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Development of a Chromatography Textbook Based on Project-Based Learning Using an Ethnoscience Approach with Augmented Reality

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Abstract

Advances in chemistry during the Fourth Industrial Revolution demand learning that integrates concept mastery with 21st-century skills, yet current materials rarely combine local wisdom and digital technology. This study aimed to develop a chromatography textbook based on Project-Based Learning (PjBL), using an ethnoscience approach and Augmented Reality (AR), suitable for learning. The Research and Development (R&D) method, using the 4D model (Define, Design, Develop, Disseminate), was employed. The pilot study involved 20 Chemistry Education students, with expert validation sheets and student response questionnaires as instruments. The results of the expert validation indicated that this textbook is highly suitable, with an average content suitability percentage of 93.75%, graphic suitability of 93.75%, presentation suitability of 94.84%, and linguistic suitability of 100%. A pilot test conducted on a small group revealed highly positive student responses, with an average score of 3.88 (97.02%). These findings imply that integrating PjBL, ethnoscience, and AR can effectively support contextual, student-centered, and technology-enhanced chemistry learning. In practice, this approach can serve as a model for developing innovative instructional materials for other chemistry topics and for supporting curriculum transformation toward 21st-century skills.

Keywords: Augmented reality; chromatography; ethnoscience; PjBL; textbook

Introduction

Advances in chemistry education in the era of the Fourth Industrial Revolution demand not only mastery of concepts but also the development of 21st-century skills, including problem-solving, collaboration, and technological literacy. However, global evidence from UNESCO (2024) indicates that approximately 62% of science students across disciplines experience significant difficulties understanding abstract and instrument-based materials. This issue is particularly critical in chemistry, where many concepts are inherently abstract and require visualization, experimentation, and interpretation. As a consequence, students' laboratory competencies and their ability to apply scientific knowledge in real-world contexts remain relatively low.

In the context of chemistry education, analytical chemistry and specifically chromatography represent one of the most challenging topics for students. Chromatography requires an integrated understanding of theoretical concepts, experimental procedures, and data interpretation skills. Ideally, these competencies are developed through direct laboratory experience. However, in many educational settings, including Indonesia, chemistry instruction is still predominantly lecture-based, with limited opportunities for meaningful laboratory practice due to constraints such as inadequate facilities and resources (Munawwarah & Alqadri, 2025; Susanti et al., 2025). In addition, teaching materials are often not contextualized to students' cultural backgrounds or everyday experiences, making the learning process less meaningful. Consequently, chromatography is frequently taught in an abstract and decontextualized manner, leading to low student engagement and understanding. Supporting this, Sari et al. (2024) identified that the main factors contributing to learning difficulties in analytical chemistry include limited availability of teaching materials (57.78%, moderate category), students' low mastery of content (58.31%, moderate category), and suboptimal laboratory quality (69.73%, moderate category).

To overcome these challenges, various innovative approaches have been proposed and implemented. One promising approach is the integration of immersive technologies, such as

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Augmented Reality (AR), which enables visualization of abstract concepts and simulation of laboratory processes. Previous studies have shown that AR can significantly enhance students' conceptual understanding and engagement compared to conventional learning methods (Verdiatmoko & Pinandita, 2025; Zebua, 2025). In addition, Project-Based Learning (PjBL) has been widely recognized as an effective pedagogical model to promote active learning, critical thinking, and problem-solving skills. A meta-analysis by Tafakur et al. (2023) demonstrated that PjBL has a significantly greater impact on students' critical thinking skills compared to other learning models. In the context of analytical chemistry, PjBL has been shown to improve students' analytical competencies and learning outcomes, particularly in distillation- and chromatography-related topics (Simalango & Situmorang, 2024).

Furthermore, the ethnoscience approach offers a contextual learning framework by integrating local wisdom, culture, and real-life practices into science education. Ethnoscience enables students to connect abstract scientific concepts with familiar phenomena in their environment, thereby enhancing understanding, motivation, and cultural awareness. Studies have shown that ethnochemistry can improve conceptual understanding, critical and creative thinking, scientific literacy, and students' cultural character (Cahyani & Wahyudiati, 2023; Junaidi et al., 2025; Sutrisno et al., 2020; Zidny & Eilks, 2022). In practice, ethnoscience-based learning materials have commonly been developed for topics such as batik, traditional foods, natural indicators, fermentation, and local natural phenomena (Erna et al., 2026; Munawwarah & Alqadri, 2025; Sudirman et al., 2025; Widarti et al., 2025). Chromatography, as a key topic in analytical chemistry, requires an understanding of concepts, procedures, and data interpretation, ideally gained through hands-on laboratory experience (Munthe & Sitorus, 2025; Sutrisno et al., 2024). However, teachers and pre-service teachers still face challenges in linking chemistry concepts with local contexts, mainly due to limited resources and a lack of integrated teaching materials (Marpaung et al., 2025).

