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Contextual-Based Teaching Materials: Solid Bioethanol Producing from Rice-Washing Wastewater

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Abstract

Providing contextual chemistry teaching materials remains a challenge, given that currently available textbooks still do little to connect the material to real life. This study aims to develop instructional materials on alcohol compounds in the context of producing solid bioethanol from rice-washing wastewater using the 4STMD method. The research method used was Developmental Research (DR), which consists of three stages: design, development, and evaluation. The participants involved in this study were 67 twelfth grade high school students in Bandung for the characterization test and 62 students for the comprehension test, as well as a feasibility test involving 5 high school chemistry teachers. The development process began with the design stage, which produced a preliminary draft of the instructional materials. Next, during the development stage the 4STMD instructional material development method was used, a selection process was conducted, resulting in 2 Learning Objectives and 12 Concept Labels based on 8 textbooks. From this stage, the characterization process identified 6 texts categorized as difficult, which were then subjected to didactic reduction through the use of explanations in the form of images and symbols, sentence reformulation, and omission. In the evaluation stage, the results of the instructional material feasibility test showed a "highly feasible" rating of 89.76%, and the results of the student comprehension test indicated that the instructional material had a high level of comprehension at 90.9%, placing it in the "self-directed learning material" category.

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1. INTRODUCTION

The teaching and learning process consists of three main components: teachers, students, and instructional materials. Various studies in the field of science education show that when designing learning activities, teachers tend to rely on and use teaching materialss as their primary reference (Chambliss, M. J., & Calfee, 1998). This is evidenced by the finding that more than 70% of science teachers rely on teaching materials (Dufitumukiza & Twizeyimana, 2023). The use of teaching materialss is not limited to teachers as a guide for teaching; students also use them as one of their learning references (N. Setiawan, 2023). This is in line with showing that teaching materialss play an important role as the primary reference for students to acquire information and knowledge.

Although they play an important role in learning, the quality of chemistry teaching materialss not fully meet curriculum requirements and to be insufficient in covering the material being taught. The same finding also found by Silviana (2016) on the feasibility analysis of chemistry teaching materialss, which found that in terms of the scope and the depth of concepts, the coverage of alkanes is still lacking, and some material is not entirely scientifically accurate. This aligns with research Triana Krisandi (2024) that also concluded that twelfth grade

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chemistry teaching materialss generally still provide minimal context for science in everyday life. Yet it is precisely this contextual aspect that is actually engaging for students and simultaneously serves as an effective means of reinforcing concepts. Existing teaching materials tend to focus more on presenting content and solving problems without incorporating experimental activities relevant to the material; as a result, students merely memorize concepts without practicing how to observe, formulate hypotheses, and draw conclusions from data.

A review of several high school chemistry teaching materials currently in use shows that scientific phenomena are often used merely as literacy stimuli at the beginning of a chapter. These phenomena are not further integrated into real-world problem-solving activities, so the application of chemistry remains confined to textual discourse without becoming a learning experience. Meanwhile, in the chemistry learning process, Contextual Teaching and Learning helps students connect theory with aspects of daily life (Giammatteo & Valdivia, 2021). Context-based learning on hydrocarbon material is easier for students to understand (Lubis & Rahmania, 2022). Contextual chemistry instruction on redox topics has a positive impact on students learning motivation and learning outcomes (Zulfania et al., 2025). Furthermore, chemical concepts are easier to grasp when contextualized through culture or ethnochemistry rather than through direct chemistry instruction alone (Wahyuni et al., 2025). One local resource in Bandung that can be utilized as a learning context is the home-based industry producing the traditional snack *rengginang*. The *rengginang* production process uses glutinous rice (Oryza sativa var. glutinosa) as its main raw material, which requires repeated washing and soaking before steaming. This results in an enourmous volume of liquid waste in the form of glutinous rice washing water, which is concentrated in a particular location.

This rice-washing wastewater often causes environmental problems and water pollution due to its unpleasant odor if it is not properly treated before discharge (D. Setiawan et al., 2020). Chemically, this wastewater has great potential because it contains carbohydrates in the form of 80–85% starch, as well as cellulose, hemicellulose, gluten protein, sugars, and B vitamins, which are abundant in the aleurone layer that is washed away during the washing process (Maharani, 2023). The high starch content makes rice washing water a potential source for producing bioethanol through fermentation.

