



Development of Augmented Reality-Based Chemistry Learning Media Integrated with Local Wisdom on Colloid System Material to Reduce Misconceptions and Improve Learning Outcomes

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Abstract: Development of Augmented Reality-Based Chemistry Learning Media Integrated with Local Wisdom on Colloid System Material to Reduce Misconceptions and Improve Learning Outcomes. Chemistry education on colloid systems presents persistent challenges due to the abstract and submicroscopic nature of the concepts involved, which conventional instructional methods struggle to address effectively. This study aimed to develop Augmented Reality (AR)-based chemistry learning media integrated with local wisdom for colloid system instruction, evaluate its validity and practicality, and measure its effectiveness in reducing misconceptions and improving students' learning outcomes. Using the ADDIE development model with a one-group pretest-posttest design, the study was conducted at SMA Swasta Methodist 7 Medan involving 26 students of class XI IPA. The developed media consisted of two AR marker-based learning tools: Marker 1 covering dispersed substances, dispersion media, and colloid types contextualized through local cultural examples such as gulai and teh talua, and Marker 2 visualizing colloid properties including Brownian motion, the Tyndall effect, coagulation, dialysis, adsorption, and electrophoresis through animated microscopic representations. Validation results showed average scores of 4.4 (content) and 4.3 (language) categorized as valid, and a perfect score of 5 (very valid) across all media aspects. The instrument validation reached 93.1%, categorized as highly feasible. Student learning interest ranged from good to very good (74.04%–80%), and observation data confirmed active participation (75%–95%). The N-gain score of 0.47 indicated moderate improvement in conceptual understanding, while posttest results demonstrated substantial reduction of misconceptions across all colloid concepts. The AR-based media integrated with local wisdom was concluded to be valid, practical, and effective for colloid system learning.

Keywords: augmented reality, colloid system, local wisdom, misconception reduction, learning outcomes.

Abstrak: *Judul Development of Augmented Reality-Based Chemistry Learning Media Integrated with Local Wisdom on Colloid System Material to Reduce Misconceptions and Improve Learning Outcomes.* Pembelajaran kimia pada materi sistem koloid menghadapi tantangan yang konsisten akibat sifat konsep yang abstrak dan submikroskopik, yang sulit diatasi

melalui metode pembelajaran konvensional. Penelitian ini bertujuan untuk mengembangkan media pembelajaran kimia berbasis Augmented Reality (AR) terintegrasi kearifan lokal pada materi sistem koloid, mengevaluasi validitas dan kepraktisannya, serta mengukur efektivitasnya dalam mereduksi miskonsepsi dan meningkatkan hasil belajar siswa. Menggunakan model pengembangan ADDIE dengan desain one-group pretest-posttest, penelitian dilaksanakan di SMA Swasta Methodist 7 Medan melibatkan 26 siswa kelas XI IPA. Media yang dikembangkan terdiri dari dua media pembelajaran berbasis marker AR: Marker 1 mencakup zat terdispersi, medium pendispersi, dan jenis-jenis koloid yang dikontekstualisasikan melalui contoh budaya lokal seperti gulai dan teh talua, serta Marker 2 memvisualisasikan sifat-sifat koloid meliputi gerak Brown, efek Tyndall, koagulasi, dialisis, adsorpsi, dan elektroforesis melalui representasi mikroskopik animasi. Hasil validasi menunjukkan skor rata-rata 4,4 (konten) dan 4,3 (bahasa) berkategori valid, serta skor sempurna 5 (sangat valid) pada seluruh aspek media. Validasi instrumen mencapai 93,1% berkategori sangat layak. Minat belajar siswa berada pada kategori baik hingga sangat baik (74,04%–80%), dan data observasi mengonfirmasi partisipasi aktif siswa (75%–95%). Skor N-gain sebesar 0,47 menunjukkan peningkatan pemahaman konsep kategori sedang, sementara hasil posttest menunjukkan reduksi miskonsepsi yang signifikan pada seluruh konsep koloid. Media berbasis AR terintegrasi kearifan lokal disimpulkan valid, praktis, dan efektif untuk pembelajaran sistem koloid.

Kata kunci: *augmented reality, sistem koloid, kearifan lokal, reduksi miskonsepsi, hasil belajar.*

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▪ INTRODUCTION

Chemistry education presents persistent challenges rooted in the abstract nature of chemical concepts, requiring students to simultaneously navigate macroscopic, submicroscopic, and symbolic levels of representation, a cognitive demand that often exceeds conventional instructional methods. Most chemical phenomena are invisible to the naked eye, making it difficult for students to construct accurate mental models of molecular structures, chemical bonds, reaction mechanisms, and three-dimensional molecular geometry (Elford et al., 2022b). These challenges are especially pronounced in the topic of colloids, where students must grasp the submicroscopic behavior of dispersed phases, colloidal particle interactions, and phenomena such as the Tyndall effect concepts that are inherently invisible and resistant to direct observation (Hatta et al., 2021).

Empirical evidence of these difficulties is extensive. (Miterianifa et al., 2020) demonstrated that high school students consistently commit comprehension errors, process skill errors, and careless errors when solving colloid-related problems, with understanding errors being the most prevalent across all academic ability levels stemming from students' low ability to grasp abstract concepts such as dispersed phases and the submicroscopic behavior of colloidal systems. These challenges are further compounded by low scientific literacy among Indonesian students: Indonesia's results from the 2022 Programme for International Student Assessment (PISA) placed the country at a lower rank in science literacy, while a survey among chemistry teachers in Palu revealed that teaching methods remain dominated by lectures with limited use of interactive and engaging learning media, contributing to low student interest in studying colloids (Ladjidji et al., 2024).

