by answering these questions.

Method

Research Design and Procedures

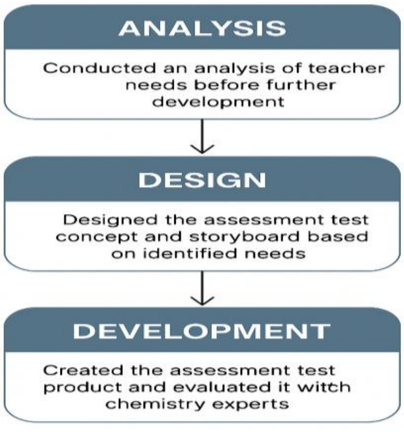

Figure 1. ADDIE development model

This study uses a research and development method called Research and Development (R&D). In addition, this study used the ADDIE model which has five stages: analysis, design, development, implementation, and evaluation. However, the ADDIE stage used in this study only goes up to development, which is a limited trial to see the feasibility and effectiveness of the developed TTMCVR. The ADDIE model was chosen for its relevance and effectiveness in guiding the systematic development of educational products (Adriani et al., 2020). According to research by Darnawati & Yulianto (2024) with the ADDIE development model, the stages carried out in the research can be seen in Figure 1.

Sample and Data Collection

The data in this study were obtained from the validation results conducted by material experts (chemistry education experts) and media experts, namely two chemistry education lecturers from UNS and five high school chemistry teachers in Surakarta through Focus Group Discussion (FGD). Material experts evaluate the accuracy of existing concepts and the relevance of the content used, while media experts assess the visual, technical, and media presentation aspects of the developed storyboard. This validation aims to ensure that the instrument meets the appropriate academic and media quality standards before it is widely used. The TTMC instrument consists of 10 multiple-choice questions linked to five simulation-based scenarios designed to diagnose student misconceptions in reaction rates.

Validation focused on two main products: the TTMC assessment items and the supporting storyboard. The content aspect of the questions includes the suitability of the material used with the truth of science, the development of science, and real life. The language aspect includes the language used being communicative; the sentences used being easily understood by Indonesian language rules, and the questions' readability. The presentation aspect includes aspects of the clarity of the sequence and consistency of the question structure, including question prompts that are conveyed, easy to understand, and do not cause many interpretations. The visual appearance of the questions used must also be clear. Each validator rated the instrument using a 1-4 point Likert scale across defined indicators. These ratings were used to determine the validity of items and storyboard components.

Data Analysis

The content validity analysis of the TTMC assessment instrument integrated with ethnochemistry charged VR with reaction rate material in this study used Aiken's formula (1985) with the following formula (Aiken, 1985).

$$V = \frac{\sum S}{n\,(C-1)} \quad (1)$$

Where S = R – Lo
Description:
V = Aiken index
S = the score given by the validator minus the lowest score in the category
R = score given by the validator
Lo = lowest assessment score (1)
C = highest assessment score (4)
n = number of validators

An item was considered valid if the V Value reached 0.76 or more. This is in accordance with the assessment standards in the Aiken formula with seven validators (Aiken, 1980).

Result and Discussion

Results

In this section, we'll present the validation results for each question item and the VR storyboard, clarifying their Aiken values. The validation of the 10 items on the VR-integrated TTMC with ethnochemistry content yielded high Aiken values ranging from 0.81 to 1.00 (Table 1), significantly exceeding the minimum acceptable threshold of 0.76.

Results of Content Validity of TTMC Integrated with VR-Based Assessment with Ethnochemistry Content on Reaction Rate Material

The results of the validity analysis of this research instrument are based on the assessment of 7 experts in their fields using the Aiken formula. Aiken's validity index is used in determining the level of content validity because a test or non-test instrument is proven valid if experts believe that the instrument developed can measure the ability to be measured (Retnawati et al., 2024).