Despite the potential of these approaches, several critical gaps remain. First, the implementation of AR in chemistry education remains uneven and is often not pedagogically integrated into structured teaching materials, such as textbooks or modules (Sari et al., 2025). Second, although ethnoscience has been widely applied, its integration into analytical chemistry topics, especially chromatography, remains very limited (Junaidi et al., 2025; Widarti et al., 2025; Zidny & Eilks, 2022). Third, while PjBL has shown strong effectiveness as a standalone approach, studies that combine PjBL with ethnoscience and AR within a unified instructional design remain scarce. Existing studies tend to focus on only one or two approaches rather than integrating all three into a coherent, pedagogically grounded learning resource. This lack of integration results in missed opportunities to simultaneously address conceptual understanding, contextual relevance, and technological engagement in chemistry learning.

In addition, the current transformation of higher education curricula emphasizes student-centered learning, project-based approaches, the integration of digital technology, and the strengthening of cultural and environmental literacy. In the post-pandemic era, there is also an increasing demand for hybrid and self-directed learning resources that are flexible, interactive, and accessible. Without the development of teaching materials that are both pedagogically and technologically integrated, the teaching of chromatography risks remaining abstract, less engaging, and disconnected from students' real-life experiences.

Therefore, the study aimed to develop a chromatography textbook based on PjBL, using an ethnoscience approach and AR, suitable for learning. The uniqueness and novelty of this study lie in the integration of three key elements: PjBL, ethnoscience, and AR into a single, systematically designed instructional material specifically for chromatography learning. This textbook is expected not only to facilitate conceptual understanding and practical skills but also to enhance students' engagement, critical thinking, cultural awareness, and technological literacy. By bridging the gap between abstract concepts, local contexts, and digital innovation, this study contributes to the development of more meaningful, contextual, and future-oriented chemistry education.

Methods

Research design

This study used a Research and Development (R&D) approach, adapting the 4D model (Define, Design, Develop, Disseminate). This design was chosen based on the study's objective: to develop and produce a textbook suitable for teaching chromatography. Each stage was carried out systematically, beginning with needs analysis, product design, development, and validation, and concluding with limited dissemination.

Research target

The research targets two main aspects: the product and the users. The product developed was a PjBL-based chromatography textbook using an ethoscience approach, aided by AR. Meanwhile, the research subjects in the pilot study phase were 20 students from the Chemistry Education Program. Students were selected as the target users because they are future educators who need innovative learning resources to improve their understanding of abstract chemical concepts.

Research data

The data for this study consists of both

qualitative and quantitative data. Qualitative data were obtained from feedback, critiques, and suggestions provided by subject-matter and media experts during the product validation process. This data was used to refine and improve the product under development. Meanwhile, quantitative data were obtained from the textbook's feasibility validation assessment results and student responses regarding the product's use. This quantitative data consists of Likert-scale assessment scores, which were converted to percentages to determine the level of feasibility and response categories.

Research instruments

The research instruments used in this study included a validation sheet and a student response questionnaire. The validation sheet was used by subject-matter and media experts to assess the textbook's suitability against the standards of the Badan Standar Nasional Pendidikan (BSNP), which include content, graphics, presentation, and language. The student response questionnaire was used to evaluate user feedback on the developed textbook. The instruments were designed using a Likert scale with several rating categories reflecting respondents' levels of agreement.

Data analysis

Data analysis in this study was conducted using a descriptive quantitative approach. The scores were calculated as averages and then converted into percentages using the formula in Equation (1).

$$\text{Percentage} = \frac{\text{score obtained}}{\text{maximum score}} \times 100\% \quad (1)$$

The resulting percentages were then categorized according to the feasibility criteria (Aprilia, 2023), as presented in **Table 1**.

Table 1. Criteria for evaluating the suitability of textbooks

Results		Follow-up
Percentage (%)	Qualification	
< 40	Unacceptable	Revision with extensive notes
41 – 60	Satisfactory	Revision with some notes
61 – 80	Acceptable	Implementation with minor revisions
81 – 100	Highly acceptable	Implementation

In addition, qualitative data from expert suggestions and comments were analyzed descriptively to inform product improvements. This analysis was conducted systematically to ensure that the developed product meets quality standards and can be used effectively in learning.