Augmented Reality (AR) has emerged as a transformative pedagogical response to these challenges. By superimposing computer-generated contextual information onto the physical world, AR eliminates the reliance on two-dimensional representations of three-dimensional molecular phenomena that characterizes traditional textbook

instruction (Abdinejad et al., 2021). A systematic review of 49 papers published between 2011 and 2020 by (Mazzuco et al., 2022) identified a significant increase in AR research in chemistry education since 2018, with molecular structures constituting the most frequent topic of AR application (18.9%), followed by chemical bonds and chemical reactions. In the affective domain, AR increases motivation and engagement by providing immersive, interactive learning experiences, while in the cognitive domain it facilitates visualization of abstract concepts, enhances knowledge retention, and supports spatial skill development (Mazzuco et al., 2022). Confirmed through a quasi-experimental study with 118 seventh-grade students that AR technology significantly increased student achievement and, critically, eliminated student misconceptions a finding of particular relevance to colloid instruction where persistent conceptual errors are well-documented (Irfachsyad & Meidia, 2020).

Regarding learning outcomes and scientific literacy, (Cahyani & Fadly, 2024) conducted a large-scale study involving 714 students from five high schools in Indonesia and found that mobile game-based learning with AR significantly improved both chemical literacy and numeracy compared to conventional instruction. (Ladjidji et al., 2024) demonstrated that VR-based learning media on colloid material significantly improved students' chemical literacy, with the experimental class achieving an average posttest score of 87 compared to a pretest score of 38.8, representing a substantial learning gain that underscores the power of technology-enhanced instruction on this specific topic.

The integration of local wisdom through ethnoscience approaches has gained scholarly attention as a complementary strategy for making chemistry education more contextually meaningful and relevant. When students encounter abstract chemical concepts through familiar cultural practices and everyday phenomena from their own communities, comprehension and motivation are demonstrably enhanced (Sapta et al., 2025). Developed an AR-based chemical literacy instructional material integrating Madurese cultural wisdom that achieved a teacher usability score of 91.50% and a student readability score of 87.91%, indicating high feasibility. However, their study focused exclusively on product feasibility rather than evaluating effectiveness in reducing misconceptions through an experimental design (Arifiani & Irwanto, 2024). (Cahyani & Fadly, 2024) further reported that ethnoscience integration positively impacts students' skills and motivation by increasing their perception of chemistry's relevance to daily life, yet the combination of ethnoscience with AR specifically for misconception reduction on colloid material has not been examined.

Despite the growing body of research on AR in chemistry education, several significant gaps remain. First, while AR and ethnoscience-based approaches have each been studied independently, no study has simultaneously integrated these two elements into a single coherent AR-based instructional media specifically targeting colloid material existing literature treats these as separate research strands (Razvan Ioan et al., 2024; Zidny & Eilks, 2022). Second, the systematic measurement of misconception reduction through rigorous pretest-posttest experimental designs remains underdeveloped in AR-based chemistry learning; although found that AR eliminates misconceptions, the generalizability of this finding to the colloid topic specifically is limited, and most AR studies prioritize attitudinal outcomes or general achievement over systematic misconception diagnosis (Miterianifa et al., 2020). Third, the assessment of learning outcomes and scientific literacy within AR-supported, ethnoscience-integrated chemistry learning on colloid material is insufficiently documented, particularly with respect to whether cultural contextualization through local wisdom amplifies the cognitive benefits

of AR (Sari et al., 2021). Fifth, studies integrating local wisdom with AR technology specifically for colloid learning remain scarce, and those that do exist have not employed experimental designs capable of demonstrating effectiveness in reducing misconceptions (Junaid et al., 2022).

These gaps collectively reveal an underexplored area with substantial potential, and the present study addresses them by developing an AR-based chemistry learning media that simultaneously incorporates AR visualization technology and local wisdom content specifically for the colloid topic a dual integration not achieved in any existing study focused on misconception reduction and learning outcomes (Mansour et al., 2025; Sumarni et al., 2022).

The primary novelty of the present study lies in this integration: (a) (Khairani & Prodjosantoso, 2023) augmented Reality technology for visualizing abstract colloid concepts at the submicroscopic level, enabling students to observe phenomena such as Brownian motion, colloidal particle interactions, and the Tyndall effect in an interactive three-dimensional environment; and (b) local wisdom content that contextualizes colloid learning within students' cultural and everyday environment, transforming abstract chemical principles into meaningful experiences grounded in familiar practices (Ladjidji et al., 2024). Rather than presenting local wisdom as a decorative element, the present study positions cultural practices as authentic substantive contexts through which fundamental colloid concepts can be understood, thereby enhancing both relevance and meaningfulness of chemistry learning. This integrated approach represents a significant departure from prior research, which has predominantly emphasized motivation and general achievement outcomes without systematically measuring misconception reduction on colloid material (Widiastari & Redhana, 2021).

