JKPK (Jurnal Kimia dan Pendidikan Kimia), Vol. 10., No. 3, 2025 pp. 642-659
Chemistry Education Study Program, Universitas Sebelas Maret ISSN 2503-4146
http://jurnal.uns.ac.id/jkpk ISSN 2503-4154 (online)

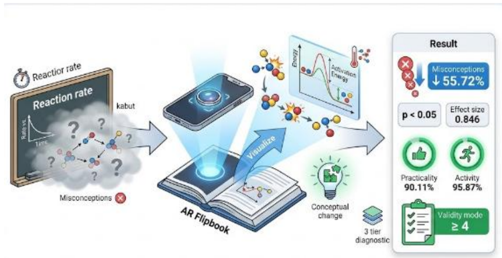
An Augmented Reality-Based Interactive Flipbook to Foster Conceptual Change in Learning Chemical Reaction Rates

Ananda Oktaviani, Aldi Firman Syahputra, Diah Ayu Apriliasari, Moh. Threewahyu Saifulloh, Eva Ayu Safitri, Kusumawati Dwiningsih*

Chemistry Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, Surabaya, Indonesia

ABSTRACT

Misconceptions about chemical reaction rates often persist because the topic involves abstract processes that are difficult to visualize through conventional instruction. This study developed and evaluated an Augmented Reality (AR) based interactive flipbook for reaction rate learning, focusing on validity, practicality, and initial effectiveness in reducing misconceptions and supporting conceptual change. Research and Development (R and D) was conducted using a modified 4D model limited to the define, design, and develop stages. Content and construct validity were assessed by chemistry education experts, learning media experts, and chemistry teachers. Practicality was examined through student response questionnaires and observations of learning activities. Effectiveness was measured using a three tier diagnostic test, with pretest and posttest results analyzed using the Wilcoxon test and effect size. Expert evaluation indicated that the flipbook met validity criteria, with mode scores of at least 4 across all assessed aspects. Practicality outcomes were high, reflected by a 90.11% questionnaire score and 95.87% activity observation score. The intervention reduced average misconceptions by 55.72%, supported by a significant difference ($p < 0.05$) and a very large effect size (0.846). Results suggest AR integrated flipbooks can strengthen visualization of reaction rate concepts and facilitate conceptual change by directly targeting common misconceptions. Further studies with broader implementation are recommended to strengthen generalizability.



Keywords: *Augmented Reality; Interactive flipbook; Conceptual change; Misconception; Chemical reaction rate.*

*Corresponding Author: kusumawatidwiningsih@unesa.ac.id

How to cite: A. Oktaviani, A. F. Syahputra, D. A. Apriliasari, M. T. Saifulloh, E. A. Safitri, and K. Dwiningsih, "An augmented reality-based interactive flipbook to foster conceptual change in learning chemical reaction rates," *JKPK (Jurnal Kimia dan Pendidikan Kimia)*, vol. 10, no. 3, pp. 642-659, 2025. [Online]. Available: https://doi.org/10.20961/jkpk.v10i3.109225

Received: *2025-09-22* ***Accepted:*** *2025-12-12* ***Published:*** *2025-12-31*

INTRODUCTION

Chemistry is a branch of natural science that explains natural phenomena through facts, principles, theories, and scientific procedures. Chemistry learning has a distinct multirepresentational character that integrates macroscopic, submicroscopic, and symbolic levels [1]. Effective learning requires coherent integration of these representations so that students develop accurate conceptual understanding and avoid conceptual errors. Abstract chemistry concepts often create learning difficulties that increase the risk of misconceptions, indicating the need for pedagogical strategies and innovative learning media that align with 21st century learning demands.

Science literacy remains a major concern at the international level. The PISA 2022 report [2] indicates that science literacy in many countries is still at an alarming level, reflecting weaknesses in scientific reasoning and conceptual understanding. Improvement of learning quality through pedagogical innovation and better learning media is therefore urgent, especially in contexts where student performance remains below the OECD average.

Misconceptions can be defined as discrepancies between students' understanding and established scientific concepts [3]. Misconceptions constitute a global challenge in chemistry education and have been reported across multiple educational contexts [4], [5]. Evidence shows that misconceptions occur in many chemistry topics, including chemical bonding, organic reactions, solutions, electrolysis, and stoichiometry [3], [6]. Misconceptions hinder learning progress because incorrect concepts interfere with the understanding of subsequent material and disrupt the construction of coherent knowledge structures.

One topic that is prone to misconceptions is reaction rate. Reaction rate not only emphasizes numerical and symbolic aspects, but also requires students to understand even invisible particles. Learning complexity increases in the subtopic of factors affecting reaction rate, where students must connect experimental variables to collision theory and kinetic explanations [7]. Persistent misconceptions include the belief that catalysts are consumed, the assumption that higher temperature always increases reaction rate without considering activation energy, and the idea that concentration affects only the amount of substance rather than collision frequency. Misconception rates reported among Indonesian senior high school students in this topic range from 20 to 41% across concentration, temperature, surface area, and catalyst factors [8].

Several factors contribute to misconceptions in chemistry, including abstract content, unsystematic content organization, and ineffective instructional strategies. Traditional instruction that relies on lectures, limited discussions, and macroscopic practicum activities often fails to support integration of the three representations. Lecture based instruction tends to position students as passive recipients of information, while discussions may remain ineffective when students retain initial misconceptions. Macroscopic practicum provides empirical experience but often fails to bridge understanding at the submicroscopic level. Limited cognitive conflict in conventional approaches reduces opportunities for conceptual change [3], [9]. This condition emphasizes the need for new learning approaches that are more effective, adaptive, and technology-based.

Conceptual change requires learning experiences that challenge initial ideas and support reconstruction of understanding. Posner et al. [10] describe conceptual change as a process that occurs when learners experience dissatisfaction with prior concepts and adopt new concepts that are more intelligible, plausible, and fruitful. Constructivist learning theory emphasizes that knowledge is constructed through interaction with new experiences, involving assimilation and accommodation to form scientifically accepted understanding [3], [6], [11], [12]. Cognitive theories including cognitive load theory, dual coding theory, and multimedia learning theory also support the use of visualization and interactive representations to reduce cognitive burden and strengthen meaning.