The bioethanol produced is not left in its liquid form which is prone to evaporation and difficult to distribute but is instead converted into solid bioethanol. The purpose of converting bioethanol into a solid form is that solid bioethanol has several advantages over other alternative fuels, namely: during combustion, it produces no soot, no smoke, and no harmful gas emissions; it is non-corrosive and non-carcinogenic (Sani et al., 2016). Its solid form also makes it easier to transport and store (Retno & Nuri, 2011).

The production of solid bioethanol from rice-washing wastewater is used as a context in chemistry teaching materials. This context can be linked to the chemistry topic of alcohol compounds. Bioethanol is a colorless liquid with a distinctive odor, a boiling point of 78˚C, and a freezing point of -112˚C. These characteristics are similar to those of ethanol (Perry, 1999). Ethanol is a type of alcohol compound. The topic of alcohol compounds is part of the material on carbon compounds derived from alkanes in Phase F of Twelfth Grade high school/MA/*Program Paket C* under the Learning Outcome “Explain carbon compounds”. Through this context, students can learn about the concept of alcohols, ranging from alcohol reactions to an understanding of their physical and chemical properties, as well as their use as an alternative fuel.

In order to present this material and context systematically, a method for developing instructional materials is required. One method that features detailed stages and clear criteria for the development of instructional materials is the 4STMD method (Marfu’ah et al., 2022). The Four Steps Teaching Material Development (4STMD) consists of four main stages: selection, structuring, characterization, and didactic reduction (Anwar, 2023). These stages constitute the process of developing instructional materials so that they are ready for use by teachers in the classroom or by students for self-directed learning. Therefore, this study aims to develop and produce chemistry instructional materials on alcohol compounds using the 4STMD method, with the context of producing solid bioethanol from rice-washing wastewater.

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2. METHOD

3.1. Research Design

This study employed the Development Research (DR) method, which consists of three stages: Design, Development, and Evaluation (Richey, R. C., Klein, J. D., & Nelson, 2004). This study was conducted in one public senior high school in Bandung, West Java, Indonesia. This method guides the overall research process, beginning with the design stage for curriculum analysis and optimization as the basis for developing laboratory procedures. This is followed by the development stage, which focuses on creating instructional materials using the 4STMD method. The final stage is the evaluation stage, which assesses the quality of the instructional materials through feasibility tests and student comprehension tests.

3.2. Participants

This study involved five high school chemistry teachers who served as validators for the feasibility test of the teaching materials. A total of 67 students twelfth grade high school participated in the characterization stage and 62 students in the comprehension test in the evaluation stage.

3.3. Stages of The 4STMD

This book was developed using the four stages of the 4STMD method (Anwar, 2023). The selection stage involved aligning the content and context of the instructional materials with curriculum standards and ensuring scientific accuracy by drawing on material from eight basic chemistry teaching materialss. The substantive context which is the production of solid bioethanol from rice-washing wastewater and the pedagogical context e.g., environmental awareness were integrated as a means of developing students potential. Next is the structuring stage, which is the process of organizing learning content in a logical and scientifically accurate manner by creating concept maps, macro-structures, and three-level representations. The characterization stage involved testing the first draft of the instructional materials with 67 students by identifying key ideas and student responses to each text segment to determine which concepts students found difficult to understand. Finally, the didactic reduction stage simplifies concepts that are considered difficult into concepts that are easier to understand. This is achieved through reduction techniques such as sentence reformulation, omission, and the use of explanatory images and symbols.

3.4. Research Instruments

Two main instruments were used to evaluate the quality of the book. The feasibility questionnaire is a validation instrument that was administered to five high school chemistry teachers. This questionnaire was adapted from the feasibility standards established by adapted from *Peraturan Kepala Badan Standar, Kurikulum dan Asesmen Pendidikan No. 39 Tahun 2022*. It covers four feasibility standards: content, presentation, design, and graphics. The comprehension test instrument which involves identifying main ideas was administered to students. This instrument was adapted from the 4STMD characterization stage, which requires students to write down the main ideas from each text excerpt to assess their understanding of the material on alcohol compounds.