Table 1. Aiken index analysis results for two tier multiple choice integrated virtual reality based assessment with ethnochemistry content on reaction rate material

Question Item	V Value	V Table	Conclusion
1	0.84	0.76	Valid
2	0.89	0.76	Valid
3	0.90	0.76	Valid
4	0.87	0.76	Valid
5	0.90	0.76	Valid
6	0.95	0.76	Valid
7	0.86	0.76	Valid
8	0.95	0.76	Valid
9	0.89	0.76	Valid
10	0.92	0.76	Valid

Based on the results of the Focus Group Discussion (FGD) that have been carried out, Table 1 shows the content validity value of 7 assessors, including experts on question items and storyboard experts from media and material aspects, using the Aiken formula. In the FGD process, the validators/experts were asked to evaluate the accuracy and relevance of the question items to ensure their suitability for the objectives to be achieved in the study.

Ethnochemistry VR Storyboard Validity Results on Reaction Rate Material

Table 2. Results of Aiken index analysis of storyboard for two tier multiple choice integrated virtual reality based assessment with ethnochemistry content on reaction rate material

Indicator	V Value	V Table	Conclusion
The images in the storyboard are interesting and easy to understand	0.86	0.76	Valid
The sentences used are easy to understand	0.95	0.76	Valid
The suitability of the size of the writing in the storyboard is appropriate in each section	0.81	0.76	Valid
The suitability of the size of the images in the storyboard is balanced and well organized	0.90	0.76	Valid
The images and videos used in the storyboard match the theme	1.00	0.76	Valid
The images used in the storyboard are interesting	0.95	0.76	Valid
The typeface in the storyboard is easy to read	0.90	0.76	Valid
The combination of text and background in the storyboard is balanced and attractive	0.90	0.76	Valid
The color gradation used in the storyboard is appropriate	0.76	0.76	Valid
Images and videos have provided ethnochemistry reinforcement	0.95	0.76	Valid
Suitability of material with misconception indicators	1.00	0.76	Valid
Well-organized presentation of material	0.90	0.76	Valid
The material presented is easy to understand	0.95	0.76	Valid
Material presented in the form of narrative questions in accordance with the concept of ethnochemistry	0.86	0.76	Valid
Images and videos can visualize material concepts	0.95	0.76	Valid
Systematic presentation of misconception questions is good	0.86	0.76	Valid

Table 2 presents the results of the content validity analysis of the VR storyboards assessed by 7 validators using the Aiken formula. In the FGD process, the validators reviewed the media and content aspects of the storyboards made by the researchers to ensure their effectiveness in conveying the intended message and suitability for the research objectives to be achieved.

Discussion

In this section, we will focus on interpreting the results presented in the results section, specifically how the high validity scores of the TTMC items and VR storyboard demonstrate the effectiveness of the integrated ethnochemistry tool in detecting misconceptions and enhancing science education.

High Validity Scores and Expert Assessment for TTMC Instrument

The high Aiken values (ranging from 0.76 to 1.00) for the TTMC items and the VR storyboard indicate that the instrument is valid and reliable. These results suggest that the experts found the content of the items and the VR media to be appropriate for their intended purpose. The validity scores confirm that the instrument is well-aligned with the study's objective, "detecting misconceptions in students' understanding of chemical reaction rates." The Ciu Bekonang ethnochemistry, chosen to integrate local cultural context into the scientific material, was particularly praised by experts for enhancing the cultural relevance of the reaction rate concepts. Using culturally grounded content supports the theory that integrating local knowledge can increase student engagement and motivation (Rahayu, 2019; Zidny et al., 2020). The high validity scores imply that experts viewed this integration as beneficial in terms of its cultural relevance and ability to effectively communicate complex scientific concepts in a way that resonates with students' everyday experiences (Widarti et al., 2025).

Instrument TTMC Integrated Virtual Reality Based Assessment Effectiveness in Misconception Detection

The primary goal of the TTMC instrument was to identify and address common misconceptions about reaction rates, such as the effect of concentration, surface area, temperature, and catalysts. The strong validity results for the test items related to these misconceptions (e.g., water concentration, surface area, and temperature) suggest that the instrument effectively detects and addresses students' misunderstandings (Kharisma et al., 2024).

The development of this ethnochemistry VR-integrated TTMC instrument consists of five scenarios, where each scenario discusses the steps in making ciu bekonang as the ethnochemistry chosen in this study. In this study, a specific context such as how to make ciu bekonang is used to illustrate the relevance of factors affecting reaction rates so that it can help bridge the gap between abstract scientific concepts and students' daily experiences.

