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Development of Acid-Base Teaching Materials Using the Four Step Teaching Material Development Method for Vocational Students in Agricultural Product Processing Agribusiness

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Abstract. Chemistry learning in vocational schools is often limited to general concepts and lacks connection with students' vocational expertise, making it difficult for them to apply theory to practice in agricultural product processing. This study aims to develop acid–base teaching materials using the four-step teaching material development (4STMD) method for students in the agricultural product processing agribusiness program at vocational high schools. The research responds to the lack of curriculum-aligned and contextually relevant resources that integrate chemistry with vocational practices. The study employed development research (DR), focusing on the first two stages of the 4STMD method: selection and structuring. In the selection stage, materials were designed based on basic competencies 3.5 and 4.5, producing eight learning indicators and sixteen concept labels. Acid–base concepts were compiled from national and international textbooks and contextualized with agricultural applications, such as pH control in fermentation. In the structuring stage, concept maps, macro structures, and three levels of representation (macroscopic, microscopic, and symbolic) were developed to link chemical theory with agricultural practices. The draft materials were refined through expert review to ensure clarity and scientific accuracy. The results indicate that the developed teaching materials are systematic, scientifically valid, and relevant to the curriculum. They also integrate substantive and pedagogical contexts that support students' vocational learning needs. This study shows that the 4STMD method is effective for producing chemistry teaching materials that are structured, contextual, and applicable, thereby enhancing the relevance and quality of chemistry education in vocational high schools.

Keywords: acid-base, teaching materials, 4STMD, vocational education

Introduction

Vocational high schools are educational institutions designed to provide students with specialized skills according to their chosen expertise programs, with the expectation of producing human resources who are knowledgeable and skilled in entering both the industrial and business sectors. The existence of vocational high schools not only supports

students' academic and personal development, as is the case in general senior high schools, but also ensures their readiness and career advancement after graduating from the institution (Widiyanti et al., 2020; Wiyarsi et al., 2020).

Chemistry instruction at vocational high schools plays a strategic role in supporting students' mastery of vocational competencies, particularly in the agricultural product processing agribusiness program. This program is one of the vocational expertise programs in Indonesian vocational schools that prepares students with skills to process agricultural products derived from plants, livestock, plantation crops, and spices into value-added food products. Learning activities within this program include production, packaging, storage, and marketing processes (Kemendikbudristek, 2022, as cited in Fatimah et al., 2025).

To support these skills, chemistry serves as an essential subject, especially in explaining physical and chemical changes in food processing, such as fermentation, pH control, the use of additives, and product quality testing. However, in practice, chemistry is still taught in a general context and is often not integrated with students' specific vocational fields. As a result, students find it difficult to connect chemical theory with their practical training, which contributes to low motivation and limited engagement in chemistry learning (Haryani et al., 2021). This problem is also confirmed by Febrianto et al. (2019), who found that teachers often struggle to find teaching materials relevant to students' vocational programs, due to the lack of context-based resources aligned with industry needs. In addition, Fatimah et al. (2023) stated that teachers in the agribusiness processing of agricultural products program encounter challenges in connecting science subjects with agribusiness practices. Vocational students, however, require contextual and practical learning to help them solve problems related to agricultural product processing in their future careers.

This research focuses on acid-base topics, which are highly relevant to agricultural product processing, such as the fermentation of kimchi and yoghurt. Acid-base topics are particularly applicable to fermentation-based food processing, where pH changes and weak acid formation serve as key indicators of quality. Research by Qi et al. (2022) demonstrated that pH control during yoghurt fermentation significantly affects protein denaturation, texture, and water-holding capacity. Likewise, Lee et al. (2020) found that during kimchi fermentation, the pH dropped from 6.17 to as low as 3.48, while acidity increased steadily due to lactic acid production. These findings affirm that pH regulation and weak acid behavior are essential to understanding fermentation processes, making them ideal contexts for teaching acid-base concepts in vocational settings.