3.5. Data Analysis Techniques

The suitability data from the teacher questionnaire were analyzed using descriptive percentages to determine the validity of the teaching materials. The suitability percentage was calculated using the formula below (Ridwan & Sunarto, 2013).

$$\% = \frac{\text{Total score obtained}}{\text{Maximum total score}} \times 100\% \tag{1}$$

The resulting percentages were then categorized according to the criteria in Table 1.

Table 1. Criteria for the suitability of teaching materials (adapted from Ridwan & Sunarto, 2013)

Interval score	Criteria
81% – 100%	Highly suitable
61% – 80%	Suitable
41% – 60%	Fairly suitable
21% – 40%	Not suitable
0% – 20%	Highly unsuitable

Data on students' comprehension of main ideas were analyzed to determine how easily students understood theinstructional material. Comprehension scores (K) were calculated based on the percentage of students who correctly identified the main idea of each text (Rankin & Culhane, 1969). The resulting overall percentages were categorized using the criteria in Table 2 as follows.

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Table 2. Criteria for understanding the teaching materials

K	Comprehensibility
60% < K ≤ 100%	High (Independent Category)
40% < K ≤ 60%	Medium (Instructional Category)
K ≤ 40%	Low (Difficult Category)

3. RESULT AND DISCUSSION

This section presents the findings from the teaching materials development process, which followed the Design, Development, and Evaluation (DDE) model. The results are presented in three parts: the development of instructional materials, the teachers assessment of the teaching materials's suitability, and the students understanding of the teaching materials. Finally, these findings are discussed and compared with related research.

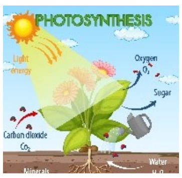
3.1. Result

3.1.1. Teaching Materials Development

The result of the development of teaching materials on alcohol in the context of producing solid bioethanol from rice-washing wastewater were determined based on the findings of two stages: the design stage and the development stage. The result of the design stage identified aspects closely rated to alcohol and chemistry understanding, specifically the learning outcome of explaining carbon compounds. Therefore, this study utilized that learning outcome to further develop the teaching materials. In addition, the result of the optimazation parameters indicated that the optimal conditions were a fermentation time of 5 days with the addition 5 grams of yeast, resulting in a combustion duration of 37 minutes and 12 seconds. The optimum value referred to in this study is the time when the fermentation time and yeast mass produce the longest flame burning duration without producing soot, thus serving as the basis for developing practical procedures in teaching materials.

At the development stages the application of the 4STMD method resulted in a well-structured, context-based teaching materials on alcohol compounds, refined through didactic reduction. The selection phase yielded 12 learning objectives and 12 concept labels based on 8 basic chemistry teaching materialss. The structuring stage yielded a concept map, a macro structure, and multiple representations. The characterization stage successfully identified 6 out of 28 texts that were conceptually difficult for students to understand Table 3. below present an analysis of the text characteristics.

Table 3. Analysis text and didactic reduction

Text	Characteristic Analysis; Types of Reduction	Didactic Reduction Result
Text 5: Raw materials for the production of solid bioethanol From an ecological perspective, bioethanol offers advantages through the principle of a closed carbon cycle, in which CO_2 emissions released during combustion are reabsorbed by plants, thereby maintaining a balanced environmental carbon. Furthermore, the hydroxyl groups in its structure supply internal oxygen, ensuring complete combustion without soot. In addition to rice washing water, ethanol can also be produced from various other materials containing sucrose (molasses), starch (rice, corn, potatoes, and cassava), or cellulose (grass and rice straw). Its chemical characteristics and the abundant availability of raw materials make bioethanol a breakthrough solution to	Complex text; Rewording sentences and using symbols and images to provide explanations	**Text 5: Raw materials for the production of solid bioethanol** From an environmental perspective, bioethanol is very eco-friendly. This is because the carbon dioxide (CO_2) produced by its combustion does not accumulate as air pollution; instead, it is reabsorbed by plants through photosynthesis. Chemistry Around Us Do you remember the photosynthesis reaction below? $6CO_2\ (g) + 6H_2O\ (l)$ (carbon dioksida) (water) + light energy ⟶ $C_6H_{12}O_6\ (aq) + 6O_2\ (g)$ (glucose) (Oxygen)  Figure 7. Photosynthesis Through this reaction, plants convert CO_2 emissions into glucose a form of stored energy and