Results and Discussion

Define

During the define phase, problem and conceptual analyses, learning objective formulation, and task analysis were conducted to identify the core issues in chromatography instruction. The problem analysis revealed a significant gap in current teaching practices. Based on interviews with two separation chemistry lecturers, chromatography learning still predominantly relies on conventional textbooks that emphasize theoretical explanations and lack integration with active learning approaches and digital technologies. In particular, existing teaching materials have not incorporated PjBL, ethnoscience, or AR, thereby limiting students' opportunities to engage in contextual, interactive, and technology-supported learning.

The conceptual analysis further highlighted the need for structured and progressive learning content. Chromatography material was mapped into five main topics: paper chromatography, thin-layer chromatography, column chromatography, liquid chromatography, and gas chromatography. This structure reflects the hierarchical complexity of chromatography techniques and supports the development of both conceptual understanding and procedural knowledge.

In addition, the task analysis emphasized the importance of integrating learning activities that promote higher-order thinking skills. The use of the six PjBL syntaxes was identified as a suitable framework for addressing this need, particularly for encouraging students to engage with real-world problems, conduct literature-based inquiry, and apply chromatography concepts in a more meaningful way. The analysis also indicated the importance of incorporating local contexts as learning resources, as this can enhance relevance and student engagement, which are currently lacking in existing instructional materials.

Overall, the define phase identified three key needs: (1) the development of teaching materials that integrate PjBL to promote active and inquiry-based learning, (2) the inclusion of ethnoscience to contextualize chromatography concepts within local culture, and (3) the use of AR to support visualization of abstract and instrument-based concepts. These findings form the foundation for the design and development of the chromatography textbook.

Design

During the design phase, the development of the textbook was guided by the key findings identified in the define phase, particularly the need for (1) active and inquiry-based learning through PjBL, (2) contextualization of chemistry concepts through ethnoscience, and (3) visualization support using AR. Therefore, the design process focused on integrating these three elements into a coherent and pedagogically grounded instructional material.

Design of PjBL and ethnoscience-based learning scenarios

The primary design decision was to embed PjBL syntax and ethnoscience context into every chapter of the textbook. This was based on the

finding that existing materials lack contextual and student-centered learning experiences. Each chapter was therefore structured around a project theme derived from local cultural practices in North Sumatra, aiming to make chromatography learning more meaningful and relevant.

For example, the use of salaon leaves (Indigofera tinctoria *L.*) as a natural dye in ulos weaving was selected as a learning context because it represents an authentic local practice with clear connections to chemical concepts, particularly compound extraction and separation. This context was intentionally chosen to bridge abstract chromatography concepts and real-world applications, while also introducing issues of efficiency and sustainability by comparing with synthetic dyes such as ponceau GRB. The inclusion of real data and problem-based questions was designed to stimulate critical thinking and encourage students to evaluate both scientific and socio-cultural aspects.

The integration of PjBL stages into the textbook was also based on the need to shift learning from passive to active. Students are required to formulate problems, design separation strategies, and make decisions about chromatographic techniques, thereby promoting higher-order thinking skills. Literature review tasks were included to strengthen conceptual understanding before application, while project planning and scheduling activities were designed to foster independence and responsibility.

Collaborative project implementation using local materials reflects the ethnoscience approach and addresses the lack of contextual learning resources. Documentation and reporting activities were incorporated to support scientific communication skills, while reflection and discussion at the final stage were designed to reinforce conceptual understanding and encourage metacognitive awareness. Overall, the learning scenario was designed to ensure that students not only understand chromatography concepts but also apply them in meaningful and culturally relevant contexts.

Development of research instruments

The development of research instruments was driven by the need to obtain valid and reliable data to evaluate the quality of the textbook under development. Instruments such as interview guidelines, textbook feasibility questionnaires based on BSNP standards, and student response questionnaires were designed and validated by experts. This step ensures that the assessment of the textbook's effectiveness, feasibility, and student acceptance is methodologically sound and aligned with the research objectives.

Selection and structure of the textbook

The structure of the textbook was designed to integrate content, pedagogy, and technology. This decision was based on the finding that existing textbooks are generally content-oriented and lack interactive and contextual components. Therefore, the developed textbook includes not only conceptual explanations but also PjBL-based activities, ethnoscience contexts, and AR features.