A needs analysis has also highlighted that acid-base topics are essential in the context of agricultural product processing, especially for understanding pH control, the impact of pH on spoilage, neutralization reactions, and determining optimal pH levels for processing (Cahyani, 2022). Therefore, designing relevant and contextual teaching materials will help students connect chemical theory with agricultural processing practices in their field of study (Herlina et al., 2023).

In response to these challenges, context-based learning has been shown to improve students' chemical literacy, as materials are presented through real-life problems relevant to their field (Wiyarsi et al., 2020). A systematic literature review by Minata et al. (2022) concluded that context-based chemistry learning significantly enhances cognitive, affective, psychomotor, and social competencies when implemented with relevant contexts and student-centered strategies. Such learning encourages critical thinking, metacognition, chemical literacy, and scientific argumentation skills, which are highly essential for 21st-century competencies.

In this regard, teaching materials play a central role in supporting effective learning. Teaching materials are any form of content that is systematically and structurally arranged to meet curriculum demands and serve as learning resources for students as well as instructional tools for teachers (Anwar, 2023). According to Kosasih (2021), teaching

materials contain content related to knowledge, experience, and theories designed specifically to help teachers and students understand specific topics outlined in the curriculum. Therefore, the availability of well-developed teaching materials that align with students' vocational contexts is essential for achieving meaningful learning. Furthermore, teachers need to be able to develop such materials independently to ensure that the learning process remains effective and consistent with its objectives.

However, the availability of chemistry teaching materials for vocational high schools remains limited, and teachers often lack sufficient experience in developing integrated resources that support the competency needs of vocational expertise programs (Harjono et al., 2022; Haryani et al., 2021; Wibowo et al., 2021). To overcome this challenge, the development of high-quality teaching materials requires a method with clear and structured stages. In this regard, the four steps teaching material development (4STMD) method proposed by Anwar (2023) provides a systematic and detailed framework consisting of four stages: selection, structuring, characterization, and didactic reduction. This method offers several advantages for the development of teaching materials. First, it allows the integration of content from various sources while embedding values that students can acquire when engaging with the materials. Second, the method facilitates the organization of concepts into a more structured framework and enables the mapping of these concepts according to their levels of difficulty. Third, it provides opportunities for developers to reconstruct texts that may be difficult for students into more accessible forms through the didactic reduction stage (Anwar, 2023).

The effectiveness of the 4STMD method has been demonstrated in various studies. Marfu'ah et al. (2022) developed colloid teaching materials and reported a student comprehension rate of 89.57% (self-instructional category) and a feasibility score of 95.42% (very feasible). Ashari et al. (2025) created alcohol compound teaching materials contextualized with bioethanol production from cassava peels. The results showed a comprehension score of 87.05% and a feasibility score of 98.28%, both classified as high. Similarly, Oktasari et al. (2021) applied the 4STMD method to hydrocarbon materials and found that 26.32% of difficult content segments were successfully simplified through the characterization and didactic reduction stages, leading to a significant improvement in students' understanding. These findings consistently indicate that 4STMD is an effective method for developing chemistry teaching materials that are systematic, contextual, and accessible, and that align well with students' cognitive levels and vocational needs. Therefore, this study aims to develop acid–base teaching materials for vocational students by applying the 4STMD method, with a focus on the selection and structuring stages, and to describe the contextualization of concepts, concept maps, and three levels of representation relevant to agricultural product processing.

Methods

This study employed the design and development research (DDR) method, also referred to as development research (Richey & Klein, 2007). DDR is a systematic study of the processes of design, development, and evaluation, aiming to provide an empirical foundation for developing instructional or non-instructional products and tools, as well as for refining existing models (Richey & Klein, 2007). The research followed three major phases: design, development, and evaluation.

The sampling technique applied in this study was convenience sampling, a non-random method carried out in the simplest way without random selection (Mendenhall et al., 2013). This technique was chosen because not all vocational high schools offer the Agribusiness Processing of Agricultural Products (APHP) program, so only relevant schools were selected.