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Text	Characteristic Analysis; Types of Reduction	Didactic Reduction Result
 Figure 7. (a) Rice straw, (b) rice, (c) corn, and (d) potatoes environmental problems caused by the use of fossil fuels.		release oxygen back into the air. It is this cycle that makes bioethanol known as an environmentally friendly alternative fuel. Another advantage is that the presence of hydroxyl groups (–OH) in the alcohol structure allows for more complete combustion without soot. This also results in lower carbon dioxide (CO_2) emissions. Bioethanol can also be produced from various other materials, including: 1. Molasses, which contains sucrose, 2. Starch-containing materials such as rice, corn, potatoes, and cassava, 3. Cellulose-containing materials such as grass and rice straw.  Figure 7. (a) Rice straw, (b) rice, (c) corn, Cellulosic materials have a highly complex polymer molecular structure and are strongly bound to lignin (the woody substance that makes up plant cell walls). Since microorganisms such as yeast cannot ferment cellulose directly, these polymer chains must first be broken down. Therefore, a hydrolysis process is required to break down cellulose into simple sugar monomers namely, glucose before yeast can carry out the fermentation process to produce alcohol. Its superior chemical properties and the abundant availability of raw materials make bioethanol a breakthrough solution to the environmental problems caused by our reliance on fossil fuels.
Text 16: Synthesis of Alcohol **2. Chemical Method** Currently, methanol is produced from synthesis gas, a mixture of CO and H_2. When CO and H_2 pass over a catalyst at the appropriate temperature and pressure, methanol is formed . $CO\ (g) + 2H_2\ (g) \xrightarrow{\text{catalyst}} CH_3OH\ (l)$ Industrially, ethanol is produced by reacting ethylene with water in the presence of an acid catalyst.	Complicated text; The use of symbolic explanations and omissions	**Text 16: Synthesis of Alcohol** **2. Chemical Methods** Some alcohol compounds produced chemically: a) Production of methanol Currently, methanol is produced from synthesis gas, a mixture of CO and H_2. When CO and H_2 pass over a catalyst at the appropriate temperature and pressure, methanol is formed. $CO\ (g) + 2H_2\ (g) \xrightarrow{\text{catalyst}} CH_3OH\ (l)$ Carbon monoxide Hydrogen Methanol