The organization of the material into five chapters, paper, thin-layer, column, liquid, and gas chromatography, was intended to provide a logical progression from simple to complex concepts. Each chapter includes elements such as learning objectives, concept maps, trigger questions, and structured project activities. These components were deliberately included to support different dimensions of learning, including conceptual understanding, inquiry, engagement, and critical thinking.

In addition, the inclusion of reflection sections, competency tests, and supporting materials (e.g., glossary and references) was intended to facilitate self-assessment and reinforce learning outcomes. This design ensures that the textbook functions not only as a source of information but also as a comprehensive learning guide.

AR media design

The integration of AR media was based on the finding that students have difficulty understanding abstract and instrument-based concepts in chromatography. Therefore, AR was used as a visualization tool to represent chromatographic processes and equipment in three dimensions.

The selection of HexaGEN and Assemblr Edu was based on their accessibility and ability to support the development of interactive 3D learning media. The design process focused on converting static images into 3D models and embedding them in AR environments accessible to students. This approach allows students to interact with learning objects, thereby enhancing engagement and conceptual understanding.

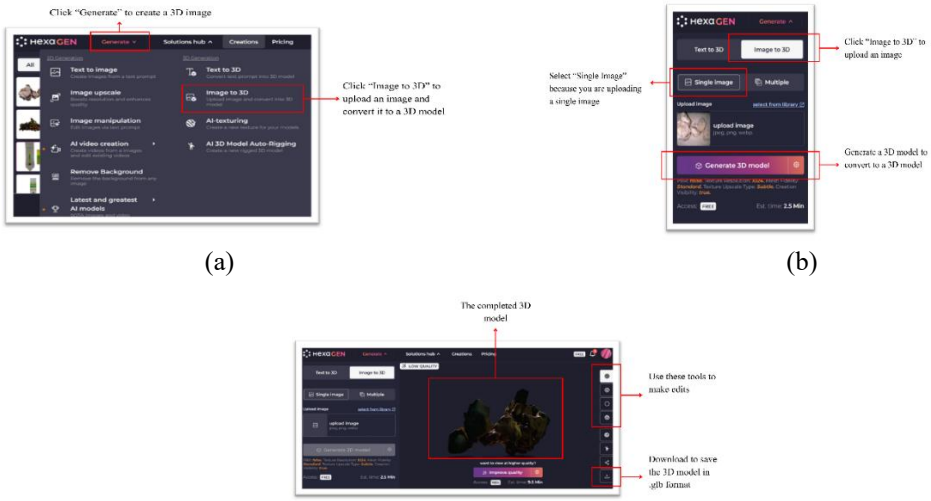
Importantly, AR was not included merely as a technological addition, but as a pedagogical solution to address specific learning difficulties identified in the define phase. By enabling visualization of abstract processes, AR supports deeper understanding and complements the PjBL and ethnoscience approaches.

As shown in **Figure 1**, creating a 3D model begins by selecting the "Generate" menu. Next, select "Image to 3D" to upload the image to be converted into a 3D model (**Figure 1a**). Then, select the "Single Image" option since only one image is being uploaded. After the image is uploaded, the user selects "Generate 3D" to convert the image into a 3D model (**Figure 1b**).

Finally, the resulting 3D model is displayed in the center of the screen. Initial editing is performed using the tools available on the right side of the interface. Once the editing process is complete, the 3D model can be downloaded by clicking the Download button, which saves the file

in .glb format (**Figure 1c**). The resulting 3D model is imported into the Assemblr.Edu software, as shown in **Figure 2**.

