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Development of Colloid System Module Context "Batik Waste Treatment" Using Four Steps Teaching Material Development Method

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Abstract: This study aims to develop a contextual colloidal system module with a batik wastewater treatment context that is suitable for senior high school students. The development of this module is motivated by the widespread use of teaching materials that do not fully align with curriculum demands, focusing solely on scientific content without applying a contextual approach. The research method employed is Design Development Evaluation (DDE), while the development of the teaching material follows the Four Steps Teaching Material Development (4STMD) model. In the design stage, analysis and planning of the type of teaching material to be developed were conducted, resulting in an initial draft of the module. The development stage, based on 4STMD, consists of four steps: selection, structuring, characterization, and didactic reduction, leading to the creation of a draft teaching material. The evaluation stage involved feasibility testing by chemistry teachers and experts, and comprehensibility testing with students. The evaluation results indicate that the developed contextual teaching material, based on the batik wastewater treatment context, is aligned with the curriculum, conceptually accurate, and feasible for use as independent learning material. The feasibility test yielded a percentage score of 95.4%, and the comprehensibility test yielded a score of 92%.

Keywords: 4STMD; Colloid; Contextual; Module; Teaching Material.

Introduction

One of the main challenges in chemistry education is the lack of meaningful connection between scientific concepts and students' real-life experiences. Ethnoscience-based learning, which integrates indigenous knowledge and cultural practices into science education, has the potential to address this issue. However, its implementation remains limited. Most existing modules still prioritize conceptual understanding alone, overlooking the importance of fostering students' awareness and concern for real-world problems. This often results in a learning experience that feels abstract, disengaged, and irrelevant to students' everyday lives. In contrast, studies have shown that when chemistry lessons are perceived as relevant and connected to students' cultural and social environments, their enthusiasm and engagement tend to increase significantly (Maulidiningsih, 2023).

The development of teaching modules in chemistry education has been widely implemented, as shown in the study by Witri (2023) on topics in green chemistry. One of the key focuses in these developments is the effort to make chemistry learning more relevant and applicable to real-world contexts, especially through the use of practical examples and interdisciplinary approaches. In line with this, an e-module employing a problem-based learning approach, incorporating scientific literacy and video demonstrations, was developed for teaching acid and base concepts to 11th

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grade senior high school students (Yani, Y. P. et al., 2022). To further strengthen the role of innovative teaching strategies, recent studies have also emphasized the importance of integrating technological tools and structured instructional models in classroom settings. The research of Rahma et al. (2023) makes a meaningful contribution to this effort by promoting the integration of technology in chemistry education and serving as a valuable reference for curriculum developers and teachers in implementing e-modules based on the 5E instructional model as an effective tool for enhancing the chemistry learning process at the high school level.

However, despite these advancements, many modules still fall short in fostering contextual understanding and meaningful learning experiences. They tend to prioritize conceptual content and rote memorization over critical thinking and real-world application.

This disconnect between learning content and students' lived experiences is especially evident in topics like colloids, which, despite their practical relevance, are often taught in ways that rely heavily on memorization and lack contextual depth, have led to low student interest in colloids topic, (Kristina, 2020).

One of the important concepts in colloids topic that offers significant benefits is coagulation. Coagulation is the process of disrupting the stability of particles, leading to the formation of a suspension (Ekoputri et al., 2023). In several chemistry topics taught in schools, the underlying scientific reasoning behind the formulation of a theory is often not explained; instead, the content is delivered directly. This approach may result in less meaningful learning and can potentially lead to misconceptions (Kamila, 2021).

To make such material more engaging and easier to grasp, efforts can be made through the development and improvement of teaching materials. Teaching materials are systematically organized content designed to produce learning resources for students and instructional tools for educators in implementing curriculum-aligned teaching (Anwar, 2023). The available teaching materials are still not fully aligned with the curriculum requirements (Marfu'ah, 2022). This is also supported by a preliminary study conducted through interviews with students and teachers at a senior high school in Cirebon, which revealed that the teaching materials used were solely oriented toward conceptual content without any connection to everyday life.