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Text	Characteristic Analysis; Types of Reduction	Didactic Reduction Result
$CH_2{=}CH_2\ (g) + H_2O\ (l) \xrightarrow{\text{acid catalyst}} CH_3CH_2OH\ (l)$ 2-Propanol (isopropyl alcohol) can be produced from propene (propylene) in the same way. $CH_3CH{=}CH_2\ (g) + H_2O\ (l) \longrightarrow$ CH_3 – $\overset{CH_3}{\underset{OH}{C}}$ – H (l) Hydration means that water is added. This is an addition reaction. $H_2C{=}CH_2\ (g) + H_2O\ (g) \underset{\text{catalyst (phosphoric acid)}}{\overset{570^\circ C,\ 60\text{-}70\ atm}{\rightleftharpoons}}$ H–$\overset{OH}{\underset{OH}{C}}$–$\overset{OH}{\underset{OH}{C}}$–OH (l) ➢ The reaction is reversible and exothermic. ➢ High pressure and low temperature yield the best results. However, in practice, the reaction is carried out at 570 °C to achieve a reasonable reaction rate. ➢ A catalyst is also used to accelerate the reaction.		b) Ethanol Production Industrially, ethanol is produced by reacting ethylene with water in the presence of an acid catalyst. $CH_2{=}CH_2(g) + H_2O(l) \underset{\text{catalyst (phosphoric acid)}}{\overset{570^\circ C,\ 60\text{-}70\ atm}{\rightleftharpoons}} CH_3CH_2OH(l)$ Etilen Air Etanol This ethanol production reaction involves a hydration process, which is an addition reaction in which a water molecule is added to ethylene. This reaction is reversible and exothermic. According to the theory of chemical equilibrium, low temperature and high pressure conditions will yield the greatest amount of product. However, at low temperatures, the reaction proceeds very slowly. Therefore, in industrial practice, the reaction is carried out at high temperatures (around 570°C) to ensure a sufficiently fast reaction rate. Catalysts are also used to help accelerate this reaction. c) Production of 2-propanol 2-Propanol (isopropyl alcohol) can be produced from propene (propylene) in the same manner.
Text 22: Typical Reactions of the Hydroxyl Group (–OH) **3. Substitution Reactions** In acidic solutions, alcohols can undergo substitution reactions. A substitution reaction is a reaction in which a functional group in a chemical compound is replaced by another functional group. $CH_3CH_2CH_2CH_2{-}OH\ (l) + H{-}Br\ (g) \underset{\text{kalor}}{\xrightarrow{H_2SO_4}}$ 1-butanol $CH_3CH_2CH_2CH_2{-}Br\ (l) + H_2O\ (l)$ 1-bromobutana (95%) $CH_3CH_2\overset{CH_3}{CH}{-}OH\ (l) + H{-}Cl\ (l) \xrightarrow{ZnCl_2}$ 2-butanol $CH_3CH_2\overset{CH_3}{CH}{-}Cl\ (l) + H_2O\ (l)$ 2-klorobutana (66%) $(CH_3)_3C{-}OH\ (l) + H{-}Cl\ (l) \longrightarrow$ $(CH_3)_3{-}Cl\ (l) + H_2O\ (l)$ t-butil klorida (88%)	Complicated text; Omission and Use of Symbolic Representations	**Text 22: Typical Reactions of the Hydroxyl Group (–OH)** **3. Substitution Reactions** In acidic solutions, alcohols can undergo substitution reactions. A substitution reaction is a reaction in which a functional group in a chemical compound is replaced by another functional group. $CH_3CH_2CH_2CH_2{-}OH\ (l) + H{-}Br\ (g) \underset{\text{kalor}}{\xrightarrow{H_2SO_4}}$ 1-butanol $CH_3CH_2CH_2CH_2{-}Br\ (l) + H_2O\ (l)$ 1-bromobutane $CH_3CH_2\overset{CH_3}{CH}{-}OH\ (l) + H{-}Cl\ (l) \xrightarrow{ZnCl_2}$ 2-butanol $CH_3CH_2\overset{CH_3}{CH}{-}Cl\ (l) + H_2O\ (l)$ 2-chlorobutane $(CH_3)_3C{-}OH\ (l) + H{-}Cl\ (l) \longrightarrow$ $(CH_3)_3C{-}Cl\ (l) + H_2O\ (l)$ t-butyl chloride

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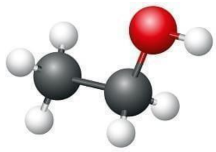
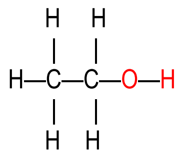
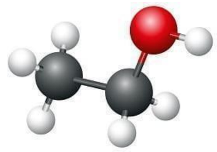
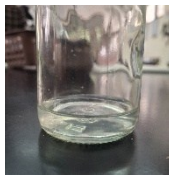
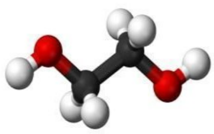
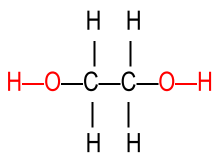
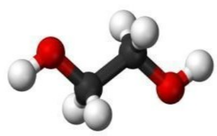
Text	Characteristic Analysis; Types of Reduction	Didactic Reduction Result
Text 24: Uses of Alcohol  IUPAC Name: Ethyl Alcohol Common Name: Ethanol Molecular Formula: CH_3CH_2OH $C_6H_{12}O_6(aq) \xrightarrow{enzym} 2CH_3CH_2OH(aq) + 2CO_2(g)$ Ethyl alcohol is one of the oldest known pure organic chemicals. It has countless applications, serving as a solvent for organic chemicals as well as in cosmetics. The production of ethyl alcohol through the fermentation of grains and sugar has existed for thousands of years. During fermentation, starch or complex sugars are broken down and ultimately converted into simple sugars ($C_6H_{12}O_6$), which are then converted into ethyl alcohol.	Complex text; Sentence reformulation & Use of illustrations and symbols for explanation	**Text 24: Uses of Alcohol**   IUPAC Name: Ethyl Alcohol Common Name: Ethanol Molecular Formula: CH_3CH_2OH Alcohol, or ethanol (CH_3CH_2OH), has countless applications. Ethanol is used as a solvent for organic chemicals and as a starting compound for the production of dyes, synthetic drugs, and cosmetics. Ethanol is also a component of 70% alcohol solutions and alcoholic beverages. In addition, ethanol is used as a fuel. The combustion reaction is as follows: $C_2H_5OH\ (l) + O_2\ (g) \longrightarrow 2CO_2\ (g) +$ Ethanol Oxygen Carbon dioxide $3H_2O\ (l)$ + heat Water The production of ethyl alcohol through the fermentation of grains and sugar has been around for thousands of years. During fermentation, starch or complex sugars are broken down and eventually converted into simple sugars ($C_6H_{12}O_6$), which are then converted into ethyl alcohol.  Figure 15. Bioethanol from rice washing water $C_6H_{12}O_6\ (aq) \xrightarrow{Yeast} 2CH_3CH_2OH\ (aq) +$ Glucose Ethanol $2CO_2\ (g)$ Carbon dioxide
Text 26: Uses of Alcohol  IUPAC Name: ethane-1,2-diol Common Name: Ethylene glycol Molecular Formula: $HOCH_2CH_2OH$	Complex text; The use of illustrations and symbols for explanation	**Text 26: Uses of Alcohol**   IUPAC Name: ethane-1,2-diol Common Name: Ethylene glycol Molecular Formula: $HOCH_2CH_2OH$