In the design phase, a preliminary study was conducted that included curriculum analysis in vocational high schools under the APHP program. The curriculum analysis identified the key competencies required by students, defined the learning objectives for acid–base topics, and determined the main content to be delivered based on those objectives. The development phase involved preparing chemistry teaching materials using the 4STMD method, which consists of four sequential steps: selection, structuring, characterization, and didactic reduction (Anwar, 2023). Each step in this process was reviewed by experts before moving to the next stage. The evaluation phase focused on assessing the feasibility and comprehensibility of the developed teaching materials. The feasibility test was conducted by vocational chemistry teachers using an instrument adapted from the National Book Center, while the comprehensibility test was administered to APHP students using a comprehension worksheet. To provide a clearer overview of the entire research procedure, the research flow is illustrated in Figure 1, which presents the development process of chemistry teaching materials using the 4STMD method within the design and development research framework.

The data obtained at the selection stage were analyzed descriptively based on chemistry lecturers' reviews of the appropriateness of indicators, concept labels, explanations, and integration of substance with pedagogical contexts, along with suggested improvements. Data from the structuring stage were also analyzed descriptively, summarizing reviewers' feedback regarding the organization of concept maps, macrostructure, and three levels of representation that required revisions. This study was limited to the selection and structuring stages; therefore, empirical testing involving students was not conducted during the development process.