Interactive digital learning media offers potential to address these challenges by supporting visualization and engagement. Flipbooks can present material systematically and attractively, while augmented reality (AR) can visualize submicroscopic phenomena in two or three dimensions, bridging macroscopic observations and particle level explanations [13], [14]. Studies have reported that AR can enhance motivation, visualization skills, and conceptual understanding in science learning [15]. AR can also support cognitive conflict by making invisible chemical processes more observable and testable against students' initial ideas [16].

Extensive studies have examined flipbooks and augmented reality (AR) separately, yet a research gap remains regarding their integration. Most AR studies focus on visualization and motivation but rarely examine the specific role of AR in reducing misconceptions in reaction rate material. Conversely, flipbook studies are generally static and do not utilize AR for visual and manipulative aspects. The integration of interactive flipbooks with AR has the potential to combine the strengths of both media, namely systematic presentation, submicroscopic visualization, and the cognitive conflict necessary for conceptual change. Based on these gaps, this study aims to develop and evaluate AR-based interactive flipbooks for chemical reaction rate material. The research focuses on testing the validity, practicality, and initial effectiveness of the media in facilitating conceptual change and reducing students' misconceptions. The significance of this study lies in its theoretical contribution, enriching the literature on the integration of interactive learning media for conceptual change, and in its practical contribution, providing tools that can be directly applied by chemistry teachers in secondary schools.

METHODS

Research Design

This study employed a Research and Development (R&D) approach using the 4D model developed by Thiagarajan et al. [17], which consists of the define, design, and develop stages. The disseminate stage was not carried out because this study focused on testing the validity, practicality, and initial effectiveness of the developed learning media. This design was chosen in line with the research objective to produce an innovative product while testing its feasibility at an early stage (pilot study).

Participants

The limited trial involved a group of senior high school students enrolled in the science program (equivalent to grade 11) at a high school in Indonesia. The participating students had previously studied reaction rate material as part of the regular curriculum. Participants were selected using purposive sampling based on curriculum suitability, time availability, and their readiness to take part in learning activities. The limited sample size was considered sufficient for initial research focusing on product feasibility, though further studies with a broader scope are still needed.

Preliminary research (pilot study) with a small sample is commonly conducted to assess feasibility, instrument clarity, and initial media effectiveness, as well as to identify potential implementation obstacles before applying it on a wider [18]. In line with this, Whitehead et al. [19] emphasize that the number of samples in a pilot study is not intended to produce estimates of population parameters but rather to provide an initial picture of the effectiveness of the intervention. Furthermore, Montgomery [20] argues that the justification for the sample size in a feasibility study should be based on the methodological objectives to be achieved, not merely on practical rules. Thus, the limited number of participants in this study is methodologically acceptable because it aligns with the characteristics of early-stage development research.

Instruments

The instruments used in this study consisted of the following:

1. Expert Validation Sheet
   This was used to assess the content validity and construct validity of the AR-based interactive flipbook. Three validators were involved, consisting of a chemistry education expert, a learning media expert, and a high school chemistry teacher. Each validator assessed the flipbook using a Likert scale ranging from 1 to 5, as shown in Table 1, with the following scoring criteria [21]:

Table 1. Likert Scale

Assessment	Score
Not good	1
Not very good	2
Fairly good	3
Good	4
Very good	5

2. Student Response Questionnaire
   This was used to measure the practicality of the media and students' perceptions regarding the ease of use, attractiveness, and usefulness of the media. The response questionnaire was reviewed before being used in the trial.
3. Student Activity Observation Sheet
   This was Used to record student engagement during learning, such as reading learning objectives, answering conceptual questions, interacting with AR features, and completing exercises and evaluations. The student observation sheet was reviewed before being used in the trial.
4. Three-Tier Diagnostic Test
   This instrument consisted of 16 questions covering factors that affect reaction rates (concentration, temperature, surface area, and catalysts). Each question included three levels of answers: concept (tier 1), conceptual reasoning (tier 2), and level of confidence (tier 3). This instrument enabled the identification of students' conceptual understanding, misconceptions, and lack of understanding [22]. This question is adapted from research previously conducted by Safputry in 2024 [23].

Media Development Procedure

1. Define Stage

   This stage involved analyzing learning needs, learner characteristics, and initial misconceptions, as well as formulating learning objectives.

2. Design Stage

   This stage included designing the flipbook structure, selecting the presentation format, and integrating AR components to visualize submicroscopic representations such as particle collisions and activation energy. The flipbook was equipped with contextual phenomena, conceptual questions, animations, and AR simulations to trigger cognitive conflict.

   The media creation process was carried out using several software programs, including Macromedia Flash, Canva, Flip PDF Professional, and the Assembler Studio application or AssemblerEdu website. Meanwhile, diagnostic test instruments were developed and administered using Google Forms. AR was integrated with the flipbook through the use of markers placed on certain parts and contents of the flipbook. These markers were created using Assembler Studio.

3. Development Stage

   Expert validation was conducted, followed by revisions based on feedback, and then limited trials were carried out with students. During the limited trial, data were collected through response questionnaires, observations of student activities, and a pretest–posttest using a three-tier diagnostic test. The limited trial employed a One-Group Pretest–Posttest Design. Research Design Notation:

   O1 — X — O2

   Explanation:

   O1: Pretest

   O2: Posttest

   X: Treatment using AR-based interactive flipbook media

Data Analysis Techniques

The data analysis in this study consisted of three aspects: validity, practicality, and effectiveness.

1. Validity

   The validity of the AR-based interactive flipbook was analyzed using the mode of expert judgment scores. The media was considered valid if it obtained a mode value of ≥ 4 in each aspect or indicator.

2. Practicality

   Practicality was determined from student response questionnaires and observations of learning activities. The results were calculated in percentage form, with the media categorized as practical if the score was ≥ 61%.

3. Effectiveness

   Effectiveness was evaluated through a three-tier diagnostic pretest–posttest to identify the reduction of misconceptions. The scoring system followed [24] as presented in Table 2.