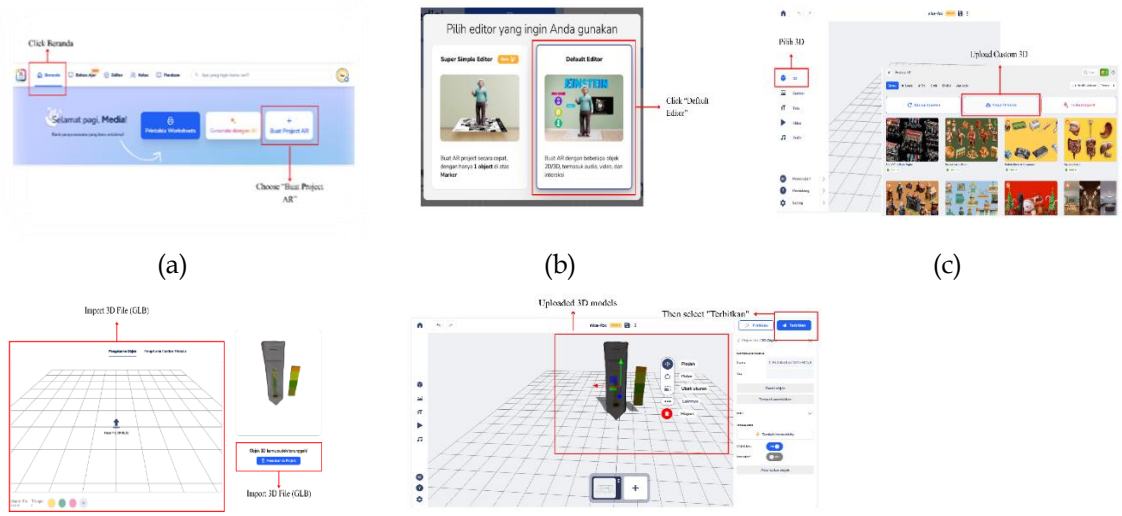
First, go to the main page or the Home page. There, you will find a button marked with a plus sign labeled "Create AR Project" (**Figure 2a**). Next, a list of editors will appear; to access more comprehensive features, such as adding multiple objects, audio, and interactions, select "Default Editor" (**Figure 2b**). Select the cube icon labeled "3D," and the "3D Library Panel" will open; then choose the "Upload Custom 3D" option to use a pre-made 3D model (**Figure 2c**).



(a) (b)

(c)

Figure 1. HexaGen interface: a) HexaGen menu, b) Steps for creating a 3D model, and c) Final 3D model



(a) (b) (c)

(d) (e)

Figure 2. AR Design: a) Starting a new project, b) Selecting an editor mode, c) Accessing the 3D library, d) Importing 3D files (GLB), and e) Object settings and publishing

Next, import the 3D asset by clicking the upload area marked with an upward arrow to locate a .GLB file. Once the upload is successful, click the blue "Add to Project" button (**Figure 2d**). After the 3D model appears on the grid, adjust its position using the move, rotate, or resize features. Once everything is positioned just right and to your liking, click the "Publish" button in the top-right corner to share your AR creation (**Figure 2e**).

Develop

The third stage of the 4D development model was the development stage. After the chromatography textbook was designed, the developed textbook, critical-thinking questions, and questionnaires on learning motivation and learning responses were validated for suitability by experts. The instruments used to assess the suitability of the developed textbook were validation sheets

completed by subject-matter and media experts, designed in accordance with BNSP suitability criteria. The overall validation results for the PjBL-based chromatography textbook, using an ethnoscience approach with AR assistance and reviewed for content, graphics, presentation, and language suitability, are presented in **Table 2**.

Table 2. Overall suitability of the chromatography textbook

Aspect	Assessment Indicator	Average Score	Percentage (%)	Average (%)
Content Quality	Relevance of content	3.33	83.33	93.75
	Accuracy of content	3.75	93.75	
	Up-to-date content	4	100	
	PjBL	3.67	91.67	
	Ethnoscience approach	4	100	
Graphic Design Quality	Textbook size	4	100	93.75
	Textbook cover design	3	75	
	Textbook layout	4	100	
	Augmented reality	4	100	
Presentation Quality	Presentation techniques	4	100	94.84
	Instructional delivery	3.67	91.67	
	Comprehensiveness of presentation	3.71	92.85	
Language Quality	Readability	4	100	100
	Compliance with the rules of proper and correct Indonesian	4	100	

Based on **Table 2**, the content suitability aspect received an average percentage of 93.75%, graphic suitability 93.75%, presentation suitability 94.84%, and linguistic suitability 100%, all of which fall into the "highly suitable" category. Two chemistry lecturers validated the material. This expert validation employed a content validity questionnaire aligned with BNSP standards. Content validity consists of five components: material relevance, material accuracy, material currency, PjBL-based design, and the ethnoscience approach, as shown in **Figure 3**.