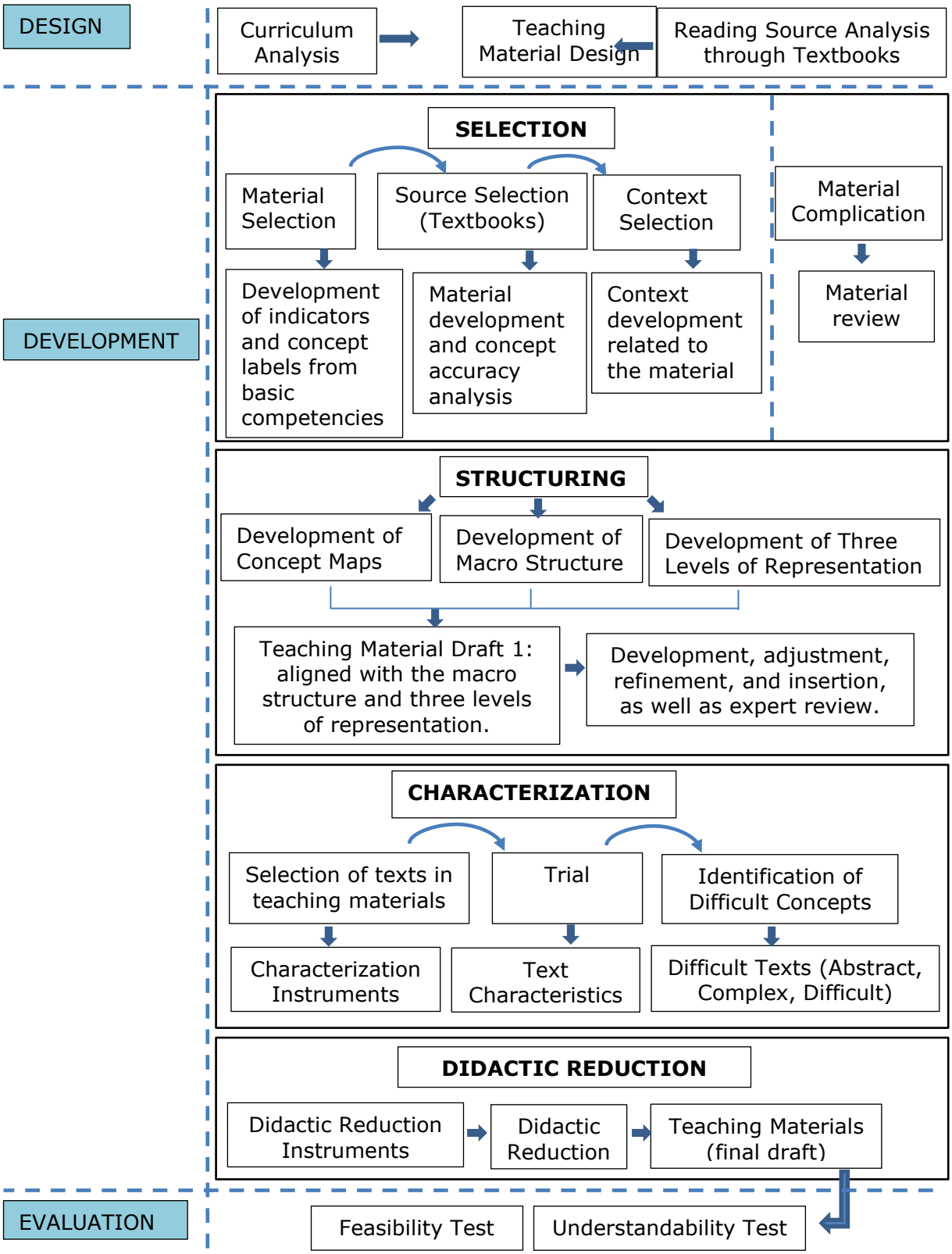

Figure 1. Research flow of chemistry teaching material development using the 4STMD method through design & development research (DDR).

Results and Discussion

Based on the designed teaching materials, this research implemented the four steps teaching material development (4-STMD) method, which consists of four stages: selection, structuring, characterization, and didactic reduction. The following section presents the process and results of applying the 4-STMD method in this study.

The initial phase is the selection stage, which consists of three essential steps. The first of these is formulating indicators and identifying concept labels. In this step, the selection process begins with choosing the material to be developed, which must refer to the applicable curriculum. Therefore, a selection of the basic competencies required by the curriculum must be conducted. Basic competencies are the minimum abilities that students must achieve.

Based on the results of a needs analysis of chemistry materials for vocational high school students majoring in agricultural product processing agribusiness conducted by Cahyani (2022), acid-base material is included in basic competency 3.5: *Analyzing the concept of solution preparation and its properties*, as well as basic competency 4.5: *Preparing solutions with specific concentrations and volumes*. The study also revealed that chemistry material related to solutions does not only cover general aspects of solutions, but also includes several subtopics, namely chemical equilibrium, acids and bases, buffer solutions, and colligative properties of solutions (Cahyani, 2022).

After conducting a curriculum analysis and determining the basic competencies within the acid-base topic, the next step is to establish the indicators and concept labels. This aims to measure the achievement of the basic competencies and to determine the relevant acid-base concepts sourced from textbooks. The results of the development of indicators and concept labels for the acid-base material are shown in Table 1.

Table 1. Development of indicators and determination of concept labels

Basic Competence	Competency Achievement Indicators	Concept Labels
3.5 Analyzing the concept of solution making and its properties	3.5.1 Explaining the concept of acid and base theories	1. Arrhenius Acid-Base Theory 2. Brønsted-Lowry Acid-Base Theory 3. Lewis Acid-Base Theory
	3.5.2 Explaining the strength of acids and bases	1. Strong acid 2. Weak acid 3. Strong base 4. Weak base
	3.5.3 Explaining the concept of acidity (pH)	1. pH 2. pOH
	3.5.4 Explaining ion equilibrium in acid and base solutions	1. Water equilibrium constant (Kw) 2. Weak acid equilibrium constant (Ka) 3. Weak base equilibrium constant (Kb)
	3.5.5 Explaining acid-base indicators	1. Natural indicators 2. Litmus indicator

		3. Universal indicator 4. pH meter
4.5 Preparing solutions with specific concentrations and volumes	4.10.1 Measuring the pH range of solutions by observing color changes using acid-base indicators	Acid-base experiment
	4.10.2 Measuring solution pH using a pH meter	
	4.10.3 Designing and conducting an experiment on acid-base indicators from natural materials	

The basic competencies in the acid-base topic presented in Table 1 show that eight indicators were developed, consisting of five indicators for basic competency 3.5 and three indicators for basic competency 4.5. These basic competencies then serve as a reference for determining 16 concept labels.

The second step in the selection stage is the development of concept descriptions aligned with the indicators and concept labels, which have been reviewed by experts. To explain the concepts listed in the concept labels, credible and reliable sources are needed. In developing the material, the researchers used several chemistry textbooks as references to ensure the scientific accuracy of each concept explanation.