Table 2. Three-tier *pretest-posttest scoring*

Tier 1 Answer	Tier 2 Reason	Tier 3 Yes/No	Category	Score
Correct (B)	Correct (B)	Yes (Y)	Understands the concept (UC)	1
Correct (B)	Incorrect (S)	Yes (Y)	Misconception (MC)	3
Incorrect (S)	Correct (B)	Yes (Y)	Misconception (MC)	3
Incorrect (S)	Incorrect (S)	Yes (Y)	Misconception (MC)	3
Correct (B)	Correct (B)	No (T)	Does not understand the concept (DNC)	2
Correct (B)	Incorrect (S)	No (T)	Does not understand the concept (DNC)	2
Incorrect (S)	Correct (B)	No (T)	Does not understand the concept (DNC)	2
Incorrect (S)	Incorrect (S)	No (T)	Does not understand the concept (DNC)	2

The misconception reduction was calculated using the following formula [25]:

$$\%P = \frac{\Sigma MB - \Sigma MA}{\Sigma MB} x\ 100\%$$

Explanation:

%P	=	percentage of misconception reduction
∑MB-MA	=	difference between the number of initial misconceptions and the number of final misconceptions
∑MB	=	number of initial misconceptions

The criteria for misconception reduction are presented in Table 3.

Table 3. Misconception Reduction Criteria

Percentage of Misconception Reduction	Shift Category
> 56,30%	High
56,30% - 17,18%	Moderate
<17,18%	Low

Furthermore, statistical analysis was conducted using the Wilcoxon signed-rank test, considering the small sample size and non-parametric data distribution. In addition, Cohen's effect size was calculated to determine the magnitude of the intervention's effect. The interpretation categories are shown in Table 4.

Table 4. Cohen's Effect Size

Cohen's value	Category
0,2	Small
0,5	Moderate
≥ 0,8	Large

RESULTS AND DISCUSSION

The results of this study indicate that the interactive flipbook based on Augmented Reality (AR) that was developed has a high level of validity, practicality, and effectiveness in supporting students' conceptual understanding of reaction rate material. Validity was confirmed through expert assessments that ensured the suitability of the content and media construct; practicality was supported by positive responses and active student engagement during learning; while effectiveness was demonstrated through a significant reduction in misconceptions, as measured by a three-tier diagnostic test. These findings highlight the novelty of this research, namely the integration of flipbook narratives with AR technology and the conceptual change approach. Unlike previous studies that employed AR independently, this study shows that when AR is integrated into a systematic narrative flow, the processes of cognitive conflict, accommodation, and conceptual reconstruction can be facilitated more effectively.

AR is particularly relevant in chemistry learning because it can convert abstract submicroscopic phenomena into clearer visual representations [13], [26]. Digital flipbooks also support engagement and concept retention through integrated text, images, and interactive animations [14]. Integration of AR into a conceptual change oriented flipbook therefore provides a more comprehensive approach that combines visualization strength with structured learning support for misconception reduction.

AR based flipbook was designed with a structured flow that guides learners progressively through factors affecting reaction rates. Access to each factor is unlocked only after completion of evaluation tasks in the previous section, supported by a login mechanism embedded in each conceptual change menu. This structure promotes mastery learning and encourages sequential reconstruction of concepts. The tiered design aligns with conceptual change principles because it provides learners with repeated opportunities to identify, test, and revise misconceptions related to each factor before advancing to subsequent content (see Figures 1 and Figure 2). This systematic flow functions not only as content organization but also as a pedagogical strategy that strengthens deeper conceptual change.

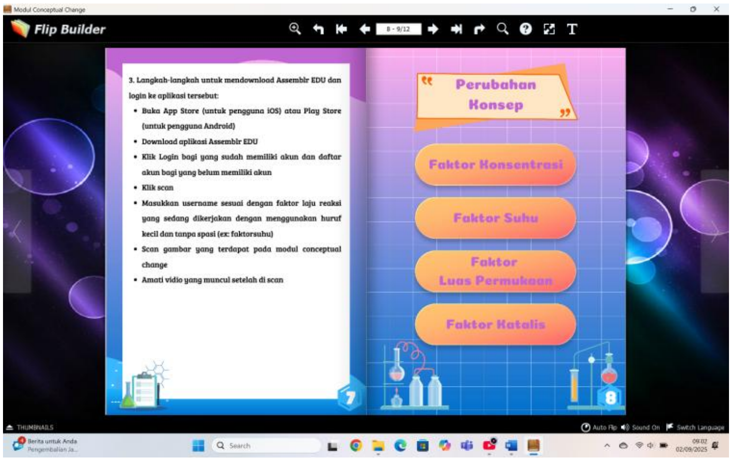


Figure 1. Concept Change Menu

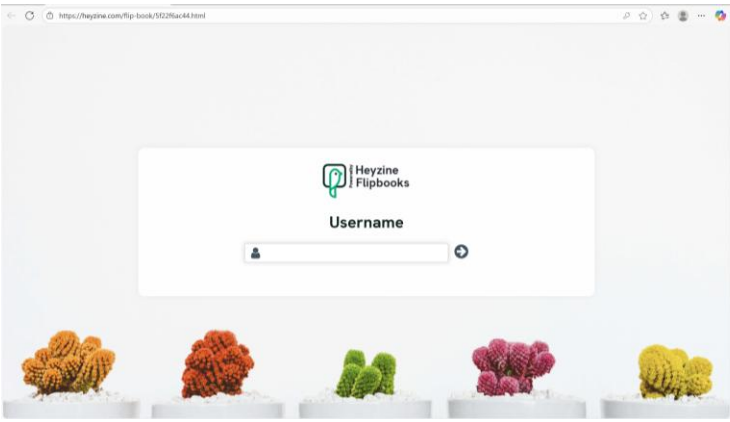


Figure 2. Initial Display

1. Validation of AR-based Interactive Flipbooks

Table 5. Media Validation Results

Validity	Modus	Criteria
Content	5	Very valid
Construct	5	Very valid
Media validation results	5	Very Valid

Expert validation results show that the flipbook meets validity criteria in terms of content and construct, with a mode score of ≥ 4 across all indicators. Content validity is reflected in the accuracy of chemical concepts, systematic presentation, and integration of contextual phenomena (e.g., catalysts, particle collisions, activation energy). Construct validity is demonstrated through the clarity of language, layout, and the integration of interactive features such as quizzes, animations, and AR simulations.

The strong content and construct validity reported in Table 5 indicates that the AR-based interactive flipbook has been developed in alignment with cognitive principles that support chemistry concept learning. In line with dual coding theory, humans think not only through words but also through visual representations such as images or animations [27], [28]. The high validity obtained shows that the combination of narrative (verbal) with AR visualization (nonverbal) has been organized appropriately, enabling students to build a dual understanding of the phenomenon of reaction rate. This is crucial because information processed through two different but complementary cognitive channels has a greater chance of being stored in long-term memory and recalled when students encounter similar problems.