To improve the effectiveness of chemistry learning, one promising strategy is innovating the components of teaching materials such as content, depth, design, and language through the application of specific approaches or integration of technology (Hamid et al., 2017).

Teaching materials developed based on specific approaches or models that can make the learning process more effective and optimal. Contextual approach can be used as a learning model and learning approach. Contextual used as a learning model or Contextual Teaching and Learning (CTL) is designed to enhance students' motivation by encouraging them to apply what they have learned in meaningful ways within the context of their daily activities and social interactions. Rather than relying on rote memorization, students gain understanding through direct experience. Knowledge is not perceived as a collection of ready-made facts and concepts to be passively received, but as something that learners actively construct for themselves (Fadillah et al., 2017). Contextual used as learning approach means learning concept that helps teachers connect the subject matter being taught with real-world situations of students, by encouraging them to relate their existing knowledge to its application in their lives as members of families and communities (Sofiana and Wibowo 2019). The effectiveness of contextual approach implementation largely depends on the selection of meaningful contexts that align with the subject matter and incorporate prompts or guiding questions designed to engage students in solving real-world challenges, thereby facilitating the achievement of intended learning outcomes (Inayah 2020). Based on research conducted by Ilyas and Liu (2020) the e-learning contextual approach boosts students' motivation by encouraging them to investigate and discover concepts, making learning more enjoyable and engaging.

While various studies have explored the development of contextual teaching materials in chemistry, few have integrated local cultural elements into the learning design. To address this gap, the incorporation of ethnoscience offers a novel dimension—connecting scientific concepts with indigenous knowledge and cultural practices. This integration not only strengthens contextual relevance but also promotes cultural appreciation, making it a unique and innovative approach in science education. Based on Sari et al., (2023) ethnoscience based learning can be effectively combined with various other approaches and models, including contextual learning, collaborative learning, context-based learning, direct instruction, problem-based learning, and project-based learning. This integration has been shown to foster and enhance key 21st-century competencies, such as critical thinking, creativity, scientific process skills, conceptual understanding, character development, chemical literacy, and scientific literacy.

In developing teaching materials, there are several development models, including ADDIE, ASSURE, 4D, and 4STMD. All four are teaching material development models; however, the ADDIE, ASSURE, and 4D models are not specifically designed for developing teaching materials. In contrast, the 4STMD model includes detailed stages, starting from selecting basic competences and concept, the creation of concept maps, macro structures, and multiple representations, which together form the structure of the developed teaching materials (Marfu'ah, 2022). This structured and conceptually rich approach makes the 4STMD model particularly suitable for designing contextual and meaningful learning experiences. Its relevance and practicality have also been supported by prior research, which demonstrated that the 4STMD model, through its systematic four-stage process, is effective in the development of contextual and project-based teaching materials (Darmilah et al., 2025).

Various applications of chemistry can be found in everyday life, such as colloid systems. (Andrean et al., 2024) Studies on coagulation within the concept of colloids have proven beneficial in water purification processes, as shown in several studies. Among them, the application of coagulation in treating urban wastewater has been proven effective in improving nitrogen removal (Luo et al., 2024). Furthermore, the application of coagulation in the management of contaminated water sources has resulted in a significant reduction in most physicochemical parameters (Tahraoui et al., 2024). One critical area where coagulation plays an essential role is in the treatment of textile wastewater, which, if not properly disposed of, can lead to severe environmental issues due to the presence of heavy metals (Astuti et al., 2023). Coagulation is also applied in the treatment process of textile wastewater, including batik wastewater (Lolo and Pambudi, 2020). This presents the potential to use batik wastewater treatment as a context for module development, resulting in a module that is contextual, accessible, and engaging for students. This approach is supported by research from Japan, which found that colloid material is more effectively learned when based on real-world phenomena (Ishido et al., 2021).

Studies on the development of colloid teaching materials have been conducted in several previous researches; however, they have not specifically focused on batik wastewater treatment as a context. Therefore, the purpose of this study is to develop teaching materials using the 4STMD method and a contextual approach to provide a more meaningful learning experience in colloid concepts.