Based on the identified problems and research gaps, this study aims to: (1) develop an AR-based chemistry learning media integrated with local wisdom for colloid material; (2) evaluate the validity and feasibility of the developed media through expert validation and user testing; (3) measure the effectiveness of the media in reducing students' misconceptions about colloid concepts through pretest and posttest results; (4) assess the improvement in students' learning outcomes using validated assessments and N-Gain analysis; and (5) examine students' perceptions and responses toward the AR-based learning media in terms of engagement, usability, and motivation. In this study, misconception refers to students' systematic conceptual errors regarding submicroscopic colloid phenomena that differ from scientifically accepted concepts, identified through diagnostic tests conducted during the pretest and posttest stages (Elford et al., 2022a).

▪ METHOD

This research was conducted at SMA Swasta Methodist 7 Medan during the even semester of the 2025/2026 academic year. The type of research used was *Research and Development* (R&D) with the ADDIE development model consisting of *Analysis, Design, Development, Implementation, and Evaluation*. This study aimed to develop an *Augmented Reality* (AR)-based chemistry learning media integrated with local wisdom on colloid system material to reduce misconceptions and improve students' learning outcomes.

Research Design

The research design used was *One Group Pretest-Posttest Design* to determine changes in students' understanding before and after using AR learning media.

Research Subjects

The research subjects consisted of expert validators, chemistry teachers, and students of class XI IPA. The validators consisted of a material expert and a media expert. The research sample consisted of 26 students of class XI IPA selected using the *purposive sampling* technique.

Table 1. Research Subjects

No	Research Subjects	Total
1	Material expert	1 person
2	Media expert	1 person
3	Chemistry teacher	1 person
4	Students of class XI IPA	26 students

This study involved three validators. The media validator holds a Master's degree (S2) in Chemistry Education with a research focus on the development of digital and interactive learning media. The material validator holds a Master's degree (S2) in Chemistry Education with expertise in chemistry content quality and curriculum. The third validator was a practicing chemistry teacher at the research school, providing practical feedback on media usability and content relevance in classroom settings.

Development Model

The study used the ADDIE development model consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. In the analysis stage, observations and interviews identified students' difficulties in understanding abstract colloid concepts due to limited interactive media. The design stage involved preparing colloid learning materials integrated with local wisdom, AR media, instruments, and assessments. In the development stage, the AR-based learning media was created and validated by material and media experts. The implementation stage was conducted with 26 students of class XI IPA through pretest, AR-assisted learning activities, posttest, and student response questionnaires. Finally, the evaluation stage was carried out based on validation results, student responses, learning outcomes, and misconception reduction after using the AR learning media.

Research Instruments

The research instruments used in this study included material and media validation sheets, structured essay questions for the pretest and posttest, student response questionnaires, observation sheets, and research documentation to support data collection and analysis. Essay responses were assessed using a scoring rubric developed specifically for this study. Each item in the essay questions was scored on a scale of 0-10 with the following criteria: a score of 10 indicates a complete and accurate explanation (categorized as Understanding); scores of 8 and 6 indicate partially correct explanations with decreasing completeness (categorized as Partial Understanding); a score of 4 indicates only one correct element; a score of 2 indicates a very brief and inaccurate response; and a score of 0 indicates no response (scores 0-4 categorized as Not Understanding). Responses demonstrating systematically incorrect but consistent conceptual explanations were further categorized as Misconception.

Data Collection Techniques

Data collection techniques included observation, interviews, tests, questionnaires, and documentation. Tests were administered in the form of *pretest* and *posttest* to determine the improvement of students' learning outcomes after using the AR learning media.

Validation Technique

Media validation was conducted by material experts and media experts using validation sheets. Material validation included content and language aspects, while media validation included display and usability aspects.

The validation data were analyzed using the following formula:

$$P = (\Sigma X / \Sigma X_i) \times 100$$

Table 2. Validation Criteria

Percentage	Category
81–100%	Very Valid
61–80%	Valid
41–60%	Fairly Valid
21–40%	Less Valid
0–20%	Invalid

Data Analysis Technique

The data were analyzed using descriptive quantitative analysis. The improvement in students' learning outcomes was analyzed using the N-Gain formula:

$$\text{N-Gain} = (\text{Posttest score} - \text{Pretest score}) / (\text{Maximum score} - \text{Pretest score})$$

Table 3. N-Gain Categories

N-Gain Value	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

Learning outcome data were analyzed based on *pretest* and *posttest* results, while student response data were analyzed using questionnaire percentage scores and students' responses during the use of AR learning media.

RESULT AND DISCUSSION

Product Development Results

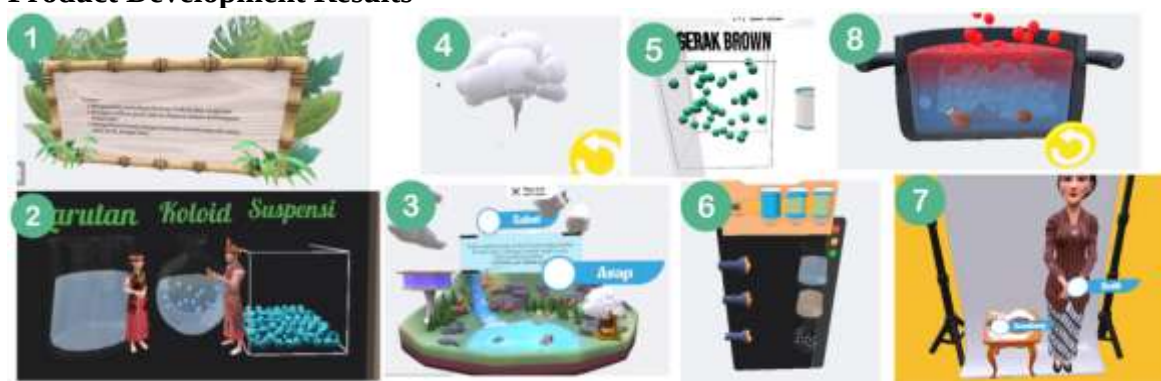


Figure 1. Product Development

The product development resulted in AR-based chemistry learning media on colloid systems organized into three learning objective levels, containing eight AR