Construct validity also reflects the application of multimedia learning theory, which emphasizes three main principles: dual channels, limited capacity, and active processing [29]. The AR-based interactive flipbook in this study was designed with learners' cognitive capacity in mind, using concise text, relevant visual presentations, and AR animations that directly illustrate abstract concepts such as particle collisions and activation energy. The validity results, which show high consistency among experts, confirm that this medium successfully balances verbal and visual elements proportionally, thereby avoiding excessive cognitive load.

These findings are also consistent with the cognitive load theory framework, which distinguishes between intrinsic load, extraneous load, and germane load [27], [30]. Reaction rate material indeed carries a high intrinsic load because it involves abstract concepts and submicroscopic representations. However, through structured media presentation, this flipbook successfully reduces extraneous load, which often arises from unsystematic material presentation or irrelevant visualizations. At the same time, it promotes germane load, which is essential for forming new conceptual schemas. AR-based visualizations also play an important role in helping students build concrete analogies, for example through animations of particle collisions under various concentrations or temperatures, making misconceptions easier to overcome and conceptual understanding more firmly reconstructed.

Flipbooks with a variety of features greatly contribute to attracting students' interest in learning. The validity results above also confirm that the access control, audio-visual, and quiz features implemented are considered effective in supporting student learning and are valid for use. These features also enable students to more easily review material that they feel they have not fully understood [14].

These validation results further confirm that flipbooks are aligned with the curriculum and provide accurate scientific visualizations. This finding is consistent with previous studies [15], [31], which emphasize that accurate submicroscopic representations are essential for building conceptual understanding in chemistry. The use of AR as a visualization tool is also consistent with the findings of Yamtinah et al. [32], which reported validity results in the valid category.

2. Practicality of Using AR-based Interactive Flipbooks

The practicality of the media was confirmed through student questionnaire results of 90.11% and observation scores of 95.87%. Students rated the flipbook as easy to use, engaging, and helpful for understanding abstract concepts. Observation data also indicated that students actively answered conceptual questions, scanned AR markers, and completed exercises and evaluations. The results of the practicality questionnaire and student activity observations are presented in Figure 3 and Figure 4 below.

These findings are consistent with previous studies showing that AR can increase engagement and learning motivation [16], [33]. The integration of AR into flipbooks combines the advantages of structured media with interactive visualization, thereby supporting students' active engagement [33]. The use of AR in this learning medium is also considered effective in minimizing misconceptions by providing visible particle representations [34].

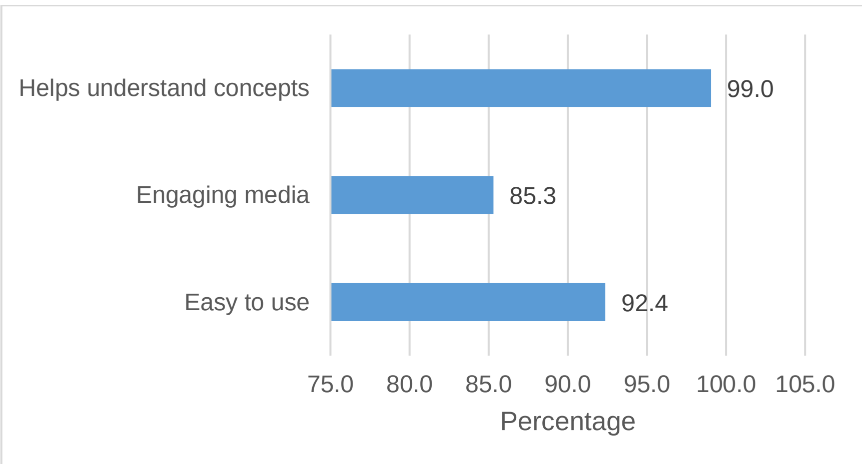


Figure 3. Results of the Student Response Questionnaire

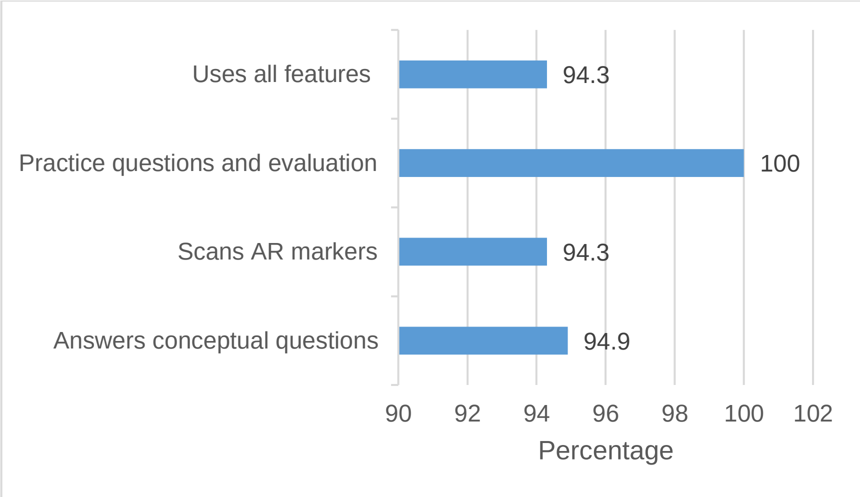


Figure 4. Results of Observation of Student Activities

The high level of learner engagement can be explained by Keller [35] ARCS Motivation Model, which asserts that learning motivation is determined by four main aspects: attention, relevance, confidence, and satisfaction. The AR-based interactive flipbook clearly fulfills these four aspects. First, attention is achieved because AR presents unique visualizations that capture students' interest (see Figure 5). Second, relevance is demonstrated through the contextual phenomena presented, such as examples from everyday life, including the use of cleaners, fish preservation, satay sales, and fruit ripening to explain factors that influence reaction rates (see Figure 6). Third, confidence is enhanced as students are able to practice and verify their understanding independently through interactive quizzes and evaluation questions. Fourth, satisfaction is attained when students successfully complete the exercises and realize that they have understood concepts that were previously considered difficult. Thus, the high practicality of this medium reflects not only its ease of use, but also the increased learning motivation of students in accordance with ARCS theory.