Method

This development research uses the DDE development model, which consists of three phases: the design phase, the development phase, and the evaluation phase (Richey and Klein 2019). using the 4STMD (Four Steps Teaching Material Development) method by Anwar (2023) as the teaching material development method.

Optimization

In optimizing the treatment of batik wastewater, samples of wastewater from small-scale home-based batik producers were used, with the treatment method employed being coagulation. Optimization seeks to establish the ideal set of conditions that can be conveniently monitored or evaluated (Sumarna et al., 2023). Observations were determined the most effective coagulant which used to treat the batik waste. Coagulant that used are $FeSO_4$ and ($Al_2(SO)_4.18H_2O$) or Tawas. A 1000 mL sample of batik wastewater was used, with initial measurements of pH and turbidity conducted using a turbidimeter. For samples treated with $FeSO_4$ as a coagulant, the pH was first adjusted to 8 by adding NaOH, as $FeSO_4$ performs optimally within a pH range of 8–11 (Hutabarat et al., 2023). The coagulant was then added at a concentration of 200 ppm with a volume of 3 mL. Stirring was carried out at 320 rpm for 15 minutes using a magnetic stirrer. Subsequently, 3 mL of PAC flocculant was added using a dropper, followed by slow stirring at 55 rpm for 7.55 minutes. After stirring, observations were recorded, including the final pH and turbidity levels. The results of this optimization served as the basis for designing an experimental procedure that students can follow in the context of colloid learning activities.

Preparation of Module

In developing and evaluating the teaching materials, a sample of 60 eleventh-grade students from a senior high school in Cirebon City was involved. Data collection techniques included review and the collection of students' responses. The instruments used were instrument for evaluating the correctness of concepts, learning outcomes, and learning objectives; instrument for assessing the appropriateness of concept maps, macro structures, and multiple representations; a characterization instrument; a feasibility test instrument for the teaching material and a comprehensibility test instrument. For the feasibility test, a standardized instrument from the Ministry of Education and Culture's Center for Books (Pusat Perbukuan Kemendikbud) was used, covering four aspects: content feasibility, language feasibility, presentation feasibility, graphical feasibility, and contextual feasibility. It is important to note that comprehensibility testing and readability testing are two different aspects. Comprehensibility refers to the reader's ability to grasp and understand the text, which is more closely related to the reader's quality itself.

Text in Module	
Characteristic Text	
Easy	Hard
If easy, write the main idea	
If hard, write the reason	

Figure 1. Characterization Instrument (Anwar, 2023)

The data from students' answers were analyzed by calculating the number of correct main idea responses, dividing it by the total number of main idea responses, and then multiplying by 100%, according to Formula 1.

$$Percentage\ score\ (x) = \frac{Jb}{s} \times 100\% \quad (1)$$

Explanation:
Jb = Number of students who correctly answered the main idea
S = Total number of students/respondents

The resulting percentage is then interpreted as follows in the category of teaching materials produced and a conclusion was drawn.

Table 1. Level of Understanding (Arifin. 2016)

K	Level of Understanding
60% < K ≤ 100%	High (Category Independent)
40 %< K ≤ 60%	Medium (Instructional category)
K ≤ 40%	Low (Category Difficult)

Result and Discussion

The result of this research distinguised into two parts, there are optimization and developing the teaching material.

Optimization

The optimization process was conducted to determine the most effective coagulant in treating batik wastewater. Before adding coagulant, sample 1 (using coagulant $FeSO_4$ were adjusted to pH 8 because of range pH optimum for coagulation with $FeSO_4$ and Floculation with PAC in range 6-9, so that the optimum result can be reached (Nisa and Aminudin 2019). The treatment of wastewater using $FeSO_4$ and alum as coagulants resulted in different turbidity reductions. Batik wastewater treated with $FeSO_4$ reduced the turbidity value from 222 NTU to 2.11 NTU, with the pH approaching neutral at 8. Meanwhile, batik wastewater treated with alum reduced the turbidity to 8.39 NTU, with a pH of 9. This is due to the fact that alum is not as effective in conditions with excessively alkaline pH levels.