According to Anwar (2023), one of the most reliable sources for concept validity is international textbooks used by scientists around the world, which can serve as alternative primary references in teaching material development. To ensure the correctness of the concepts, it is important to formulate standardized concepts derived from multiple textbooks, as different books often explain the same concept in different ways (Anwar, 2023). Several textbooks used as reference materials are listed in Table 2.

Table 2. Textbooks used in the development of teaching materials

Authors	Year	Book Title
Kenneth W. Whitten, Raymond E. Davis, M. Larry Peck, & George G. Stanley	2014	Chemistry Tenth Edition
Martin S. Silberberg	2007	Principles of General Chemistry
Ralph H. Petrucci, F. Geoffrey Herring, Jeffry D. Madura, & Carey Bissonnette	2011	General Chemistry: Principles and Modern Applications Tenth Edition
Raymond Chang	2005	Chemistry 10th Edition
Raymond Chang	2010	Chemistry 10th Edition
Steven S. Zumdahl, Susan A. Zumdahl, & Donald J. DeCoste	2018	Chemistry 10th Edition

Suswanto Djony P. Dan Siti Naqiyah	2019	Kimia Bidang Keahlian Agribisnis dan Agroteknologi untuk SMK/MAK
Theodore L. Brown, *et al*.	2017	Chemistry: The Central Science 14th Edition

Table 2 presents several chemistry textbooks referenced in the acid-base material to examine the relevance of chemical theory to the conceptual content. Anwar (2023) stated that textbooks can serve as valuable references to minimize errors in the representation of content, images, and diagrams in the development of teaching materials. In this stage, the conceptual content of the acid-base material, as referenced from textbooks, can be reviewed in Figure 2.

No.	Label Konsep	Uraian Konsep/Materi	Sumber
1.	Teori asam-basa Arrhenius	*The first person to recognize the essential nature of acids and bases was* ***Svante Arrhenius.*** *Based on his experiments with electrolytes, Arrhenius postulated that* ***acids produce hydrogen ions in aqueous solution****, while* ***bases produce hydroxide ions****. At the time, the Arrhenius concept of acids and bases was a major step forward in quantifying acid–base chemistry, but this concept is limited because it applies only to aqueous solutions and allows for only one kind of base—the hydroxide ion.*	Steven S. Zumdahl, Susan A. Zumdahl, & Donald J. DeCoste. (2018). *Chemistry 10th Edition.* Boston: Cengage Learning
		By 1830 it was evident that all acids contain hydrogen but not all hydrogen containing substances are acids. During the 1880s, the Swedish chemist Svante Arrhenius (1859–1927) defined acids as substances that produce H^+ ions in water and bases as substances that produce OH^- ions in water. Over time the Arrhenius concept of acids and bases came to be stated in the following way. • *An acid is a substance that, when dissolved in water, increases the concentration of H^+ ions.* • *A base is a substance that, when dissolved in water, increases the concentration of OH^- ions.*	Brown, *et al.* (2017). *Chemistry: The Central Science 14th Edition.* London: Pearson
		From a practical standpoint, acids can be identified by their sour taste, their ability to react with a variety of metals and carbonate minerals, and the effect they have on the colors of substances called acid base indicators. Methyl red is an acid base indicator that appears red in acidic environments and yellow otherwise (see Figure 2). From a chemist's point of view, however, an ***acid*** *can be defined as a substance that provides hydrogen ions (H^+) in aqueous solution. This definition was first proposed by* ***Svante Arrhenius*** *in 1884. When* ***HCl dissolves in water****, complete ionization into* ***H^+*** *(aq) and* ***Cl^-*** *(aq) occurs:* $HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$	Ralph H. Petrucci, F. Geoffrey Herring, Jeffry D. Madura, & Carey Bissonnette. General Chemistry: Principles and Modern Applications Tenth Edition. Pearson Canada Inc. 2011. Hal

Figure 2. Examples of developed conceptual accuracy descriptions referenced from textbooks