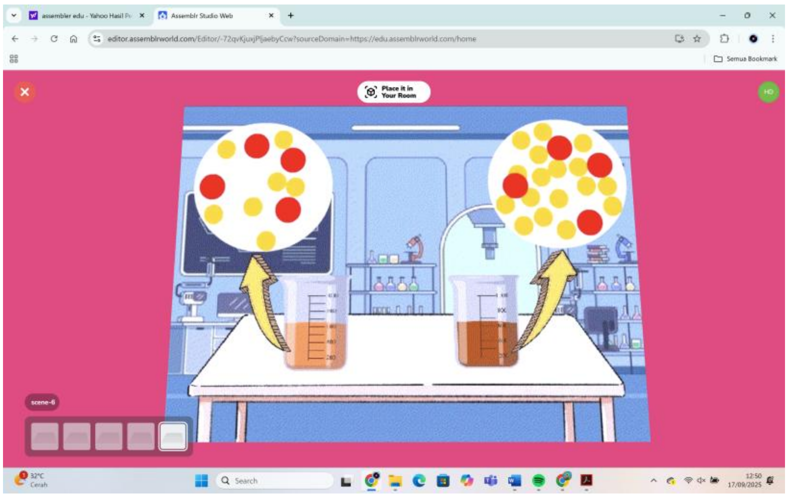


Figure 5. AR Features for Concentration Factor

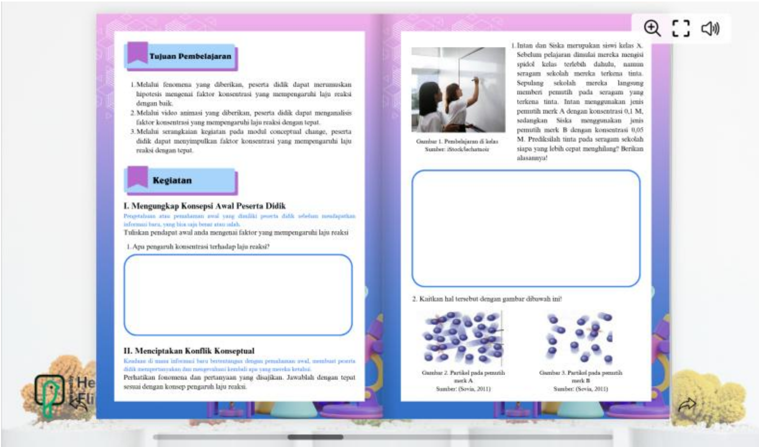


Figure 6. Phenomena in Concentration Factors

3. Effectiveness of Media in Conceptual Change of Students

The results of the three tier diagnostic test indicate an average misconception reduction of 55.72%. Table 6 shows that the total misconceptions decreased from 249 (pretest) to 110 (posttest), resulting in a reduction of 55.78%. The Wilcoxon test further confirmed a statistically significant difference between pretest and posttest scores ($p < 0.05$). As presented in Table 7, the analysis produced $Z = -4.475$ with Asymp. Sig. (2 tailed) = 0.000, indicating a meaningful improvement after the intervention. In addition, the effect size of 0.846, categorized as large in Table 8, reflects a strong influence of the AR based interactive flipbook on students' conceptual understanding. Although the misconception reduction falls within a moderate range, the large effect size suggests that the flipbook had a substantial impact on concept restructuring. These outcomes exceed those reported by Tiro dan Afadil [36], who found only a small reduction in misconceptions (−12%) using conventional AR based media. This comparison emphasizes the stronger potential of integrating AR into interactive flipbooks to facilitate conceptual change.

Table 6. Misconception Reduction Results

∑ Pretest misconceptions	∑ Posttest misconceptions	Misconception reduction (%)
249	110	55.78

Table 7. Wilcoxon Test Results

Component	Results
N	28
Z	-4.475
Asymp. Sig. (2-tailed)	0.000

Table 8. Effect Size Results

Effect Size	Category
0.846	Large

The three tier diagnostic test used in this study provides methodological value by enabling deeper identification and analysis of students' misconceptions. This instrument does not only classify responses as correct or incorrect, but also reveals students' underlying reasoning and confidence levels. Results showing a reduction in moderate misconceptions alongside a high effect size suggest that improvement was not limited to answer changes, but reflected deeper conceptual restructuring for most learners. The three tier test therefore functioned effectively to capture the depth of conceptual change while strengthening evidence for the effectiveness of the developed AR based flipbook media.

These findings are consistent with the research of Jusniar et al. [37], which reported very high validity and good reliability of the three-tier instrument in identifying misconceptions about reaction rates. However, compared to that study, the present research not only mapped misconceptions but also demonstrated the actual impact of digital media intervention on conceptual restructuring. Meanwhile Yonata dan Azizah [38] study on the four-tier diagnostic test indicates the potential of a more complex instrument, but the results of this study show that the three-tier is adequate, practical, and reliable for the secondary school context. Additionally, the findings of Fikri et al. [39] on the online implementation of the three-tier test demonstrate the flexibility of the instrument, which aligns with this study since the use of digital media also requires adaptation of evaluation instruments. Therefore, the contribution of this study lies not only in its success in reducing misconceptions through innovative media but also in proving that the three-tier system remains relevant for measuring the impact of technology-based learning on abstract concepts such as reaction rates.

The effectiveness of AR-based interactive flipbooks in reducing misconceptions can also be explained through the conceptual change theory framework proposed by Posner et al. [10]. This theory emphasizes that knowledge restructuring occurs when learners undergo a series of stages: dissatisfaction with their initial misconceptions, intelligibility and plausibility through the acceptance of new, more logical information, and finally fruitfulness, when the new conception can be applied consistently. The results of this study indicate that interactive flipbooks are able to systematically facilitate all of these stages. Learners are first encouraged to identify their misconceptions through diagnostic questions, then confronted with contextual phenomena that create cognitive conflict, supported by AR visualizations that illustrate concept accommodation at the submicroscopic level, and finally asked to reconstruct concepts through interactive quizzes and evaluations. This pattern is consistent with previous findings that conceptual change-based strategies are more effective than conventional knowledge transfer approaches in addressing misconceptions [26], [33]. Presenting phenomena closely related to everyday life can also help reduce students' cognitive conflicts and misconceptions [4]. Empirical support from the Wilcoxon test results and the large effect size values in this study reinforce the argument that AR-based flipbooks not only provide an interactive learning experience but also function as conceptual scaffolding, enabling learners to transition from incorrect intuitive concepts to accurate scientific understanding.