1 2 3

Figure 2. (1) Results of wastewater treatment using $FeSO_4$
(2) Sample before treatment
(3) Results of wastewater treatment using Alum

Based on the optimization of both, it can be observed that the most effective coagulant for treating batik wastewater is $FeSO_4$. This is because $FeSO_4$ disrupts colloidal stability more effectively than alum ($Al_2(SO)_4.18H_2O$).

Selection Stage

In the selection phase, the basic competencies (KD) used were 2 (Table 2.). Subsequently, competency achievement indicators were developed, and concept labels were generated.

Table 2. KD, Indicator, Concept Label

KD	Indicator	Concept Label
Classify various types of colloidal systems and explain the applications of colloids in daily life based on their properties.	Explain the definition of a colloid	Definition of a colloid
	Classify the types of colloids	Types of colloids
	Mention the properties of colloids	Colloid properties
	Explain the methods of colloid preparation	Methods of colloid preparation
	Explain the application of colloid properties in everyday life	application of colloid properties in batik production
Create food products or other items that are colloidal in nature or involve colloidal principles	Conduct an experiment on liquid waste treatment using colloid principles	Treatment of batik wastewater using the coagulation method

Seven textbooks and three scientific articles were used as reference sources for the colloid material concepts. The selected materials were then reviewed by an expert lecturer (a chemistry lecturer) to ensure the conceptual accuracy of the content (Khoirunnisa et al., 2023). The next step is to develop the pedagogical content and the substantive content of the selected colloid concept. Substantive content refers to the selected materials used in developing the module, which relate to phenomena, occurrences, facts, data, and applications across various areas of life (Anwar, 2023). The selected substantive content is related to the application of colloid concepts in daily life, particularly those associated with the production process and the treatment of batik wastewater. The chosen pedagogical content focuses on fostering environmental awareness, which is developed through efforts to address the issue of untreated batik wastewater being discharged into the environment.

Structuring Stage

Mention gambar 3 dan 4 secara umum

In the structuring phase, a concept map (Figure 4.) and the macrostructure (Figure 3.) of the colloid concept were developed to prevent partial learning among students. The macrostructure outlines how the module framework is organized, starting with Learning Activity 1, which covers the general concept of colloids; Learning Activity 2, which discusses the application of colloids in the production and treatment of batik wastewater; and Learning Activity 3, which contains experiment of Batik waste treatment using coagulation method. In structuring stage, beside a concept map and macrostructure, the output of this phase is multiple level of representation that bring in developing the colloid system module (Table 3.)

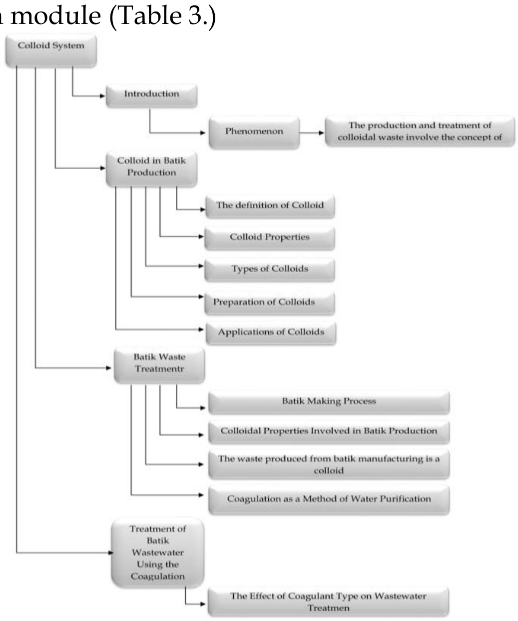


Figure 3. Concept Map

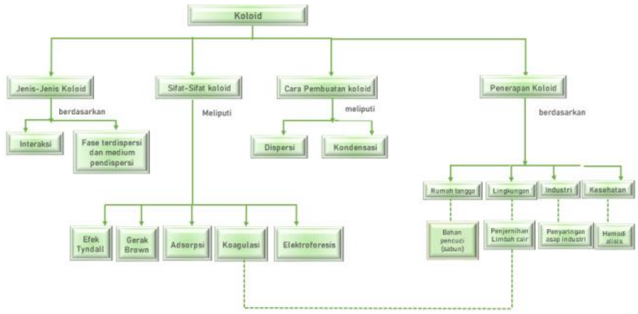
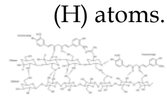