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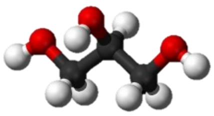
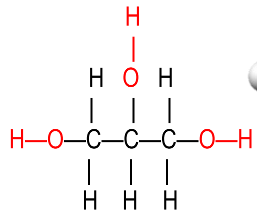
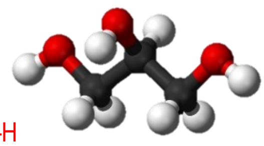
<table>
<tr><th>Text</th><th>Characteristic Analysis; Types of Reduction</th><th>Didactic Reduction Result</th></tr>
<tr><td>Ethylene glycol belongs to the class of diols, which are alcohols containing two hydroxyl groups (–OH). It is a colorless liquid that is soluble in water but insoluble in nonpolar solvents. Its primary uses today include as an antifreeze or coolant, or as a raw material for the production of polyester films and fibers, such as Dacron.</td><td></td><td>Ethylene glycol belongs to the class of diols, which are alcohol compounds containing two hydroxyl groups (–OH). It is a colorless liquid that is soluble in water but insoluble in nonpolar solvents. Its primary uses today are as an antifreeze in cars and as a raw material for the production of polyester films and fibers, such as Dacron.

When winter arrives in regions with four seasons, extreme temperatures can cause a car's radiator fluid to freeze quickly. However, the radiator fluid remains intact be cause it contains an antifreeze agent called ethylene glycol.

Figure 16. Radiator Coolant

At the microscopic level, ethylene glycol acts as a barrier between water molecules. This barrier prevents water molecules from coming together and freezing into ice crystals. As a result, the freezing point of the solution drops. Consequently, the radiator fluid remains liquid even in extremely cold temperatures, and the car's engine is protected from ice buildup.</td></tr>
<tr><td>Text 27: Uses of Alcohol

IUPAC Name: propane-1,2,3-triol
Common Name: Glycerol
Molecular Formula: $HOCH_2CH(OH)CH_2OH$

Glycerol is a triol, which is an alcohol containing three hydroxyl groups (–OH). It is a colorless liquid that is soluble in water. Unlike ethylene glycol, glycerol is non-toxic but has a sweet taste that makes it useful in candies and prepared foods. Often known as glycerin, glycerol is also used in cosmetics and tobacco as a moisturizer, in the manufacture of plastics, and as a solvent.</td><td>Complex text; Use of explanations in the form of images and symbols & rephrasing of sentences</td><td>Text 27: Uses of Alcohol


IUPAC Name: propane-1,2,3-triol
Common Name: Glycerol
Molecular Formula: $HOCH_2CH(OH)CH_2OH$

Glycerol is a triol, which is an alcohol compound containing three hydroxyl groups (–OH). It is a colorless liquid that is soluble in water. Glycerol is a clear, thick syrup-like substance; it has a sweet taste and is safe to eat, so it is often added to food products such as candy and ready-to-eat meals. Glycerol is also commonly known as glycerin; it is used in cosmetics as a moisturizer, in the manufacture of plastics, and as a solvent.