The VR-based TTMC instrument was developed through five contextual scenarios, each aligned with the conceptual aspects of reaction rate material. Across the ten question items, the Aiken's V index ranged from 0.84 to 0.95, all exceeding the minimum threshold of 0.76, indicating that the items possess high content validity as judged by experts.

The first scenario is the initial stage of making ciu bekonang, which is mixing water and molasses. This first scenario contains question items 1, 2, and 3, where in question number 1, students will be given a submicroscopic illustration of the ratio of water and molasses. This is used to avoid misconceptions in the form of the assumption that if the concentration increases, the space for collisions will increase so that the probability of reaction increases (Rahayu et al., 2024). In this question, students are expected to be able to analyze the effect of the ratio of molasses and water on the fermentation rate. The validity of these three question items showed high results: the first item was 0.84, the second item was 0.89, and the third item was 0.90. These results validate the effectiveness of the VR-integrated TTMC instrument as a tool for detecting misconceptions at the submicroscopic level, particularly in the context of the fermentation reaction rate (Natalia & Sudrajat, 2023).

Items 4 and 5, associated with surface area concepts, received scores of 0.87 and 0.90, further reinforcing their relevance and clarity in assessing particle collision frequency. Item 6, which explores the reaction mechanism through enzyme interaction, achieved the highest score of 0.95, indicating exceptionally high validity. Item 7, addressing temperature effects, was rated 0.86, while items 8 to 10, concerning the role of catalysts and energy diagrams, obtained scores of 0.95, 0.89, and 0.92, respectively. These consistently high values across all items reflect a strong alignment between the content of the test and the conceptual indicators it aims to measure. The use of Aiken's V in this context not only confirms the validity of each item but also supports the instructional robustness of the instrument as a diagnostic tool for detecting specific misconceptions in chemical kinetics (Yonata et al., 2022).

By presenting misconceptions through interactive VR stimulation (e.g., graphs, submicroscopic illustrations), the instrument allows students to visualize and analyze chemical processes to promote more profound understanding and clear misconceptions. This approach aligns with the growing literature suggesting active, visual learning experiences help students overcome conceptual barriers (Zidny & Eilks, 2022).

Comparative Analysis with Previous Instruments

Conventional learning instruments for measuring understanding of chemistry concepts, particularly reaction rate material, generally consist of single-tier or two-tier multiple-choice questions presented textually without visual media support or local cultural context (Widiyatmoko & Shimizu, 2018). Such instruments tend to provide minimal visual stimuli and do not accommodate the relationship between scientific concepts and students' cultural experiences. Additionally, conventional instruments have limitations in representing chemical phenomena at the submicroscopic level, which is crucial in chemistry education (Supriyadi, 2023). This situation leads to poor detection of students' conceptual misconceptions, especially in understanding reaction mechanisms at the particle level. Furthermore, the conventional approach also contributes to low learning motivation. Students do not feel personally connected to the material being taught and rely on memorization rather than understanding the deeper conceptual meaning.

In contrast, the VR-based Two-Tier Multiple Choice (TTMC) instrument developed in this study offers significant advantages. This instrument presents phenomena visually, dynamically, and interactively and provides a real-world context (situated learning) through the stages of ciu bekonang production packaged in VR format. The local cultural context promoted by the ethnochemistry approach strengthens the relevance of learning to students' daily lives and enhances their sense of ownership of chemistry. Submicroscopic visualizations such as molecules, particle collisions, and fermentation processes enable students to understand abstract concepts more concretely, enhancing the instrument's ability to uncover hidden misconceptions that traditional instruments cannot access. By offering an immersive and meaningful learning experience, this approach has proven effective in increasing student engagement and interest in science.

Ethnochemistry VR Storyboard on Reaction Rate Material

The VR storyboard for making ciu bekonang includes five main scenarios; the first is the initial stage of VR; students will be given a video of ciu bekonang, which will be played in VR. Then, students will also be introduced to the tools and materials for making ciu bekonang. The tools and materials simulate simple experiments in making ciu bekonang.

Figures 2 and 3 present the virtual reality storyboard that incorporates these validated media elements, illustrating how the visual and textual components are integrated to support student engagement and understanding of acid-base concepts within ethnochemistry.