The third step in this selection stage is the selection of contexts related to acid-base materials, namely substantive context and pedagogical context. According to Anwar (2023), the substantive context refers to the instructional content linked to phenomena, events, facts, and data, as well as its benefits in various fields of life. This context should be developed through teaching materials so that students can tangibly observe real-world phenomena and events related to the subject matter they are studying, and understand

the usefulness and application of the material in various aspects of life (Anwar, 2023). Meanwhile, the pedagogical context is the context in which teaching materials are used as tools or media to develop values, attitudes, and skills. According to research by Cahyani (2022), acid and base materials are used to support vocational subjects in agricultural product processing agribusiness, such as: pH control of agricultural products to maintain their quality, the effect of pH on the spoilage of agricultural products, neutralization reactions in food processing, optimal pH in the processing of agricultural products, and how to test the pH of agricultural materials. In the substantive context, the emphasis is on the application of acid-base concepts in agricultural product processing. Examples of substantive contexts based on the conceptual content that apply agricultural processing contexts can be seen in Figure 3, while Figure 4 illustrates the pedagogical context in the acid-base materials that have been developed.

No	Uraian Materi	Konteks Substansi	Uraian Pengembangan Konteks Substansi
4	Asam lemah adalah asam yang hanya terionisasi sebagian dalam larutan air, sehingga hanya menghasilkan sedikit ion hidrogen (H^+). Dalam larutan, masih terdapat keseimbangan antara molekul asam yang belum terionisasi dan ion-ion hasil ionisasinya.	 *Sumber: tokopedia.com* Kimchi adalah makanan fermentasi tradisional Korea yang terbuat dari sayuran, seperti sawi putih dan lobak, yang difermentasi dengan garam, bawang putih, jahe, cabai, serta bahan lainnya.	Fermentasi kimchi melibatkan aktivitas bakteri asam laktat, terutama dari genus *Lactobacillus* dan *Leuconostoc*, yang mengubah gula alami dalam sayuran, terutama glukosa dan fruktosa, menjadi asam laktat ($C_3H_6O_3$). Reaksi fermentasi utama yang terjadi dapat dituliskan sebagai berikut: $C_6H_{12}O_6\,(aq) \rightarrow 2C_3H_6O_3\,(aq)$ Glukosa ($C_6H_{12}O_6$) yang terdapat dalam sayuran difermentasi oleh bakteri menjadi dua molekul asam laktat ($C_3H_6O_3$), yang bertanggung jawab atas rasa asam khas kimchi. Selain asam laktat, fermentasi ini juga menghasilkan senyawa lain dalam jumlah kecil, seperti asam asetat, karbon dioksida, dan etanol, yang turut mempengaruhi cita rasa kimchi. Asam laktat yang dihasilkan merupakan asam lemah, karena dalam larutan hanya mengalami ionisasi sebagian dan berada dalam kesetimbangan dengan ion-ionnya: $C_3H_6O_3\,(aq) \rightleftharpoons C_3H_5O_3^-\,(aq) + H^+\,(aq)$ Tanda panah dua arah menunjukkan bahwa asam laktat tidak sepenuhnya terionisasi dalam air, melainkan hanya sebagian kecil yang berubah menjadi ion laktat ($C_3H_5O_3^-$) dan ion hidrogen (H^+). Hal ini ditunjukkan oleh konstanta disosiasi asamnya ($Ka \approx 1.38 \times 10^{-4}$), yang menunjukkan sifat asam lemahnya. Karena sifat ini, asam laktat memiliki pH yang lebih tinggi dibandingkan asam kuat dengan konsentrasi yang sama dan tidak menyebabkan perubahan pH yang drastis dalam larutan. Keasaman yang dihasilkan oleh asam laktat berperan penting dalam pengawetan kimchi, karena menciptakan lingkungan asam yang menghambat pertumbuhan bakteri pembusuk dan patogen. Namun, beberapa jenis bakteri asam laktat, seperti *Lactobacillus* dan *Leuconostoc*, tetap mampu bertahan dalam kondisi ini dan terus melakukan fermentasi lanjutan. Selain itu, sifat asam lemah dari asam laktat juga memberikan rasa asam yang lebih lembut dibandingkan asam kuat seperti asam asetat. Dengan memahami konsep asam lemah, kita dapat melihat bagaimana fermentasi kimchi menghasilkan makanan yang aman, tahan lama, serta bermanfaat bagi kesehatan melalui keseimbangan pH yang stabil.