The reduction in misconceptions was moderate because this study was limited to a pilot test, meaning that learners who did not experience significant conceptual changes could lower the overall average. Moreover, the use of AR-based interactive flipbooks was carried out within a relatively short learning cycle, whereas conceptual change requires more time for misconceptions to be significantly reduced. The limitations of the current AR content, which does not yet allow for direct manipulation of particles, also constrained full interactivity. This limitation reduced the depth of new understanding achieved by students.

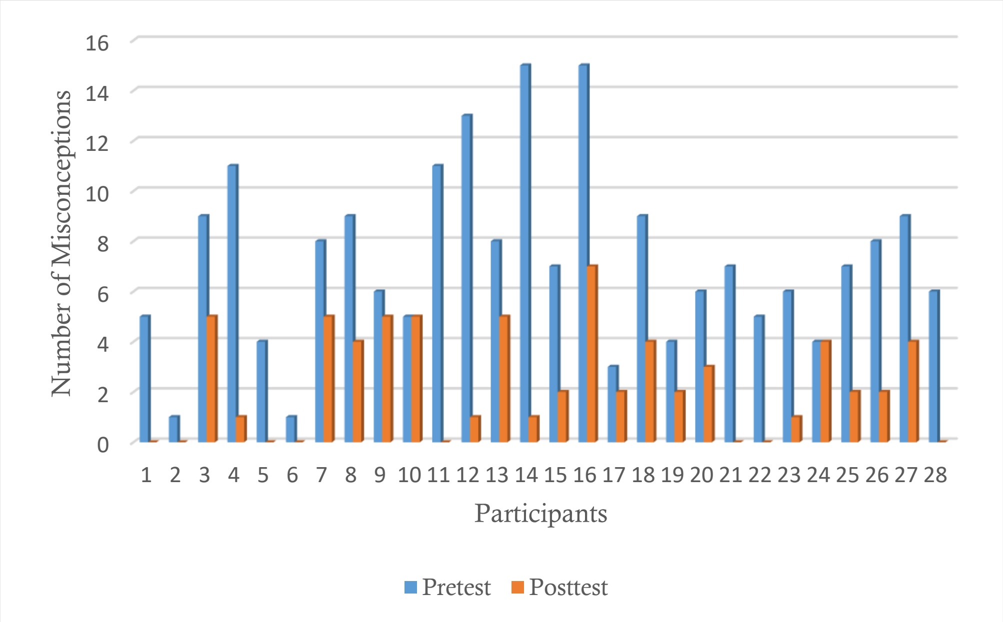


Figure 7. Results Misconception *Pretest-Posttest*

The overall trend of pretest and posttest misconceptions is also illustrated in Figure 7, which visually shows the decrease in misconception levels after students used the AR based interactive flipbook. However, Figure 7 also indicates that several students did not show changes. This result may be associated with device limitations, differences in initial ability, or varying levels of engagement during learning. Such conditions are consistent with Kruse et al. [40], who stated that AR does not always guarantee conceptual understanding without adequate learning support.

4. Discussion and Implications

The AR-based interactive flipbook developed with the conceptual change framework effectively reduced misconceptions in chemical reaction rate material. Initial concept diagnosis revealed that many students only partially understood the concentration factor and held misconceptions about surface area, such as assuming that “powder has a small surface area” because of its small particle size. To address this, the media presents analogies comparing whole cubes and smaller cubes, AR animations of particles and collisions, and visualizations of high and low temperatures. This approach helps students with low visualization skills imagine abstract submicroscopic phenomena, thereby strengthening conceptual understanding through visual representations rather than relying solely on text or verbal descriptions.

Theoretically, these results are consistent with recent research showing that conceptual change strategies improve conceptual understanding more effectively than conventional methods, especially when supplemented with visual representations and structured scaffolding [41]. They also affirm the importance of accommodation and assimilation in modern chemistry education [42]. The AR-based flipbook in this study functions as digital scaffolding within the zone of proximal development (Vygotsky) and as a multi-representational tool that supports dual coding and multimedia learning.

Practically, these findings are relevant to the demands of the 21st century, which emphasize critical thinking, problem solving, creativity, and technological literacy. AR-based interactive flipbooks help learners connect abstract concepts with contextual phenomena, for example, analyzing the relationship between concentration, temperature, or surface area and reaction rate through particle collision animations. Students are not only memorizing but also being trained to predict, evaluate, and relate concepts to everyday experiences, in line with the principle of learning by doing (Bruner). In addition, the integration of flipbooks and AR, as reported by Ripsam dan Nerdel [33], shows that while AR increases student engagement, it requires structured narratives to be more meaningful. This study confirms that AR packaged in a conceptual change-based flipbook has a more significant impact on reducing misconceptions.

Several limitations should be noted. Participant involvement was limited, so findings should be interpreted as preliminary and require confirmation through studies with larger samples. Implementation was restricted to three stages of the 4D model, excluding the dissemination stage, so effectiveness at broader scale has not yet been established. Nonparametric statistical procedures were applied because of the small sample size, and stronger conclusions will require experimental designs with larger samples. Technical constraints, including limited access to devices needed for AR features, may also have influenced student engagement. Future studies are recommended to include larger samples, comparison groups, longer intervention periods, improved AR features that allow direct manipulation, and orientation sessions to ensure adequate familiarity with AR use before data collection.

CONCLUSION

This study successfully developed and evaluated an interactive flipbook based on Augmented Reality (AR) for chemical reaction rate material, with a focus on validity, practicality, and initial effectiveness. Expert validation results showed that the media met validity criteria in terms of content and construct, with a mode score of ≥ 4 on all indicators. The practicality of the media was also confirmed by student response questionnaire results (90.11%) and observations of student activities (95.87%), which indicated that the flipbook was easy to use, engaging, and encouraged active participation. Initial effectiveness was demonstrated by a 55.72% reduction in misconceptions, significant Wilcoxon test results ($p < 0.05$), and an effect size of 0.846, indicating a strong influence on students' conceptual restructuring. Theoretically, this study enriches the literature on the integration of narrative media with immersive technology based on conceptual change. Practically, AR-based interactive flipbooks are ready to become an alternative innovative learning medium for chemistry teachers to reduce misconceptions about reaction rates.