marker displays presented in a single composite image as shown in Figure 1. The first display introduces the three main learning targets, followed by a microscopic visualization of the differences between solutions, colloids, and suspensions. The third and fourth displays feature the Berastagi mountains with fog and smoke as local wisdom contexts, where tapping the labels reveals descriptive sentences and subsequently microscopic illustrations of the colloid particles, with the fourth display specifically showing the microscopic view of smoke particles. The fifth display animates Brownian motion through randomly moving molecules, while the sixth illustrates the Tyndall effect by comparing light beam passage through a true solution, a colloid, and a suspension. The seventh and eighth displays incorporate local wisdom contexts featuring batik and rendang, where tapping the rendang label reveals descriptive text and a microscopic illustration, with the eighth display presenting the submicroscopic view of rendang in detail. Overall, the AR media employs a tap-to-reveal interactive mechanism, enabling students to explore colloid concepts progressively from macroscopic phenomena to submicroscopic representations, contextualized through local wisdom examples from Sumatera.

Validation Results

The material validation was conducted based on two aspects: content and language. The content aspect covered ten indicators including alignment with learning objectives, clarity of presentation, accuracy, currentness, depth, breadth, appropriateness of visual media selection, supporting literature, encouragement of curiosity, and alignment with students' characteristics. The language aspect covered three indicators: language use in accordance with EYD, communicative language, and effective sentence construction. The validator noted that conceptual accuracy was good and material breadth was appropriate for high school level, while recommending that the ChemAR Nusantara QR Code link remains active and accessible, with a backup link provided in case of technical disruptions. The material validation results are presented in the table below.

Table 4. The Material Validation Results

Aspect	Average Score	Category
Content	4.4	Valid
Language	4.3	Valid

The content aspect obtained an average score of 4.4 (valid), indicating that the material was appropriate, systematically organized, accurate, and able to encourage students' curiosity. The language aspect obtained an average score of 4.3 (valid), showing that the language was communicative and easy to understand. Overall, the material validation results confirm that the media is valid and feasible with minor revisions.

The media validation was conducted based on three aspects: illustration (AR provides accurate real-condition illustrations and aids visualization), media quality and appearance (AR display is attractive and durable), and attractiveness (AR reduces students' dependence on the teacher and minimizes misconceptions). The results of the media validation are presented in the table below.

Table 5. The Material Validation Results

Aspect	Average Score	Category
Illustration	5	Very Valid
Media Quality and Appearance	5	Very Valid

Attractiveness	5	Very Valid
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Based on Table 5, all aspects obtained an average score of 5, categorized as very valid. These results were achieved following a revision recommended by the media validator, who noted that the initial media only presented content at the macroscopic level. In response, submicroscopic visualizations were added to all colloid type descriptions and property explanations, including particle-level illustrations in local wisdom-based examples such as smoke and rendang. Following this revision, the validators confirmed that the media accurately represented real conditions, was visually attractive and of good quality, and was capable of reducing students' dependence on teachers while minimizing misconceptions, thus confirming its feasibility for implementation in learning activities.

Instrument Validation

The essay test instrument was validated by the validator to assess the feasibility of the instrument in terms of material, construction, language and culture, as well as instrument display. The validation results are presented in the following table.

Table 6. Instrument Validation Results

No	Aspect	Score
1	Material Aspect	38
2	Construction Aspect	37
3	Language and Cultural Aspect	36
4	Instrument Display Aspect	38
Total		149

Based on Table 6 the instrument validation results showed that all assessed aspects obtained high scores. The essay test instrument was validated in terms of material, construction, language and culture, and instrument display. The material and instrument display aspects achieved the highest score of 38, indicating highly appropriate content and appearance, while the construction aspect obtained 37, showing systematic question arrangement aligned with learning objectives, and the language and cultural aspect received 36, reflecting communicative and culturally relevant language use. Overall, the instrument obtained a total score of 149 out of 160 (93.1%), categorized as highly feasible. To strengthen these results, an informal validation was conducted by a chemistry teacher, who confirmed that the material was curriculum-appropriate, scientifically accurate, and that the pretest and posttest questions were relevant to the indicators of conceptual understanding, consistent with the quantitative validation results..

Practicality Test Results

Based on the results of the student learning interest questionnaire, the percentage for each aspect is presented as follows:

Table 7. Percentage of Student Learning Interest

Aspect	Percentage	Category
Aspect A	80%	Very Good
Aspect B	75.77%	Good
Aspect C	78.85%	Good
Aspect D	74.04%	Good

The data indicate that students' learning interest is in the good to very good category. Aspect A obtained the highest percentage, namely 80%, indicating that students have a high level of interest and attention toward the learning process. Meanwhile, Aspect D obtained the lowest percentage, namely 74.04%, but it is still categorized as good. Overall, the questionnaire results show that students have a relatively high interest in the learning activities conducted.