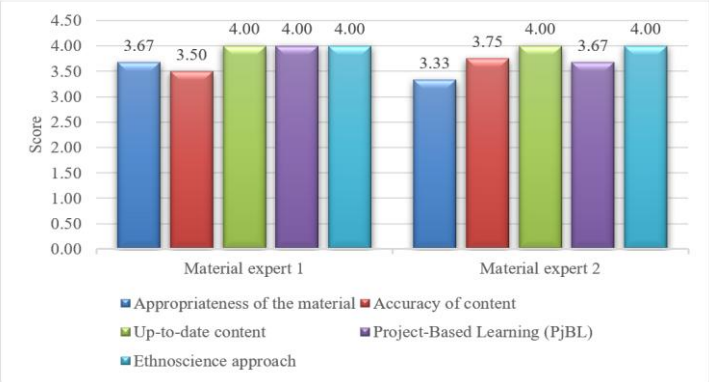


Figure 3. Expert assessment of content validity

Figure 3 showed that the indicators for content appropriateness scored 3.33 (88.33%), content accuracy 3.75 (93.75%), content currency 4.00 (100%), PjBL-based content 3.67 (91.67%), and the ethnoscience approach 4.00 (100%). Based on these data, the average suitability score from the two experts for the content suitability aspect is 93.75, which falls into the "highly suitable" category.

The content feasibility aspect received an average percentage of 93.75%, indicating that the chromatography material presented aligns with the targeted competencies, possesses good conceptual accuracy, and is relevant to advancements in scientific knowledge. The integration of PjBL syntax and the ethnoscience approach was assessed as clearly depicted, so that the textbook functions not only as a source of information but also as a learning tool that encourages students to actively construct knowledge through contextual projects (Tene et al., 2024).

One chemistry lecturer from Unimed conducted media validation. This expert media validation utilized a feasibility questionnaire instrument based on BNSP standards. The aspects tested to assess the suitability of a teaching material include graphic suitability, presentation suitability, and language suitability. The graphic suitability aspect consists of four components: book size, cover design, content design, and augmented reality. **Figure 4** shows the detailed results of the media expert's assessment of the graphic suitability aspect.

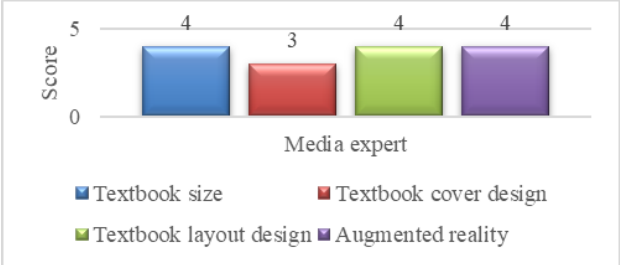


Figure 4. Expert assessment of graphic design quality

Based on **Figure 4**, the indicators for book size, content design, and augmented reality all received a score of 4.00 (100%), while the cover design received a score of 3.00 (75%). Based on this data, the average percentage for the graphic design aspect is 93.75%, which falls into the "highly feasible" category. The graphic design aspect achieved a feasibility percentage of 93.75%. This score indicates that the book size, layout, content design, and integration of AR media generally support readability and user comfort. Nevertheless, some improvements are still needed, particularly in the cover design, to make the representation of the book's content more appealing (Subandi et al., 2023).

The presentation suitability aspect consists of three components: presentation techniques, instructional presentation, and presentation completeness. The results of the media experts' assessment of the presentation suitability aspect are shown in **Figure 5**.

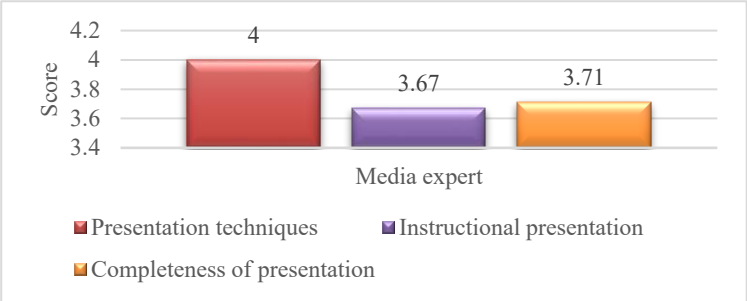


Figure 5. Expert assessment of presentation quality

Figure 5 showed that presentation techniques received a score of 4.00 (100%), instructional presentation 3.67 (91.67%), and presentation completeness 3.71 (92.85%). Based on these data, the average percentage for the presentation feasibility aspect was 94.84%, which falls into the "highly feasible" category, indicating that the flow of material presentation was systematically organized and effectively guided students through the PjBL-based learning stages (Siregar & Suparman, 2022).