Gambar 17. Glycerin</td></tr>
</table>

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The subsequent didactic reduction stage simplified these difficult concepts to make them easier for students to understand by applying reduction methods based on student feedback analysis. This included rephrasing complex sentence structures to improve text clarity, eliminating complex concepts that were not yet appropriate for students cognitive levels to make the material easier to understand without compromising core concepts, and incorporating visual aids such as images and symbols.

3.1.2. Suitability of teaching materials

The book's suitability was validated by five chemistry teachers using a questionnaire adapted from *Peraturan Kepala Badan Standar, Kurikulum dan Asesmen Pendidikan No. 39 Tahun 2022*. The assessment covered four aspects: content, presentation, design, and graphics. The results of the validation questionnaire are presented in Table 4 below.

Table 4. Results of the teaching materials feasibility validation

Feasibility aspects	Score	Criteria
Content	86,96%	Highly suitable
Presentation	79,31%	Suitable
Design	86,67%	Highly suitable
Graphics	94,12%	Highly suitable

3.1.3. Comprehension of Teaching Materials

Following expert validation, the book's comprehensibility was evaluated from the students' perspective. The final revised edition was tested on 62 twelfth grade high school students using the main idea test described in the Methods section. This test measured the percentage of students who could correctly understand and state the main ideas of the text. The results are summarized in Table 5 below.

Table 5. Summary of the student comprehension test

Parameters	Result
Amount of text	28
Number of students	62
Comprehension score	90,9%
Comprehension category	High

The data shows a very high student comprehension score of 90.9%. Based on the criteria established by source, a score above 60% is considered "High." These results indicate that this approach is highly suitable for student-led learning.

3.2. Discussion

The instructional materials were developed using the 4STMD method. The 4STMD method consists of four stages: selection, structuring, characterization, and didactic reduction. Based on the content selection, 12 learning objectives and 12 concept labels were identified. The learning objectives are derived from the Learning Outcomes outlined in the Merdeka Curriculum. The Learning Outcomes describe carbon compounds with the following Learning Objectives: 1) Identify alcohol in everyday life; 2) Understand alcohol as derivatives of hydrocarbon; 3) Determine the structure of alcohol; 4) Explain the properties of alcohol; 5) Determine the nomenclature of alcohol; 6) Classify types of alcohol; 7) Explain the synthesis of alcohol; 8) Explain the reactions of alcohol; 9) Explain the uses of alcohol; 10) Predict alcohol using simple methods; 11) Understand the raw materials for alcohol; and 12) Analyze alcohol as alternative fuels. The key concepts covered in this learning objectives are alcohols in everyday life, the structure of alcohols, the physical properties of alcohols, the chemical properties of alcohols, the nomenclature of alcohols, types of alcohols, the synthesis of alcohols, reactions involving alcohols, uses of alcohol, identification of alcohol, alcohol as alternative fuels, and materials that can be used as raw materials for alcohol production. All learning objectives and concept labels were reviewed for their relevance to the topic of alcohol by three expert lecturers, and the review results indicated that all learning objectives and concept labels were appropriate. Consequently, the author was able to trace the descriptions of each concept label through the works of Ebbing (2015), Fessenden (1982), Gallagher (2011), Hart (2003), Malone (2010), McMurry (2007), Middlecamp (2015), and Whitten (2009). This book is internationally recognized, so the accuracy of its content is acknowledged on an international scale.

The next stage of the selection process focuses on the development of the substantive and pedagogical contexts. The substantive context refers to the context of the instructional materials, which are linked to phenomena, patterns, data, facts, and benefits in various areas of life. One of the substantive topics covered is a description of materials that can be used as raw materials for alcohol production. The content includes illustrations and information about raw materials such as rice straw, corn, rice, and potatoes, which are some of the materials that can be used as raw materials for alcohol production. In addition, the lesson on alcohols as alternative fuels incorporates a pedagogical context that fosters an environmentally conscious attitude. This commitment to environmental protection is accompanied by an explanatory comparing greenhouse gas emissions generated by different energy sources such as petroleum and biomass, particularly bioethanol with the aim of illustrating their direct impact on environmental issues such as global warming and air and water quality. Through this discussion, it is hoped that students will develop an awareness of the need to prevent damage to and preserve the natural environment. The entire presentation of the material has been reviewed for appropriateness and has been deemed suitable and accurate.