Figure 4. Concept Map

Table 3. Multiple representation

Material Concept	Macroscopic	Sub Microscopic	Symbolic
Colloid Applied In the textile industry, particularly in batik production, colloids such as mordants are used to enhance the binding affinity between dyes and fabric fibers. Mordants can be classified as colloids, as demonstrated through Tyndall effect and coagulation tests.	Mordants derived from natural materials can be obtained from chitosan, a biopolymer extracted from shrimp shells, which serves as an eco-friendly alternative in textile processing 	Chitosan is regarded as a mordant due to its ability to form effective hydrogen bonds, thereby enhancing the interaction between dye molecules and textile fibers	The mechanism of dye attachment to fabric with the assistance of a mordant involves the formation of bonds between oxygen (O) atoms and nitrogen (N), as well as between oxygen (O) and hydrogen (H) atoms. 

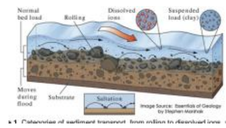
Characterization Stage

After the selection and structuring stages were completed and a module draft was formed, this stage was conducted to determine whether the concept or teaching material text developed was characterized as easy or difficult (Anwar, 2023). A limited-scale field trial was carried out by characterizing a total of 54 texts. The participants involved were 60 students selected from two classes at a public senior high school in Cirebon City.

Reduction Stage

Following the characterization result analysis, four texts specifically texts 11, 23, 37, and 41 were identified as having a high level of difficulty.

Table 4. Analysis Text and Didactic Reduction

Text	Characteristic Analysis; Kind of Didactic Reduction	Didactic Reduction Result
TEXT 23 Gold insole is said to be one example of hydrophobic colloid, Hydrophobic colloidal is *irreversible.*	Complicated Text; added an explanation in the form of a picture	Gold insoles are one example of hydrophobic colloids. Hydrophobic colloidal *irreversible or irreversible or returning to the original state.*  Figure of Gold Sol Ruby
Text 37 The use of detergent soap and soap for bathing is an application of colloids, where soap and detergent are emulsifiers to form emulsions between dirt (oil) and water. The intermolecular interactions resulting from its structure are (stearic acid).	Complex Text; sentence reformulation	The use of detergent soap and soap for bathing is an application of colloids in the household sector, where soap and detergent are emulsifiers or stabilizers to form an emulsion between dirt (oil) and water. The interaction between molecules resulting from its structure is (stearic acid).
TEXT 41 Colloidal applications in environmental fields: The formation of an estuary delta can visualize as follows:  The formation of estuary deltas is influenced by: Water Flow Speed: (explanation) Amount of sediment: (Explanation) Shape of the coastline(explanation)	complex text; sentence reformulation explained by image	Colloidal applications in the environmental field The formation of the estuary delta can be visualized as follows:  The formation of estuary deltas is influenced by: 1. Water Flow Speed: (explanation) 2. Amount of sediment: (Explanation) 3. Shape the coastline (explanation)  Figure of the Unsymmetrical Delta Estuary  Figure of the symmetrical Estuary Delta

Four texts that are classified as difficult, there is an omission of text 11, because the text cannot be reduced in any way because it is not included in a requirement of competency achievement. Another reason if it is still included in the module, the concept will make student confused because its too advance to be studied at senior high school level. For text 23, 37, 41, the strategy to didactic reduction is reformulation sentence and Including images to clarify the concepts described through written complex statements.

Mention tujuan didactic reduction.