Figure 3. Example of a developed substantive context in the application of weak acids in kimchi processing

No.	Uraian Konsep/Materi	Konteks Pedagogik	Uraian Pengembangan Konteks Pedagogik
1	• Menjelaskan bahwa asam memiliki sifat masam, sedangkan basa memiliki sifat pahit dan licin. • Asam dan basa dapat dikenali menggunakan indikator.	Integrasi Nilai Religius dan Sikap Ilmiah: Dengan menekankan rasa syukur terhadap karunia Tuhan, wacana ini mengintegrasikan aspek spiritual dalam pembelajaran sains. Selain itu, sikap ilmiah seperti rasa ingin tahu, kehati-hatian, dan sikap kritis juga ditanamkan dalam teks ini.	Asam dan basa merupakan dua senyawa kimia yang sangat penting dalam kehidupan sehari-hari. Asam dan basa terdapat dalam makanan, minuman, obat-obatan, dan bahkan makhluk hidup. Asam dan basa banyak memberikan manfaat dalam kehidupan sehari-hari. Oleh karena itu, kita harus bersyukur atas karunia Tuhan Yang Maha Esa tersebut. Selanjutnya, lakukan pengamatan tentang asam dan basa yang berada di sekitar Anda. Jika ada hal-hal yang ingin Anda ketahui lebih jauh, buatlah menjadi bentuk pertanyaan. Kemudian, pelajari subbab ini untuk mendapatkan jawabannya. Dalam produk pangan, asam berperan dalam memberikan rasa dan mempertahankan kualitas, seperti asam asetat dalam cuka yang digunakan sebagai pengawet, asam sitrat dalam jeruk yang memberikan rasa segar, serta asam fosfat dalam minuman bersoda. Di sisi lain, senyawa basa seperti natrium bikarbonat digunakan dalam proses pembuatan roti dan kue, sementara amonia berperan sebagai bahan baku pupuk untuk meningkatkan kesuburan tanah. Di bidang pengolahan hasil pertanian, asam dan basa juga memiliki peran penting. Fermentasi makanan, seperti dalam pembuatan yoghurt, keju, dan tempe, melibatkan aktivitas mikroorganisme yang menghasilkan asam organik, seperti asam laktat. Selain itu, basa seperti natrium hidroksida digunakan dalam proses pengolahan minyak nabati dan pembuatan sabun dari minyak sawit. Secara umum, zat-zat yang berasa masam mengandung senyawa asam, misalnya asam sitrat pada jeruk, sedangkan basa merupakan senyawa yang mempunyai sifat licin, rasanya pahit, dan jenis basa tertentu bersifat *caustic* atau membakar, misalnya natrium hidroksida atau soda api. Meskipun asam dan basa dapat dibedakan dari rasanya, tetapi tidak disarankan (dilarang) untuk mencicipi asam atau basa yang ada di laboratorium. Asam dan basa dapat dibedakan menggunakan zat tertentu yang disebut indikator atau dengan menggunakan alat khusus.

Figure 4. Example of a developed pedagogical context

The final outcome of the entire selection stage is a collection of materials that have been developed through the concept development step and context analysis, covering both substantive and pedagogical contexts. After being reviewed by subject matter experts and declared aligned with the conceptual content, the process continues to the second stage, namely the structuring stage.

At this structurization stage, the development of the teaching material structure is carried out in three forms: concept maps, macro structure, and three levels of textual representation. A concept map is used to express meaningful relationships between the concepts within a teaching material (subject matter) in the form of propositions (Anwar, 2023). Propositions refer to two or more concepts connected by linking words (Anwar, 2023). For teachers, concept maps can serve as a tool in planning lessons on the subject matter, while for students, they help in remembering and memorizing the concepts more easily.