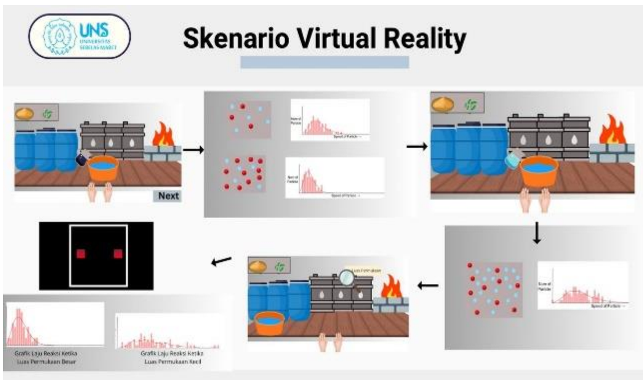

Figure 2. Scenario of mixing water and sugarcane drops in VR Ciu Bekonang storyboard

Figure 3. Yeast addition scenario on VR Ciu Bekonang storyboard

Incorporating Ciu Bekonang as an ethnochemistry topic in the VR scenarios added significant value to the instrument. The validation process showed that the ethnochemistry aspect (local cultural context) played a crucial role in student engagement, with experts agreeing that it made the material more accessible and relevant. The Ciu Bekonang process, as a local cultural activity, provides a tangible connection between students' lived experiences and the scientific concepts being taught. This contextualization of chemical principles helps students see the real-world applications of science, which is critical for improving motivation and comprehension (Widarti et al., 2025). Experts affirmed that this local cultural integration could help bridge the gap between abstract scientific concepts and students' daily lives.

Students' Cognitive Load and Visual Design in VR Media

Visual design in virtual reality (VR) based learning media plays a crucial role in instructional effectiveness, not merely an aesthetic aspect. In science learning, especially chemistry, rich in abstract concepts, inappropriate visual design can increase students' cognitive load and hinder the process of concept internalization. According to Cognitive Load Theory (Sweller & Chandler, 1991), cognitive load is divided into three types: intrinsic load related to the complexity of the material, extraneous load arising from the way information is presented, and germane load that supports the construction of understanding schemas. Effective VR media must minimize extraneous load through simple, consistent, yet informative visual displays and support germane load through visual elements that facilitate conceptual thinking processes. In this study, validators noted that colour gradients and contrast in the VR storyboard were inconsistent, particularly in molecular illustrations, making it challenging to visualize particle interactions. This visual ambiguity can divert students' cognitive focus and increase extraneous load. Conversely, colour consistency, dynamic molecular animations, and representative icons can accelerate information processing and strengthen concept retention.

Suggestions from Validators for Improvement

The media aspects of the VR storyboard, including text images and layout, scored high on the assessment results by the validators. It can be concluded that the elements in the VR storyboard are visually appealing and accessible to learners. Key strengths include the alignment of images and videos with the theme (1.00), the sentences used are easy to understand (0.95), the images used in the storyboard are attractive (0.95), and the images and videos used have provided ethnochemistry reinforcement (0.95). These make the content engaging, clear, and easy to understand, which is essential for increasing learner engagement and supporting their understanding of complex scientific concepts, especially those involving reaction rates in an ethnochemistryl context (Zidny & Eilks, 2022; Zidny et al., 2020).

Despite the high validity of the storyboard, the validators still provided suggestions for improvement, especially regarding the degradation of the colours used in the storyboard (0.76). The use of colour in the depicted molecules was considered inconsistent, and the contrast between colours should be optimized to improve clarity and visual appeal. Some aspects of the visual design, such as colour contrast in the depiction of molecules and image identification, were noted to be inconsistent. These issues, if addressed, could further improve the usability and accessibility of the instrument, ensuring that students with colour vision deficiencies can fully engage with the content (Zamudio et al., 2024). These adjustments also improve the accessibility of the storyboard, especially for learners with colour vision deficiencies, so they can still understand the content without difficulty (Elford et al., 2022).