Observation Results Data

The observation data were obtained during the learning process to determine students' activities and involvement during learning activities. To make the observation results easier to understand, the data for each assessed aspect are presented in the following diagram.

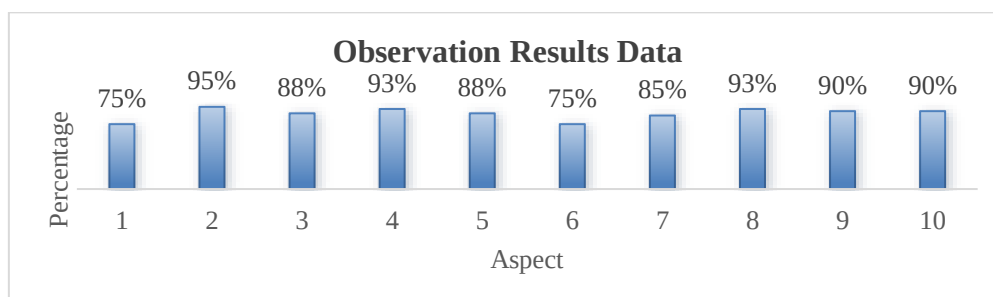


Figure 2. Observation Results Data

Based on the observation results, the percentage scores for each aspect were as follows: Aspect 1 obtained 75%, Aspect 2 obtained 95%, Aspect 3 obtained 88%, Aspect 4 obtained 93%, Aspect 5 obtained 88%, Aspect 6 obtained 75%, Aspect 7 obtained 85%, Aspect 8 obtained 93%, Aspect 9 obtained 90%, and Aspect 10 obtained 90%. The majority of aspects fell within the very good category, with Aspect 2 achieving the highest percentage of 95%, indicating that students actively paid attention to the teacher's explanations. Aspects 1 and 6 obtained the lowest percentage of 75%, yet are still categorized as good. Overall, the observation results demonstrate that the learning process was carried out well and that students showed high participation throughout the learning activities, with an overall average percentage of 87.2%, categorized as very good.

Comparison of Pretest and Posttest Scores

To determine the improvement in students' understanding of the learning material, a preliminary test (pretest) and a final test (posttest) were conducted. The scores obtained by the students were then compared to identify changes in learning outcomes after the learning process was carried out.

Table 8. Comparison of Pretest and Posttest Scores

Student	Pretest	Posttest
S1	5,5	8,77
S2	4,77	8,31
S3	4,8	6,85
S4	4,6	6,69
S5	5,3	6,77
S6	5,2	7,38
S7	4,6	7
S8	2,8	5,77

S9	2,7	5,8
S10	1,5	5,69

Based on the data presented in Table 8, there was an improvement in students' learning outcomes after the implementation of the AR-based learning media. The average pretest scores were relatively low, ranging from 1.50 to 5.50, indicating that students still had difficulties understanding several colloid system concepts before the learning process. After the learning treatment, the average posttest scores increased in all question items, ranging from 5.69 to 8.77.

The highest posttest score was obtained on question S1 with a score of 8.77, while the lowest posttest score was on question S10 with a score of 5.69. In terms of score improvement, the highest increase was found on question S10 with an increase of 4.19 points (pretest: 1.50; posttest: 5.69), indicating that students experienced the most significant conceptual improvement on this item after learning with the AR media. This was followed by question S2 with an increase of 3.54 points and question S1 with an increase of 3.27 points. The smallest improvement was observed on question S5 with an increase of 1.74 points. Overall, the higher posttest scores compared to the pretest scores indicate that the AR-based learning media had a positive effect on students' conceptual understanding and learning outcomes in colloid system material.

N-Gain Analysis

Based on the pretest and posttest results, the effectiveness of the AR-based learning media was also analyzed using the N-gain test to determine the improvement in students' conceptual understanding after the learning process. The N-gain value was calculated using the following formula:

$$g = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}}$$

The obtained N-gain score was 0.47, which is categorized as a moderate improvement. This result indicates that the AR-based learning media was sufficiently effective in improving students' conceptual understanding and reducing misconceptions in colloid system material. The average pretest score of 4.18 increased to 6.90 in the posttest, reflecting a meaningful gain in students' conceptual grasp of colloid concepts. The improvement in students' scores demonstrates that the visualization features provided by the AR learning media helped students understand abstract concepts more concretely and interactively.

Misconception Reduction Test Results

Table 9. Comparison of Pretest and Posttest Scores by Item

No	Pretest Misconceptions	Posttest Conceptual Changes
S1	Some students still experienced misconceptions in distinguishing solutions and colloids based on particle size and mixture properties. Several students assumed that cloudy mixtures are always suspensions.	Most students were able to distinguish sugar solution as a true solution and milk as a colloid based on particle size and stability properties.
S2	Students showed misconceptions in classifying sugar solution, milk, and muddy water. Some students incorrectly	Students were more capable of classifying solution, colloid, and suspension systems