The next stage is the structuring stage. At this stage, a concept map, a macro structure, and multiple representations are developed. Concept maps serve specific functions and purposes: they help students build cognitive structures, teach learning strategies, and can be used as an assessment tool (Anwar, 2023). A concept map is created to organize and present the relationships between concepts, which are indicated by connecting lines. Concepts and propositions are typically organized hierarchically, from the most general and inclusive to the most specific (Novak J. D., 1995). The result of these three forms of representation is the existence of illustrations in general, in the form of phenomena that we can see with our own eyes. We then provide a submicroscopic explanation of this phenomenon, that is, a detailed explanation. This was followed by a symbolic illustration of what happened. One example is the explanation of the properties of alcohol; at the macroscopic level, a table comparing the boiling points of various alcohols and haloalkanes is presented. The submicroscopic level explains the differences between these two groups of compounds. In the symbolic section, the author includes an illustration of what happens to the hydrogen bonds between alcohol molecules, which cause alcohol to have a higher boiling point than haloalkanes, so that students can visualize this abstract concept.

The third stage is the characterization stage. The characterization stage is carried out by providing students with texts so they can determine whether the texts are easy or difficult to understand and identify the main ideas of the texts. These texts were compiled based on the two previous stages. This study included 28 texts. Texts 1–10 were given to 23 students. Texts 11–18 were given to 22 students. Texts 19–28 were given to 22 students. Based on the results of the characterization, six texts were identified as difficult to understand: texts 5, 16, 22, 24, 26, and 27. The fourth stage is didactic reduction. Based on the analysis of text characteristics, texts 5, 24, 26, and 27 exhibit the characteristics of complex texts, while texts 16 and 22 exhibit the characteristics of intricate texts.

Didactic text reduction was carried out in several ways. Texts 5, 16, 24, 26, and 27 were didactically reduced through sentence reformulation and the use of explanations in the form of symbols and images, while text 22 was reduced through the use of explanations in the form of symbols and omission. After the revisions were made, the instructional materials were adjusted and reviewed by an expert instructor. All stages of the 4STMD method were reviewed by three expert lecturers.

The feasibility test was conducted by five chemistry teachers; the instruments used in the feasibility test were based on data from BSKAP 039 of 2022. The content feasibility aspect met the “highly feasible” criteria with a percentage of 86.96%; the presentation aspect met the “feasible” criteria with 79.31%; the design aspect met the “highly feasible” criteria with 86.67%; and the graphics aspect met the “highly feasible” criteria with 94.12%. Thus, the average feasibility percentage was 86.76%, indicating that the teaching material is highly feasible. In terms of design feasibility, there are several suggestions, such as using fonts commonly found in books with lengthy text to ensure readability, and using colors for the book cover title that provide greater contrast with the background color.

Following the feasibility study, a comprehension test was conducted on all revised instructional materials that had undergone the process of didactic streamlining and incorporated the recommendations obtained from the feasibility evaluation. Texts such as Texts 5, 16, 22, 24, 26, and 27 became easier to understand, and the overall comprehension rate reached 90.9%, indicating that the developed module can be categorized as self-study material with a high level of comprehensibility.

Figure 1. Design of teaching materials

This module is designed in A5 size (21.0 cm x 14.8 cm) and was created using Microsoft Word. The cover design reflects the book's theme of alcohol, which is explored in the context of producing solid bioethanol from rice-washing wastewater.

4. CONCLUSION

This study developed a chemistry teaching materials on alcohol compounds in the context of producing solid bioethanol from rice-washing wastewater using the 4STMD method, each stage of teaching materials development process the method was validated by three lecturers. The 4STMD method proved to be a viable framework, resulting in instructional materials validated by five chemistry teachers as a "highly suitable" teaching materials and demonstrating a "high" level of understanding among students.

The main implication of this study is that the developed teaching materials is a viable, validated resource that chemistry educators can implement to teach alcohol compounds in a more engaging and meaningful way. Furthermore, this study can be replicated by other practitioners and researchers who wish to develop contextual learning for other topics.

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