Based on **Figure 6**, both readability and compliance with Indonesian language rules received a score of 4.00 (100%). Based on this data, the average percentage for the presentation suitability aspect, at 100%, falls into the "highly suitable" category, indicating that the language used in the textbook adheres to proper Indonesian language rules and is easily understood by students.

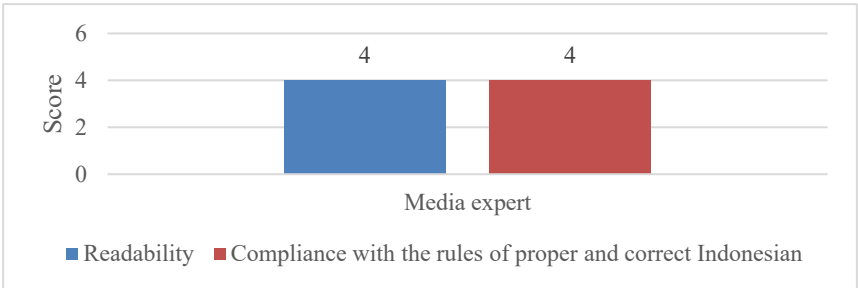


Figure 6. Expert assessment of linguistic feasibility

Disseminate

After the textbook was deemed suitable and revisions were made, a limited pilot test was conducted with 20 students using the developed textbook. This data was collected to assess the students' positive and negative responses. The students' response data from the small-group pilot test are presented in **Table 3**.

Table 3. Student response data from the small-group pilot test

Aspect	Average Score	Overall Average	Percentage (%)	Overall Average (%)
Challenge	3.93		98.13	
Curiosity	3.93		98.25	
Participation	3.88		96.88	
Confidence	3.85	3.9	96.25	97.51
Attention	3.95		98.75	
Relevance	3.88		96.88	
Satisfaction	3.9		97.5	
Category	Very Positive		Very Positive	

Based on **Table 3,** the overall average student response score was 3.9 (97.51%), placing it in the "very positive" category. Based on this data, the PjBL-based chromatography textbook, which uses an ethnoscience approach with AR support, is suitable for use. This textbook was designed by integrating the PjBL model, the ethnoscience approach, and AR technology support. The integration of these three components is the textbook's primary strength, enabling it to create a contextual, interactive, and student-centered learning experience. In project-based learning, students do not merely passively receive information. However, they are actively involved in the processes of investigation, project planning, data analysis, and solution development for the problems at hand. This active engagement encourages students to analyze, evaluate, and make decisions.

These findings are consistent with several previous studies. For example, Tafakur et al. (2023), in a meta-analysis of 29 studies, reported that Project-Based Learning (PjBL) has a significantly greater effect on students' critical thinking skills than conventional learning models. Similarly, Situmorang et al. (2022) found that the application of PjBL in analytical chemistry improved students' analytical competencies and learning outcomes, particularly in laboratory-based topics.

From an ethnoscience perspective, Cahyani & Wahyudiati (2023) demonstrated that ethnochemistry-based learning significantly enhances students' conceptual understanding, motivation, and cultural awareness. Similarly, Junaidi et al. (2025) reported that integrating local cultural contexts into chemistry learning improves students' engagement and relevance of learning materials. Nevertheless, these studies were mostly applied to general chemistry topics, such as natural indicators and fermentation, rather than analytical chemistry or chromatography.

In addition, the ethoscience approach integrated into the textbook provides a real-world context closely tied to students' lives, particularly regarding North Sumatra's local culture. The textbook developed in this research consists of five chapters linked to five local traditions of the people of North Sumatra. First, Chapter 1 on paper chromatography discusses the betel-chewing tradition of the Karo people of North Sumatra, known as "Man Belo." This tradition is present in various traditional events such as weddings, family meetings, and welcoming guests. The betel-chewing tradition involves several main ingredients: betel leaves, areca nuts, lime, and tobacco. The betel leaves and other ingredients are rolled together and chewed, producing a distinctive red color. Generally, the betel leaves used in this tradition are green, but they also come in red. In this textbook, students are asked to determine whether green betel leaves can be substituted with red betel leaves, and whether the color pigments in green and red betel leaves differ. These questions guide students in conducting a project to separate the color pigments from green and red betel leaves using paper chromatography.