No	Pretest Misconceptions	Posttest Conceptual Changes
	categorized muddy water as a colloid because of its cloudy appearance.	correctly based on particle characteristics and sedimentation properties.
S3	Several students experienced misconceptions in identifying the dispersed phase and dispersion medium in fog systems.	Students were able to correctly identify fog as a liquid dispersed in gas.
S4	Students still had difficulties analyzing dispersed phases and dispersion media in coconut milk, smoke, and wall paint systems.	Students demonstrated better understanding in determining dispersed phases and dispersion media correctly in various colloid examples.
S5	Students experienced misconceptions in identifying the colloid type of vehicle smoke based on its phase composition.	Students were able to classify smoke correctly as an aerosol colloid system.
S6	Many students experienced misconceptions in grouping milk, fog, smoke, foam, and soap foam into the correct colloid types based on phase interactions.	Students showed notable improvement in classifying colloids according to dispersed phase and dispersion medium.
S7	Students still had difficulties distinguishing emulsion, aerosol, and foam systems in daily life examples such as coconut milk, soap foam, and smoke.	Students were more capable of identifying and differentiating colloid types in everyday life phenomena.
S8	Some students assumed that all cloudy mixtures are colloids without considering sedimentation and particle stability.	Students understood that cloudy appearance alone cannot determine whether a mixture is a colloid or suspension.
S9	Students experienced misconceptions in relating the visibility of vehicle lights in fog to colloid properties, especially the Tyndall effect.	Students were able to correctly associate the phenomenon with the Tyndall effect and light scattering by colloid particles.
S10	The highest misconceptions were found in relating activated charcoal filtration, milk stability, and alum purification to colloid properties such as adsorption, coagulation, and stability. Many students were unable to connect colloid concepts with daily life applications.	Students demonstrated improved understanding in connecting adsorption, coagulation, and colloid stability with their applications in everyday life, however several students still showed partial misconceptions in explaining the concepts comprehensively.

Based on Table 9, students exhibited various misconceptions in the pretest, particularly in classifying colloid systems, distinguishing dispersed phases and dispersion media, and relating colloid properties to daily life phenomena, with the most frequent misconceptions observed in item S10. Following the implementation of the AR-based learning media, students showed improved conceptual understanding across most items, suggesting that the media was effective in reducing misconceptions and enhancing students' understanding of colloid system material.

Discussion

The product development resulted in two marker-based Augmented Reality (AR) learning media on colloid systems. Marker 1 consists of two sections: the first introduces dispersed substances and dispersion media through microscopic illustrations and local wisdom examples such as gulai and teh talua; the second presents colloid types interactively, beginning with aerosols visualized through the foggy Berastagi mountains, followed by sols, emulsions, gels, and foams in tap-to-reveal format. Marker 2 focuses on colloid properties, visualizing Brownian motion, the Tyndall effect, coagulation, dialysis, adsorption, and electrophoresis through animated microscopic representations with tap-to-reveal descriptions. Both markers feature animated AR characters that provide narration and interactive movements to enhance engagement. This design is consistent with Nazar et al. (2024), who developed an AR-based learning tool for chemistry and found that students responded positively to the app's attractiveness, ease of use, and alignment with teaching materials, with the AR successfully improving students' comprehension of chemical concepts.

The material validation yielded average scores of 4.4 (content, valid) and 4.3 (language, valid), while media validation across all three aspects illustration, media quality and appearance, and attractiveness achieved a perfect average score of 5 (very valid). The high content validity score can be attributed to the deliberate alignment of AR visualizations with the three levels of chemical representation macroscopic, submicroscopic, and symbolic which are widely recognized as essential for accurate conceptual understanding in chemistry. The perfect media validation score reflects the AR media's capacity to present phenomena that are otherwise invisible to the naked eye, such as colloidal particle interactions and Brownian motion, in an accurate and visually meaningful way. This directly addresses the root cause of misconceptions in colloid learning, which often arise from students' inability to mentally construct submicroscopic representations from static textbook illustrations. These results indicate that the developed AR media is both content-accurate and visually appropriate for use in the learning process. The high validation scores are supported by Ribič & Devetak (2025), whose systematic literature review of 46 AR-in-chemistry studies found that AR is widely recognized as a useful and easy-to-use tool that helps students improve their learning, particularly in visualizing chemical phenomena not accessible to the naked eye. The very valid rating in the illustration aspect is especially notable, as AR's capacity to provide accurate and meaningful visual representations of submicroscopic phenomena is considered one of its primary educational strengths in chemistry (Duc & Quang, 2024). Similarly, the instrument validation yielded a total score of 149 out of 160 (93.1%), categorized as highly feasible, confirming that the assessment instrument was well-constructed, conceptually accurate, and culturally relevant as reflected in the language and cultural aspect score of 36 and appropriate for measuring students' understanding of colloid systems.

The student learning interest questionnaire showed all aspects within the good to very good category, with Aspect A (attention and interest) obtaining the highest percentage of 80% and Aspect D the lowest at 74.04%. The high interest in Aspect A can be attributed to the novelty and interactivity of the AR media, which presented colloid concepts through culturally familiar local wisdom contexts, making the learning experience both engaging and personally relevant to students. This finding aligns with Yi-Ming Kao & Ruan (2022), who reported that AR applications increase student interest and motivation by making learning more interactive and enjoyable, leading to better learning outcomes. Furthermore, the observation data confirmed active student

participation throughout the learning process, with the majority of aspects obtaining percentages in the very good category ranging from 85% to 95%, while Aspects 1 and 6 obtained the lowest percentage of 75%, yet remained within the good category, yielding an overall average of 87.2% categorized as very good. The strong observation results indicate that the tap-to-reveal interactive mechanism effectively sustained students' attention and active involvement throughout the learning session. This level of student engagement is consistent with findings by Yi-Ming Kao & Ruan (2022), who demonstrated that hands-on AR learning activities evoked stronger situational interest in science compared to traditional teacher-centered demonstration strategies, particularly in chemistry topics.