Feasibility and Comprehension Test

The feasibility test was carried out by 2 chemistry teachers and 1 Indonesian teacher, the instrument used in feasibility test based on the Ministry of Education and Culture's book center (Pusbud Kemendikbud) data from each aspect is generated in Figure 5.

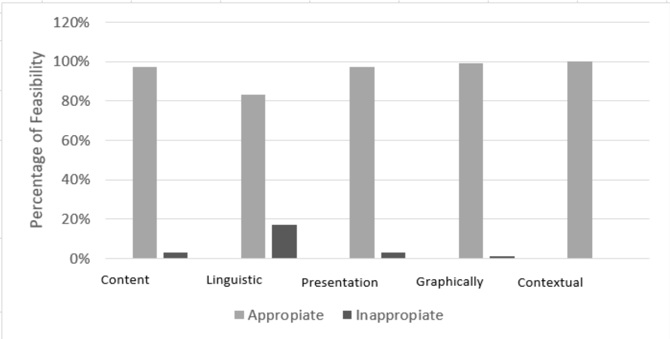


Figure 5. Percentage of Feasibility

Each aspect has very feasible criteria, content aspect has 97%, linguistic aspect has 83%, presentation aspect has 97%, graphically aspect has 99%, and for the contextual aspect give 100%, so that we can take an average of percentage feasibility is 95,4% which means the teaching material is very feasible. In aspect of Linguistic feasibility, there are a few suggestions such irregular margins, numerous typographical errors, and the replacement of the foreign term "adjusting pH" with the more appropriate term 'controlling pH' or "*mengontrol pH*" in bahasa because the module is developed in bahasa Indonesia.

Following the feasibility test, a comprehensibility test was conducted on the entire revised module, which had been improved through the process of didactic reduction and the suggestions obtained from the feasibility evaluation. Texts such as Text 23, 37, and 41 became easier to understand, and the overall comprehensibility rate reached 92%, indicating that the developed module can be categorized as a self-instructional learning material.

The module was designed in A5 size (21.0 cm x 14.8 cm) and developed using microsoft word. The cover design effectively represents the theme of the colloid module, which is developed through the context of batik wastewater treatment.

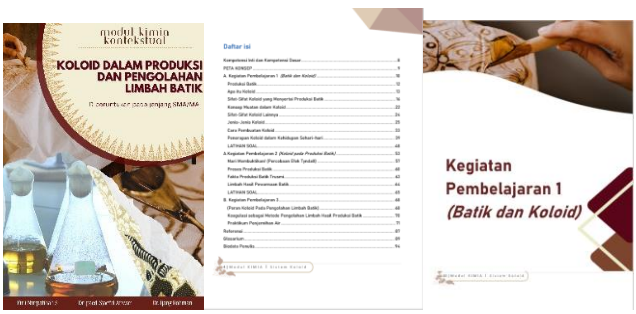


Figure 6. Design of Module

Conclusion

The optimization conducted in the batik wastewater purification process demonstrated that the use of $FeSO_4$ as a coagulant was effective in reducing turbidity levels from 222 NTU to 2.11 NTU. The presence of large flocs settling at the bottom indicated that the coagulation and flocculation process was successful, and this optimizing can serve as a reference for chemistry colloid experiments.

The characteristics of the contextual module on batik wastewater treatment, developed using the 4STMD method, resulted in teaching materials that are aligned with the curriculum, conceptually accurate, and suitable as independent learning materials. The feasibility test gives a score of 95.4%, while the comprehension test achieved a score of 92%. The developed module is a self-instructional module, which is expected to facilitate students in understanding colloid concepts, particularly the concept of coagulation. Prior to its application, the module should be tested and implemented in classroom learning, including experiments related to batik wastewater treatment.

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Study literature, F. N. S.; Discussion expert, S. A., I. R.; Collecting data, F. N. S.; Evaluating data, F. N. S., S. A., I. R.; Writing—original draft preparation, F. N. S.; Writing—review and editing, F. N. S.; Review, S. A., I. R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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