The content aspects of VR storyboards, including their alignment with the desired learning objectives and their ability to address misconceptions, also received high validity scores. For example, the congruence of the content with the misconception indicators (1.00), the clarity of the content (0.95), and the systematic presentation of misconception questions (0.86) indicate that the content is well structured and designed to effectively diagnose and correct common misconceptions in acid-base chemistry. Including ethnochemistry reinforcement (0.86), which integrates local cultural contexts into scientific content, was considered valid and already demonstrated ethnochemistry integration by selecting ciu bekonang as the ethnochemistry content. This helps to contextualize chemistry concepts and make them more relevant to students' daily experiences, thus increasing their engagement with the material (Rahayu, 2019; Zidny et al., 2020).

The validators also suggested that the storyboard include more detailed and dynamic visualizations that represent the behaviour of particles at the submicroscopic level, particularly interactions between molecules such as glucose, enzymes, and fermentation products. This representation is important to illustrate the dynamics of reaction rates in a biochemical context more concretely and easily understood by students. Incorporating interactive elements or animations that allow students to observe these processes in real-time will provide a more accurate and intuitive understanding of chemical reactions. Research has shown that dynamic visualizations, such as molecular animations, can significantly improve students' understanding of abstract concepts in chemistry (Coduto et al., 2024; Stieff, 2019). This improvement will enhance the clarity of the material and deepen students' conceptual understanding by allowing them to visualize the atomic and molecular-level processes behind reactions (Maksimenko et al., 2021).

Implications for Science Education

This study's findings have important implications for science education, especially regarding misconception detection and ethnochemistry integration. The instrument's high validity suggests that VR-based tools have significant potential to address common misconceptions in science education when combined with culturally relevant content. Moreover, such tools can create an immersive learning environment where students can directly interact with scientific phenomena, improving their conceptual understanding.

Integrating local cultural contexts, as shown with Ciu Bekonang, can enhance the relevance of science education by making it more relatable and engaging (Gultom & Rohaeti, 2024). This approach helps overcome misconceptions and motivates students by connecting scientific principles to their personal and cultural experiences. Given the increasing recognition of the importance of culturally responsive teaching, this VR-integrated ethnochemistry tool can serve as a model for future educational tools designed to bridge the gap between abstract science content and students' cultural realities.

Conclusion

This study aims to develop and evaluate the content validity of the Two-Tier Multiple Choice (TTMC) instrument and Virtual Reality (VR) storyboard that incorporate ethnochemistry elements in the context of reaction rate material. Expert validation results indicate that all items in the TTMC instrument achieved Aiken's V scores ranging from 0.84 to 1.00, exceeding the minimum acceptability threshold of 0.76. These findings indicate that the content of the instruments is appropriate and relevant for measuring conceptual understanding and identifying misconceptions among students, and consistent with the research objective of developing valid and contextually relevant ethnochemistry-based learning tools. Experts also validated the developed VR storyboard, with Aiken's V scores ranging from 0.76 to 1.00. The media aspects (including visualization, text, and layout) and content aspects (relevance to misconception indicators and integration of ethnochemistry values) were deemed valid and appropriate. Thus, the TTMC and the VR storyboard form an integrated learning tool that is structured and culturally relevant, enhancing student engagement and conceptual understanding of abstract chemistry concepts.

Acknowledgments

The authors express their gratitude to the Directorate of Research, Technology, and Community Service (DRTPM) of the Ministry of Education, Culture, Research, and Technology, as well as the Institute for Research and Community Service (LPPM) of Universitas Sebelas Maret, for supporting the Strategic Research Collaboration Program (KATALIS) under contract number 2002.1/UN27.22/PT.01.03/2024. This support has significantly contributed to the successful implementation of this research.

Author Contributions

A.I.N. contributes to data collection, analysis, and drafting the manuscript; S.Y. and S.S. was responsible for the study's conceptual framework, design, and overall supervision; A.S.S. contributes to reviewing and editing the manuscript, as well as providing supervisory support, S. and S.R. as an etnochemistry expert and supervisor.

Funding

This research was funded by the Directorate of Research, Technology, and Community Service (DRTPM) of the Ministry of Education, Culture, Research, and Technology and the Institute for Research and Community Service (LPPM) of Universitas Sebelas Maret through the Strategic Research Collaboration Program (KATALIS) under contract number 2002.1/UN27.22/PT.01.03/2024.

Conflicts of Interest

The author declares that there is no conflict of interest related to the publication of this article.