This study still has limitations, including a small number of participants, a short intervention duration, and AR features that are not yet fully interactive. Therefore, further research is recommended involving a larger sample, longer learning duration, and the development of AR with richer particle manipulation capabilities. Subsequent studies can compare this media with other learning models to gain a more comprehensive understanding of the effectiveness of AR-based interactive flipbooks in facilitating conceptual change.

REFERENCES

[1] D. W. Johnso, R. T. Johnson, and M. B. Stanne, *Cooperative Learning Methods: A Meta-Analysis*. Minneapolis, MN, USA: The Cooperative Learning Center, University of Minnesota, 2000.

[2] OECD, *PISA 2022 Results (Volume I)*. Paris, France: OECD Publishing, 2023. doi: 10.1787/53f23881-en.

[3] N. N. C. Samuel, I. O. Georgina, E. C. Nwune, J. N. Nnoli, and N. K. Oguezue, "Students' Misconceptions As A Determinant Of Academic Achievement In Organic Chemistry In Otuocha Education Zone," Awka, Nigeria: Eagle Leap Publication, May 2025. [Online]. Available: www.eagleleappublication.com

[4] H. M. Pektaş, O. Karamustafaoğlu, and H. Çelik, "The Role of Educational Data Mining and Artificial Intelligence Supported Learning Analytics on Conceptual Change: New Approaches to Differentiated Instruction," *J Sci Educ Technol*, Jun. 2025, doi: 10.1007/s10956-025-10214-3.

[5] S. N. B. M. Radzuan and C. Bin Hanri, "Science Students' Misconceptions of Basic Concepts of Chemistry on Matter and Its Particulate Properties," *International Journal of Academic Research in Progressive Education & Development*, vol. 13, no. 4, Nov. 2024, doi: 10.6007/IJARPED/v13-i4/23824.

[6] S. Kumar, "An Analysis of Common Misconceptions in Chemistry Education and Practices," *International Journal of Applied and Behavioral Sciences*, vol. 1, no. 1, pp. 01–11, Jul. 2024, doi: 10.70388/ijabs24701.

[7] A. Priliyanti, I. W. Muderawan, and S. Maryam, "Analisis Kesulitan Belajar Siswa dalam Mempelajari Kimia Kelas XI," *Jurnal Pendidikan Kimia Undiksha*, vol. 5, no. 1, pp. 11–18, Jun. 2021, doi: 10.23887/jjpk.v5i1.32402.

[8] L. A. Lestari, Subandi, and Habiddin, "Identifikasi Miskonsepsi Siswa pada Materi Laju Reaksi dan Perbaikannya Menggunakan Model Pembelajaran Learning Cycle 5E dengan Strategi Konflik Kognitif ," *Jurnal Pendidikan, Teori, Penelitian dan Pengembangan*, vol. 6, no. 6, pp. 888–894, Jun. 2021. 10.17977/jptpp.v6i6.14876

[9] I. I. Salame and P. Casino, "Using Chemistry Concepts Inventory to Identify Alternative Conceptions and Their Persistence in General

Chemistry Courses," *International Journal of Instruction*, vol. 14, no. 3, pp. 787–806, Jul. 2021, doi: 10.29333/iji.2021.14346a.

[10] G. J. Posner, K. A. Strike, P. W. Hewson, and W. A. Gertzog, "Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change," *Sci Educ*, vol. 66, no. 2, pp. 211–227, 1982. Doi: 10.1002/sce.3730660207

[11] A. Lemma, "Early Chemistry Misconceptions: Status and Implications for Science Education in Ethiopia," *African Journal of Chemical Education*, vol. 8, no. 2, pp. 190–203, Sep. 2022, [Online]. Available: https://www.researchgate.net/publication/364050391

[12] S. Wangchuk, "Misconception in Air Pressure and Use of Conceptual Change Model to Eliminate Misconception," *International Journal of English Language, Education and Literature Studies (IJEEL)*, vol. 3, no. 3, pp. 60–69, 2024, doi: 10.22161/ijeel.3.3.12.

[13] J. Levy, I. C. Chagunda, V. Iosub, D. C. Leitch, and J. S. McIndoe, "MoleculAR: An Augmented Reality Application for Understanding 3D Geometry," *J Chem Educ*, vol. 101, no. 6, pp. 2533–2539, Jun. 2024, doi: 10.1021/acs.jchemed.3c01045.

[14] H. Unayah, M. Rasyid, S. Suyanta, I. Wilujeng, and L. Rahmawati, "A Recent Study on Flipbook as Media Implementation in Science Education in Digital Age: A Systematic Literature Review," *Unnes Science Education Journal*, vol. 13, no. 3, pp. 248–258, Dec. 2024, doi: 10.15294/usej.v13i1.17200.

[15] H. Peeters, S. Habig, and S. Fechner, "Does Augmented Reality Help to Understand Chemical Phenomena during Hands-On Experiments?–Implications for Cognitive Load and Learning," *Multimodal Technologies and Interaction*, vol. 7, no. 2, Feb. 2023, doi: 10.3390/mti7020009.

[16] S. Syskowski, S. Wilfinger, and J. Huwer, "Impact and Classification of Augmented Reality in Science Experiments in Teaching—A Review," *Educ Sci (Basel)*, vol. 14, no. 7, p. 760, Jul. 2024, doi: 10.3390/educsci14070760.

[17] S. Thiagarajan, D. S. Semmel, and M. I. Semmel, *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook*. Bloomington, IN: National Center for Improvement of Educational Systems (DHEW/OE), 1974. https://files.eric.ed.gov/fulltext/ED090725.pdf

[18] E. van Teijlingen and V. Hundley, "The importance of pilot studies," *Nursing Standard*, vol. 16, no. 40, pp. 33–36, Jun. 2002, doi: 10.7748/ns2002.06.16.40.33.c3214.

[19] A. L. Whitehead, S. A. Julious, C. L. Cooper, and M. J. Campbell, "Estimating the Sample Size for a Pilot Randomised Trial to Minimise the Overall Trial Sample Size for the External Pilot and Main Trial for a Continuous Outcome Variable," *Stat Methods Med Res*, vol. 25, no. 3, pp. 1057–1073, Jun. 2016, doi: 10.1177/0962280215588241.

[20] R. Montgomery, "Sample Size Justification in Feasibility Studies: Moving Beyond Published Guidance," *Pilot Feasibility Stud*, vol. 11, no. 1, pp. 1–8, Dec. 2025, doi: 10.1186/s40814-025-01675-9.