The pretest scores ranged from 1.50 to 5.50, reflecting students' limited prior understanding of colloid concepts. Following the intervention, posttest scores improved to a range of 5.69 to 8.77, with the highest score on question S1 (8.77) and the lowest on question S10 (5.69). The most significant score gain was observed on question S10 (4.19 points), followed by S2 (3.54 points) and S1 (3.27 points), while the smallest improvement was on question S5 (1.74 points). The N-gain score of 0.47 (moderate improvement), with an average pretest score of 4.18 increasing to 6.90, can be attributed to the interactive tap-to-reveal mechanism that required active student engagement, facilitating deeper cognitive processing. Furthermore, the integration of local wisdom examples such as gulai, teh talua, rendang, and batik provided familiar cultural anchors that reinforced conceptual connections — for instance, recognizing rendang as an emulsion colloid and teh talua as a colloid rather than a true solution — thereby reducing cognitive load and supporting meaningful learning. This result is comparable to the findings of Nazar et al. (2024), who reported an N-gain score of 44.1 in an AR-based chemistry learning study, also indicating substantial improvement in students' conceptual understanding. Similarly, Juniar et al. (2025) in *Jurnal Pendidikan dan Pembelajaran Kimia* found that structured and engaging instructional approaches on colloid topics consistently yield meaningful learning gains, reinforcing the present study's findings. The improvement observed reflects AR's capacity to present abstract chemistry concepts in a more concrete, visual, and interactive manner, supported by Duc & Quang (2024), who found that 87% of students rated AR as an effective teaching method.

The misconception analysis revealed that prior to the intervention, students held misconceptions across all ten items, particularly in classifying colloid types (S5, S6, S7), distinguishing dispersed phases from dispersion media (S3, S4), and connecting colloid properties to real-life phenomena (S9, S10). The most significant misconceptions were in question S10, where students failed to relate activated charcoal filtration, milk stability, and alum purification to adsorption, coagulation, and stability. Questions S1 and S2 also revealed that students frequently misclassified mixtures based solely on macroscopic appearance without considering particle size or sedimentation properties. Following the intervention, posttest results demonstrated marked improvement across all items, with question S10 showing the greatest score gain (4.19 points), suggesting that AR visualizations of adsorption and coagulation processes were particularly effective in restructuring students' prior misconceptions. These findings are consistent with Akçayır and Akçayır (2017) as cited in Duc & Quang (2024), who found that AR technology effectively increased student achievement and eliminated misconceptions by allowing visualization of phenomena that cannot be observed with the naked eye. Beyond the role of AR visualization, the integration of local wisdom played a substantive and independent role in misconception reduction. By contextualizing colloid types within culturally

familiar phenomena such as the foggy Berastagi mountains, rendang, and batik production, the AR media provided students with concrete referents grounded in everyday experience. This ethnoscience approach transformed abstract submicroscopic concepts into meaningful, experience-based knowledge, thereby dismantling the superficial observational reasoning that underlies many common colloid misconceptions such as the tendency to classify all cloudy mixtures as suspensions based on visual appearance alone. This finding supports the argument that local wisdom integration is not merely a motivational strategy but serves a genuine cognitive function in restructuring students' conceptual frameworks. This is further supported by Ribič & Devetak (2025), who argued that AR positively influences the cognitive domain of learning, including student performance and knowledge retention, through its ability to bridge macroscopic observations with submicroscopic explanations. Overall, the results of this study confirm that the developed AR-based learning media on colloid systems is valid, practical, and effective in improving students' conceptual understanding and reducing misconceptions.

▪ CONCLUSION

This study successfully developed two marker-based AR learning media integrated with local wisdom on colloid system material through the ADDIE model. The media was declared valid with material validation scores of 4.4 (content) and 4.3 (language), and media validation scores of 5.0 across all aspects. Practicality was confirmed with student learning interest ranging from 74.04% to 80% and an observation average of 87.2%. Posttest scores improved to a range of 5.69 to 8.77 from pretest scores of 1.50 to 5.50, with an N-gain score of 0.47 indicating moderate improvement. Misconception reduction was evident across all ten question items, with the greatest improvement on question S10 (4.19 points), confirming that the developed media is valid, practical, and effective in reducing misconceptions and improving students' learning outcomes on colloid system material.

▪ REFERENCES

- Abdinejad, M., Ferrag, C., Qorbani, H. S., & Dalili, S. (2021). Developing a Simple and Cost-Effective Markerless Augmented Reality Tool for Chemistry Education. *Journal of Chemical Education*, 98(5), 1783–1788. <https://doi.org/10.1021/acs.jchemed.1c00173>
- Arifiani, R., & Irwanto, I. (2024). Augmented Reality Integrated With Mobile Learning in Chemistry Education: A Bibliometric Analysis From 2012–2022. *Journal of Educators Online*, 21(2), 26–32. <https://doi.org/10.9743/JEO.2024.21.2.14>
- Cahyani, V. P., & Fadly, D. (2024). Local Wisdom in Chemistry Learning: A literature Review on The Ethnoscience Approach. *Jurnal Studi Guru Dan Pembelajaran*, 7(3), 1262–1274. <https://doi.org/10.30605/jsgp.7.3.2024.4801>
- Duc, N. M., & Quang, N. V. (2024). 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*, 1415–1434. <https://doi.org/10.46328/ijemst.4265>
- Elford, D., Lancaster, S. J., & Jones, G. A. (2022a). Exploring the Effect of Augmented Reality on Cognitive Load, Attitude, Spatial Ability, and Stereochemical Perception. *Journal of Science Education and Technology*, 31(3), 322–339. <https://doi.org/10.1007/s10956-022-09957-0>