References

Adriani, D., Lubis, P., & Triono, M. (2020). Teaching Material Development of Educational Research Methodology with ADDIE Models. *The 3rd International Conference Community Research and Service Engagements, IC2RSE 2019*. 4th December 2019, North Sumatra, Indonesia. https://doi.org/10.4108/eai.4-12-2019.2293793

Aiken, L. R. (1980). Content Validity and Reliability of Single Items or Questionnaires. *Educational and Psychological Measurement*, *40*(4), 955–959. https://doi.org/10.1177/001316448004000419

Aiken, L. R. (1985). Three Coefficients for Analyzing the Reliability and Validity of Ratings, Educational and Psychological Measurument. *Educational and Psychological Measurement*, *45*(1). 131–142. https://doi.org/10.1177/0013164485451012

Arif, I. H., Lukman, A., & Tuara, Z. I. (2021). Penerapan Pendekatan Culturally Responsive Teaching Terintegrasi Etnokimia dalam Mengembangkan Keterampilan Siswa Abad 21 pada Materi Hidrolisis di MAN 1 TIKEP. *Urnal Ilmiah Wahana Pendidikan*, *7*(2), 194–204. https://doi.org/10.5281/zenodo.4661844

Barke, H. D., Hazari, A., & Yitbarek, S. (2009). Misconceptions in Chemistry: Addressing Perceptions in Chemical Education. *Misconceptions in Chemistry: Addressing Perceptions in Chemical Education*, 1–294. https://doi.org/10.1007/978-3-540-70989-3

Coduto, J. R., Lazicki, A., & Leddy, J. (2024). Visualizing 3D Objects in Analytical Chemistry. *Journal of Chemical Education*, *101*(1), 77–87. https://doi.org/10.1021/acs.jchemed.3c00821

Darnawati, O. E., & Yulianto, S. (2024). Development of Nearpod-Based Learning Media to Improve Learning Outcomes in Elementary School Grade V IPAS Subjects. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 8568–8577. https://doi.org/10.29303/jppipa.v10i11.7552

Elford, D., Lancaster, S. J., & Jones, G. A. (2022). Fostering Motivation Toward Chemistry Through Augmented Reality Educational Escape Activities. A Self-Determination Theory Approach. *Journal of Chemical Education*, *99*(10), 3406–3417. https://doi.org/10.1021/acs.jchemed.2c00428

Gultom, H., & Rohaeti, E. (2024). The Effectiveness of the Ethnochemistry-Based Problem Based Learning Model on Students' Problem-Solving Ability in Chemistry Learning: A Meta-analysis Study in 2021-2024. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 508–514. https://doi.org/10.29303/jppipa.v10i7.8089

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2020). Misconceptions in Rate of Reaction and Their Impact on Misconceptions in Chemical Equilibrium. *European Journal of Educational Research*, *9*(4), 1405–1423. https://doi.org/10.12973/eu-jer.9.4.1405

Kharisma, I., Pada, A. U. T., Supriatno, S., Safrida, S., & Huda, I. (2024). Content Validity of the Critical Thinking Skill Test Instrument on Computer Based Test (CBT) Ecology Lesson for High School Education. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 3533–3540. https://doi.org/10.29303/jppipa.v10i6.6914

Maksimenko, N., Okolzina, A., Vlasova, A., Tracey, C., & Kurushkin, M. (2021). Introducing Atomic Structure to First-Year Undergraduate Chemistry Students with an Immersive Virtual Reality Experience. *Journal of Chemical Education*, *98*(6),