[21] R. F. DeVellis, *Scale Development Theory and Applications Fourth Edition*, 4th ed. Los Angeles: SAGE Publications, 2017.

[22] A. S. Pramasdyahsari, D. Viviana, Sugiyanti, B. P. Pant, and I. Ratnayake, "Construction of three-tier diagnostic test for identifying student misconceptions in exponential properties," *Jurnal Riset Pendidikan Matematika*, vol. 11, no. 1, pp. 64–76, 2024, doi: 10.21831/jrpm.v11i1.73561.

[23] R. Nareswari Rachmadhaniar and D. Novita, "Feasibility of Four-Tier Multiple Choice Diagnostic Test for Identification Conception on Chemical Equilibrium Concept", *Chem.Educ.Pract*, vol. 7, no. 1, pp. 1–6, May 2024.doi: 10.29303/cep.v7i1.6633

[24] F. T. Kustiarini, E. H.V. Susanti, and A. C.S. Nugroho, "Pengunaan Tes Diagnostik Three-tier Test Alasan Terbuka Untuk Mengidentifikasi Miskonsepsi Larutan Penyangga," *Jurnal Pendidikan Kimia*, vol. 8, no. 2, pp. 171–178, 2019, doi: 10.20961/jpkim.v8i2.25236.

[25] M. Rizki, M. Nurhadi, and I. I. Widiyowati, "Penerapan Model Pembelajaran Berbasis Masalah Untuk Menurunkan Miskonsepsi Siswa Tentang Konsep Reaksi Redoks," *Jurnal Zarah*, vol. 8, no. 1, pp. 14–20, 2020. doi: 10.31629/zarah.v8i1.1974

[26] M. Bullock, N. Graulich, and J. Huwer, "Using an Augmented Reality Learning Environment to Teach the Mechanism of an Electrophilic Aromatic Substitution," *J Chem Educ*, vol. 101, no. 4, pp. 1534–1543, Apr. 2024, doi: 10.1021/acs.jchemed.3c00903.

[27] C. Clark and R. Kimmons, "Cognitive Load Theory," *EdTechnica*, 2023, doi: 10.59668/371.12980.

[28] J. O. Wooten and J. A. Cuevas, "The Effects of Dual Coding Theory on Social Studies Vocabulary and Comprehension in Elementary Education," *International Journal on Social and Education Sciences*, vol. 6, no. 4, pp. 673–691, Sep. 2024, doi: 10.46328/ijonses.696.

[29] R. E. Mayer, *Multimedia Learning*, 2nd ed. New York: Cambridge University Press, 2009.

[30] J. Sweller, "Cognitive Load During Problem Solving: Effects on Learning," *Cogn Sci*, vol. 12, pp. 257–285, 1988. doi: 10.1016/0364-0213(88)90023-7

[31] R. A. Mashami, Khaeruman, and Ahmad, "Pengembangan Modul Pembelajaran Kontekstual Terintegrasi Augmented Reality untuk Meningkatkan Keterampilan Berpikir Kritis Siswa," *Hydrogen: Jurnal Kependidikan Kimia*, vol. 9, no. 2, pp. 67–77, Dec. 2021, doi: 10.33394/hjkk.v9i2.4500.

[32] S. Yamtinah *et al.*, "Augmented Reality Learning Media Based on Tetrahedral Chemical Representation: How Effective in Learning Process?," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 19, no. 8, pp. 1–16, May 2023, doi: 10.29333/ejmste/13436.

[33] M. Ripsam and C. Nerdel, "Augmented reality for chemistry education to promote the use of chemical terminology in teacher training," *Front Psychol*, vol. 15, Jul. 2024, doi: 10.3389/fpsyg.2024.1392529.

[34] N. M. Duc and N. V. Quang, "Application of Augmented Reality in Chemistry Education: A Systemic Review Based on Bibliometric Analysis from 2002 to 2023," *International Journal of Education in Mathematics, Science and*

Technology, vol. 12, no. 6, pp. 1415–1434, Sep. 2024, doi: 10.46328/ijemst.4265.

[35] J. M. Keller, "Development and Use of the ARCS Model of Instructional Design," *Journal of Instructional Development*, vol. 10, no. 3, pp. 2–10, 1987. 10.1007/BF02905780

[36] F. Tiro and Afadil, "The Use of Augmented Reality Based-Learning Media to Reduce Students' Misconceptions," *Jurnal Akademika Kimia*, vol. 3, no. 11, pp. 140–145, Sep. 2022, doi: 10.22487/j24775185.2022.v11.i3.pp140.145.

[37] J. Jusniar, E. Effendy, E. Budiasih, and S. Sutrisno, "Misconceptions in Rate of Reaction and their Impact on Misconceptions in Chemical Equilibrium," *European Journal of Educational Research*, vol. 9, no. 4, pp. 1405–1423, Oct. 2020, doi: 10.12973/eu-jer.9.4.1405.

[38] B. Yonata and U. azizah, "Four-Tier Diagnostic Test on Chemical Kinetics Concepts for Undergraduate Students," in *International Joint Conference on Science and Engineering (IJCSE)*, Atlantis Press International, 2021. doi: 10.2991/aer.k.211215.078.

[39] R. A. Fikri, H. Suwono, and H. Susilo, "Online Three-tier Diagnostic Test to Identify Misconception about Virus and COVID-19," *JPBI (Jurnal Pendidikan Biologi Indonesia)*, vol. 8, no. 2, pp. 129–141, Jul. 2022, doi: 10.22219/jpbi.v8i2.18895.

[40] S. Kruse, W. Müller, and H. Weitzel, "A framework for analysis and development of augmented reality applications in science and engineering teaching," *Educ Sci (Basel)*, vol. 13, no. 9, p. 926, 2023, doi: 10.3390/educsci13090926.

[41] J. Addido, A. Burrows, and T. Slater, "The Effect of the Conceptual Change Model on Conceptual Understanding of Electrostatics," *Educ Sci (Basel)*, vol. 12, no. 10, pp. 1–16, Oct. 2022, doi: 10.3390/educsci12100696.

[42] M. Y. M. Wu and E. J. Yezierski, "Secondary chemistry Teacher Learning: Precursors for and Mechanisms of Pedagogical Conceptual Change," *Chemistry Education Research and Practice*, vol. 24, no. 1, pp. 245–262, Oct. 2022, doi: 10.1039/d2rp00160h.