- Elford, D., Lancaster, S. J., & Jones, G. A. (2022b). 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>
- Hatta, Miterianifa, & Octarya, Z. (2021). Promoting Scientific Literacy in Chemistry Learning on the Subject Colloid through Instructional Material Development. *Journal of Physics: Conference Series*, 1842(1). <https://doi.org/10.1088/1742-6596/1842/1/012045>
- Irfachsyad, D., & Meidia, H. (2020). Simulation study of structural and dynamic properties of bi-disperse colloidal suspensions. *Materials Science Forum*, 998 MSF, 283–289. <https://doi.org/10.4028/www.scientific.net/MSF.998.283>
- Junaid, E., Sudatha, G. W., Suartama, K., & Santosa, M. H. (2022). Ethnochemistry In Chemistry Learning: Insights from Indonesian Local Wisdom. *Jurnal Pendidikan MIPA*, 12(1), 1–7.
- Juniar, A., Sundayan Zai, N., & Tambunan, P. (2025). The Influence of the Problem Based Learning Model on Student’ Learning Outcomes and Creative Thinking Abilities in Colloid Learning. *Jurnal Pendidikan Dan Pembelajaran Kimia*, 14(2).
- Khairani, R. N., & Prodjosantoso, A. K. (2023). Application of Augmented Reality on Chemistry Learning: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, 9(11), 1221–1228. <https://doi.org/10.29303/jppipa.v9i11.4412>
- Ladjidji, D. A. P., Kurniawan, C., Ramashani, D. G., Yulianto, A. A., Massora, K., & Widastra, H. (2024). Development of virtual reality-based ethno-sdgs learning media on colloid material to improve students’ chemical literacy. *International Journal of Active Learning*, 9(2), 91–103.
- Mansour, N., Aras, C., Staarman, J. K., & Alotaibi, S. B. M. (2025). Embodied learning of science concepts through augmented reality technology. *Education and Information Technologies*, 30(6), 8245–8275. <https://doi.org/10.1007/s10639-024-13120-0>
- Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education*, 10(1), 1–26. <https://doi.org/10.1002/rev3.3325>
- Miterianifa, Ashadi, Saputro, S., & Suciati. (2020). Analysis of errors and scaffolding in problem-solving processes on colloid topic for class XI senior high school. *AIP Conference Proceedings*, 2296. <https://doi.org/10.1063/5.0030457>
- Nazar, M., Zulfadli, Rahmatillah, Puspita, K., Setiawaty, S., & Sulastri. (2024). Development of augmented reality as a learning tool to improve student ability in comprehending chemical properties of the elements. *Chemistry Teacher International*, 6(3), 241–257. <https://doi.org/10.1515/cti-2023-0070>
- Razvan Ioan, H., Olin, T., Karaman, B., & Demirel, D. (2024). Augmented Reality Labs: Immersive Learning in Chemistry. In P. Zaphiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies* (Vol. 14724, pp. 155–172). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-61691-4_11
- Ribič, L., & Devetak, I. (2025). Augmented reality in developing students’ understanding of chemistry triplet: A systematic literature review. *Chemistry Teacher International*, 7(1), 157–172. <https://doi.org/10.1515/cti-2024-0060>
- Sapta, A., Risnawati, E., Panjaitan, D. J., Marisa, & Nisa, U. K. (2025). Development of Augmented Reality Media for Local Wisdom Learning. *International Journal on*

- Informatics Visualization*, 9(4), 1450–1458.
<https://doi.org/10.62527/joiv.9.4.4359>
- Sari, Z. R. P., Ulianas, A., Putra, A., & Rahadian, Z. (2021). Improving Students' Critical Thinking Skills through Student Worksheet Colloid Systems Based on Discovery Learning and Multiple Representations at Senior High School. *Journal of Physics: Conference Series*, 1788(1). <https://doi.org/10.1088/1742-6596/1788/1/012030>
- Sumarni, W., Sudarmin, S., Sumarti, S. S., & Kadarwati, S. (2022). Indigenous knowledge of Indonesian traditional medicines in science teaching and learning using a science–technology–engineering–mathematics (STEM) approach. *Cultural Studies of Science Education*, 17(2), 467–510.
<https://doi.org/10.1007/s11422-021-10067-3>
- Widiastari, K., & Redhana, I. W. (2021). Multiple representation-based chemistry learning textbook of colloid topic. *Journal of Physics: Conference Series*, 1806(1). <https://doi.org/10.1088/1742-6596/1806/1/012185>
- Yi-Ming Kao, G., & Ruan, C.-A. (2022). Designing and evaluating a high interactive augmented reality system for programming learning. *Computers in Human Behavior*, 132, 107245. <https://doi.org/10.1016/j.chb.2022.107245>
- 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), 227. <https://doi.org/10.3390/educsci12040227>