2104–2108. https://doi.org/10.1021/acs.jchemed.0c01441
Mohamad, M. M., Sulaiman, N. L., Sern, L. C., & Salleh, K. M. (2015). Measuring the Validity and Reliability of Research Instruments. *Procedia - Social and Behavioral Sciences*, *204*(November 2014), 164–171. https://doi.org/10.1016/j.sbspro.2015.08.129
Natalia, P. D., & Sudrajat, A. (2023). Development of Three-Tier Diagnostic Test Instrument to Measure Misconceptions of Class XI Students on Reaction Rate Materials. *Jurnal Teknologi Pendidikan Jurnal Penelitian dan Pengembangan Pembelajaran*, *8*(1), 1. https://doi.org/10.33394/jtp.v8i1.6192
Novianty, I., Sholihah, W., & Aditama, Y. (2020). Aplikasi Virtual Reality Atom Kimia di Seamolec. *MATRIK: Jurnal Manajemen, Teknik Informatika dan Rekayasa Komputer*, *19*(2), 257–262. https://doi.org/10.30812/matrik.v19i2.718
Oktaviana, D., Jamaluddin, J., & Bahri, S. (2024). Penyebab Miskonsepsi Peserta Didik pada Materi Pencemaran Lingkungan di SMA Negeri 1 Kediri. *Jurnal Pendidikan, Sains, Geologi, dan Fisika (Geoscienceed Journal*, *5*(1), 6-16. https://doi.org/10.29303/goescienceed.v5i1.295
Paristiowati, M., Zulmanelis, Z., & Nurhadi, M. F. (2019). Green Chemistry-Based Experiments as the Implementation of Sustainable Development Values. *JTK (Jurnal Tadris Kimiya)*, *4*(1), 11–20. https://doi.org/10.15575/jtk.v4i1.3566
Rahayu, I. W., Widhiyanti, T., & Mulyani, S. (2024). Analysis of Misconceptions on the Factors that Affect the Reaction Rate. *KnE Social Sciences*, *2024*, 140–150. https://doi.org/10.18502/kss.v9i13.15914
Rahayu, S. (2019). Socio-Scientific Issues (SSI) in Chemistry Education: Enhancing Both Students' Chemical Literacy & Transferable Skills. *Journal of Physics: Conference Series*, *1227*(1). https://doi.org/10.1088/1742-6596/1227/1/012008
Reiser, P., Neubert, M., Eberhard, A., Torresi, L., Zhou, C., Shao, C., Metni, H., Hoesel, C. V., Schopmans, H., Sommer, T., & Friederich, P. (2022). Graph Neural Networks for Materials Science and Chemistry. *Communications Materials*, *3*(1), 1–18. https://doi.org/10.1038/s43246-022-00315-6
Retnawati, H., Hidayati, K., Apino, E., Rafi, I., & Rosyada, M. N. (2024). Exploring Influential Factors and Conditions Shaping Statistical Literacy Among Undergraduate Students in Mathematics Education. *International Journal of Cognitive Research in Science Engineering and Education*, *12*(1), 1-17. http://dx.doi.org/10.23947/2334-8496-2024-12-1-1-17
Rodriguez, J. M. G., Hunter, K. H., Scharlott, L. J., & Becker, N. M. (2020). A Review of Research on Process Oriented Guided Inquiry Learning: Implications for Research and Practice. *Journal of Chemical Education*, *97*(10), 3506–3520. https://doi.org/10.1021/acs.jchemed.0c00355
Romine, W. L., Todd, A. N., & Clark, T. B. (2016). How Do Undergraduate Students Conceptualize Acid–Base Chemistry? Measurement of a Concept Progression. *Science Education*, *100*(6), 1150–1183. https://doi.org/10.1002/sce.21240
Safiatuddin, S., & Asnawi, R. (2023). Effectiveness of Using Virtual Reality-Based Virtual Laboratories in the Internet of Things Course. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5062–5070. https://doi.org/10.29303/jppipa.v9i7.4040
Sarwi, S., Fathonah, S., Anis, M., Rozi, F., Wardani, S., & Winarto, W. (2023). Effects of Teaching Materials on Learning Salt Factory Topics Based on Ethnoscience to Improve Mastery of Students Concepts and Life Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 10418–10425. https://doi.org/10.29303/jppipa.v9i11.5611
Shidiq, A. S., Masykuri, M., & Susanti, E. (2014). Pengembangan Instrumen Penilaian Two-Tier Multiple Choice untuk Mengukur Keterampilan Berpikir Tingkat Tinggi (Higher Order Thinking Skills) pada Materi Kelarutan dan Hasil Kali Kelarutan untuk Siswa SMA/MA Kelas XI. *Jurnal Pendidikan Kimia*, *3*(4), 83–92. Retrieved from https://www.researchgate.net/publication/316076450
Soeharto, S., & Csapó, B. (2021). Evaluating Item Difficulty Patterns for Assessing Student Misconceptions in Science Across Physics, Chemistry, and Biology Concepts. *Heliyon*, *7*(11). https://doi.org/10.1016/j.heliyon.2021.e08352
Stieff, M. (2019). Improving Learning Outcomes in Secondary Chemistry with Visualization-Supported Inquiry Activities. *Journal of Chemical Education*, *96*(7), 1300–1307. https://doi.org/10.1021/acs.jchemed.9b00205
Supriyadi, S. (2023). Effect of Emotional Intelligence on Science Learning Outcomes in Students Given Associational and Conventional Multiple-Choice Tests. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 2002–2009. https://doi.org/10.29303/jppipa.v9i4.3220
Sweller, J., & Chandler, P. (1991). Evidence for Cognitive Load Theory. *Cognition and Instruction*, *8*(4), 351–362. https://doi.org/10.1207/s1532690xci0804_5
Tüysüz, C. (2009). Development of Two-Tier Diagnostic Instrument and Assess Students' Understanding in Chemistry. *Scientific Research and Essays*, *4*(6), 626–631. Retrieved from https://www.researchgate.net/publication/254383547