Next, Chapter 2 on thin-layer chromatography discusses cimpa unung-unung, a traditional Karo dish that uses singkut leaves as a wrapper. Singkut leaves are leaves that grow naturally in the forest, particularly in North Sumatra. These leaves have a distinctive characteristic that imparts a unique aroma and flavor to cimpa. Singkut leaves are used to wrap the cimpa dough, which is made from glutinous rice flour, grated coconut, and palm sugar. In the textbook, students are asked to analyze the chemical compounds and color pigments present in singkut leaves, and to determine whether singkut leaves could be replaced by other leaves as wrappers for cimpa unung-unung. These questions guided students in conducting a project focused on separating the color pigments of singkut leaves using thin-layer chromatography.

Chapter 3 on column chromatography discusses the use of salaon leaves (Indigofera tinctoria L.) as a natural blue dye in Sibolang ulos. The salaon plant was abundant in the Muara subdistrict, North Tapanuli Regency, North Sumatra. Salaon leaf extract contains indican glycosides that can be hydrolyzed into glucose and indoxyl. In a basic environment, indoxyl is easily oxidized by air into the blue indigo pigment. However, people are now beginning to switch to chemical dyes for coloring ulos. This is because preparing and using the natural salaon leaf dye takes longer. Furthermore, at the end of the narrative, students are provided with data from research findings indicating that the quality of ulos yarn dyed with salaon leaf extract is superior to that of

ponceau GRB-dyed ulos yarn. Furthermore, the textbook contains thought-provoking questions designed to stimulate students' critical thinking as they address issues related to the use of ulos dyes. These questions guide students in conducting a project to separate salaon leaf pigments using column chromatography.

Chapter 4 on liquid chromatography discusses the use of andaliman in a traditional Batak dish known as dekke naniura. Andaliman, or Batak pepper, has a spicy, bitter taste and a tingling sensation on the tongue, which is caused by certain chemical compounds found in the andaliman fruit. Furthermore, the textbook includes thought-provoking questions designed to develop students' critical thinking skills in solving problems related to the chemical components present in andaliman that give dekke naniura its distinctive flavor. These questions guide students in conducting a project focused on separating the chemical components of andaliman extract using liquid chromatography.

In Chapter 5, gas chromatography was linked to Sumatran frankincense and Toba frankincense, which are abundant in North Sumatra. This crystalline frankincense, with its distinctive aromatic scent, is frequently used in incense and perfumes. The textbook includes questions designed to prompt students to practice their critical thinking skills. Students analyze the chemical components of frankincense resin, including those responsible for its characteristic aroma profile, using gas chromatography.

This ethnoscience approach ensures that the concept of chromatography is not viewed merely as an abstract concept but as knowledge closely tied to the community's daily practices. This connection between scientific concepts and local culture enhances the relevance of learning, thereby motivating students to explore the material more deeply. Rahmawati & Atmojo (2021) have demonstrated that the ethnoscience approach increases the appeal of course material by making it more relevant to students' lives, thereby boosting their motivation to learn. A review of ethnoscience confirms that linking chemistry to traditional foods, natural dyes, and local environmental practices is an effective approach and suitable for integration with PjBL (Aisyah et al., 2025; Djarwo & Amsad, 2025; Widarti et al., 2025; Zidny & Eilks, 2022). Sari et al. (2025) found that integrating digital technology into an analytical chemistry textbook improved the critical-thinking skills of Chemistry Department students, thereby supporting SDG-4.

Therefore, compared to previous studies, this research offers a more comprehensive contribution by integrating PjBL, ethnoscience, and AR into a single instructional design specifically for chromatography. This integration not only confirms the effectiveness of each approach but also demonstrates their combined impact in creating a more contextual, interactive, and student-centered learning experience.

Conclusions

The PjBL-based chromatography textbook, using an ethnoscience approach with AR support, is highly suitable. A pilot test conducted with a small group yielded highly positive student responses. The PjBL-based chromatography textbook, using an ethnoscience approach with AR support, has proven highly suitable and has received highly positive student responses, indicating its effectiveness as an innovative learning resource for enhancing conceptual understanding, active engagement, and higher-order thinking skills. However, this study has several limitations. First, the trial was conducted on a limited sample size, which may not fully represent broader student populations. Second, the study primarily focused on feasibility and student responses, without extensive experimental testing to measure its impact on learning outcomes compared to other instructional approaches. Third, the developed AR features remain limited in scope and interactivity and may not yet fully realize the potential of immersive learning technologies. In practice, this product is recommended for integration into college chemistry education to support technology-based, student-centered learning models. Further research is suggested to test its effectiveness on a larger scale through experimental design, and to develop AR features and expand the scope of the material to optimize its implementation.

Conflict of Interest

The author declares no conflict of interest.

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