Vishnumolakala, V. R., Southam, D. C., Treagust, D. F., Mocerino, M., & Qureshi, S. (2017). Students' Attitudes, Self-Efficacy and Experiences in a Modified Process-Oriented Guided Inquiry Learning Undergraduate Chemistry Classroom. *Chemistry Education Research and Practice*, *18*(2), 340–352. https://doi.org/10.1039/c6rp00233a

Warman, O., Fajri, B. R., & Irfan, D. (2023). Rancang Bangun Virtual Lab untuk Materi Pembelajaran Tegangan Permukaan pada Praktikum Kimia Fisika I Program Studi Pendidikan Teknik Informatika, Universitas Negeri Padang. *Jurnal Pendidikan Tambusai*, *7*(3), 24718–24729. Retrieved from https://www.jptam.org/index.php/jptam/article/download/10532/8442

Widarti, H. R., Wiyarsi, A., Yamtinah, S., Shidiq, A. S., Sari, M. E. F., Fauziah, P. N., & Rokhim, D. A. (2025). Analysis of Content Development in Chemical Materials Related to Ethnoscience: A Review. *Journal of Education and Learning*, *19*(1), 422–430. https://doi.org/10.11591/edulearn.v19i1.21210

Widiyatmoko, A., & Shimizu, K. (2018). The Development of Two-Tier Multiple Choice Test to Assess Students' Conceptual Understanding About Light and Optical Instruments. *Jurnal Pendidikan IPA Indonesia*, *7*(4). https://doi.org/10.15294/jpii.v7i4.16591

Yamtinah, S., Susanti, V. H. E., Saputro, S., Ariani, S. R. D., Shidiq, A. S., Sari, D. R., & Ilyasa, D. G. (2023). Augmented Reality Learning Media Based on Tetrahedral Chemical Representation: How Effective in Learning Process? *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(8). https://doi.org/10.29333/ejmste/13436

Yonata, B., Suyono, S., & Azizah, U. (2022). Answers Argumentation Instrument to Strengthen Conception Diagnostic Test on the Concept of Chemical Kinetics: Validity Aspect. *SHS Web of Conferences*, *149*, 1007. https://doi.org/10.1051/shsconf/202214901007

Zamudio, J. O., Miguel-Gómez, J. E., Santiago, A., Montaño-Hilario, J. M., Franco-Bodek, D., García-Ortega, H., Reina, A., & Reina, M. (2024). Chemical Element Lotto: A Captivating Guessing and Cultural Game Inspired by the Mexican Lottery. *Journal of Chemical Education*, J. Chem. Educ. 2024, *101*(11), 4820–4829. https://doi.org/10.1021/acs.jchemed.4c00759

Zidny, R., & Eilks, I. (2022). Learning About Pesticide Use Adapted from Ethnoscience as a Contribution to Green and Sustainable Chemistry Education. *Education Sciences*, *12*(4). https://doi.org/10.3390/educsci12040227

Zidny, R., Sjöström, J., & Eilks, I. (2020). A Multi-Perspective Reflection on How Indigenous Knowledge and Related Ideas Can Improve Science Education for Sustainability. *Science and Education*, *29*(1), 145–185. https://doi.org/10.1007/s11191-019-00100-x