The development of the macro structure serves as a guideline for organizing the systematic flow of the teaching material. The systematic structure shown in the macro structure reflects the conceptual framework while considering didactic aspects. The structurization stage also includes the development of the three levels of representation, which aim to provide a comprehensive overview of the developed concepts or materials. Johnstone (1982, as cited in Anwar, 2023) stated that the presentation of teaching materials requires three levels of representation: macroscopic, microscopic, and symbolic. These three modes of representation help students construct the correct mental models

they need to understand the material. The interrelation between the levels of representation presented in the developed teaching material should illustrate how the three levels are interconnected (Anwar, 2023). In this stage, the macroscopic level refers to phenomena that students can observe in their daily lives, particularly those related to acids and bases in the context of agricultural product processing. The microscopic (or submicroscopic) level provides molecular-level explanations of the macroscopic phenomena, offering theoretical insight into the events observed. Meanwhile, the symbolic level presents representations in the form of symbols, images, diagrams, graphs, chemical equations, mathematical expressions, and other similar visual or symbolic forms.

The importance of developing the three levels of representation in chemistry teaching materials lies in their ability to bridge students' understanding of abstract and complex chemical concepts. Permatasari et al. (2022) stated that multiple representations can help students develop a deeper conceptual understanding, reduce cognitive load, enhance cognitive structures and mental models, and reduce misconceptions in chemistry learning. By integrating all three levels of representation, students can see the interconnections between observable phenomena, the underlying particle processes, and the corresponding symbols or chemical equations, making the learning process more meaningful and effective (Permatasari et al., 2022). The result of the development of the three levels of representation is presented in Figure 5.

Label Konsep	Makroskopik	Submikroskopik	Simbolik
Asam Arrhenius	*Sumber: alibaba.com* Asam merupakan salah satu jenis pengawet yang cukup banyak digunakan dalam industri makanan karena mikroba bersifat sensitif terhadap asam. Dalam konteks makroskopik, asam sitrat ($C_6H_8O_7$) banyak ditemukan dalam buah-buahan yang bersifat asam seperti jeruk, lemon, dan lime. Selain sebagai penambah rasa, asam sitrat juga berfungsi sebagai pengawet alami yang membantu menjaga kestabilan pH dalam produk makanan, sehingga memperpanjang umur simpannya dan menghambat pertumbuhan mikroorganisme penyebab pembusukan.	Keasaman asam sitrat terjadi karena zat ini dapat melepaskan ion hidrogen (H^+) dalam air, yang menyebabkan larutan menjadi lebih asam. Mikroba tidak dapat bertahan dalam kondisi asam akibat peningkatan konsentrasi ion H^+ yang menurunkan pH larutan. Ionisasi asam sitrat dalam air menghasilkan ion hidrogen (H^+) dan ion sitrat ($C_6H_5O_7^{3-}$), yang berperan dalam menciptakan lingkungan yang kurang mendukung bagi pertumbuhan mikroorganisme.	Persamaan reaksi ionisasi asam sitrat dalam air: $C_6H_8O_7(aq) \rightleftharpoons 3H^+(aq) + C_6H_5O_7^{3-}(aq)$. Menurut teori Arrhenius, suatu senyawa dikatakan sebagai asam jika mampu meningkatkan konsentrasi ion H^+ dalam larutan. Oleh karena itu, dalam pengolahan sari buah, keberadaan asam sitrat sangat penting karena ion H^+ yang dilepaskannya dapat menurunkan pH larutan dan menjaga kualitas produk agar lebih tahan lama.

Figure 5. Example of the three-level representation developed in this teaching material.

The final product of this structurization stage is a draft of the teaching material that aligns with the macro structure and incorporates the three levels of representation. The organization of the content follows the macro structure, while the presentation of each concept or set of concepts is arranged based on the sequence of the three levels of representation. According to Anwar (2023), concept maps are an essential component that

should be included in teaching materials. The placement of the concept map can vary depending on its function. If it serves as a guide to understand the scope of the material, it should be placed at the beginning. If it functions as a summary of the content discussed, it can be placed at the end (Anwar, 2023). In this teaching material development, the concept map is placed at the beginning, as shown in Figure 6.

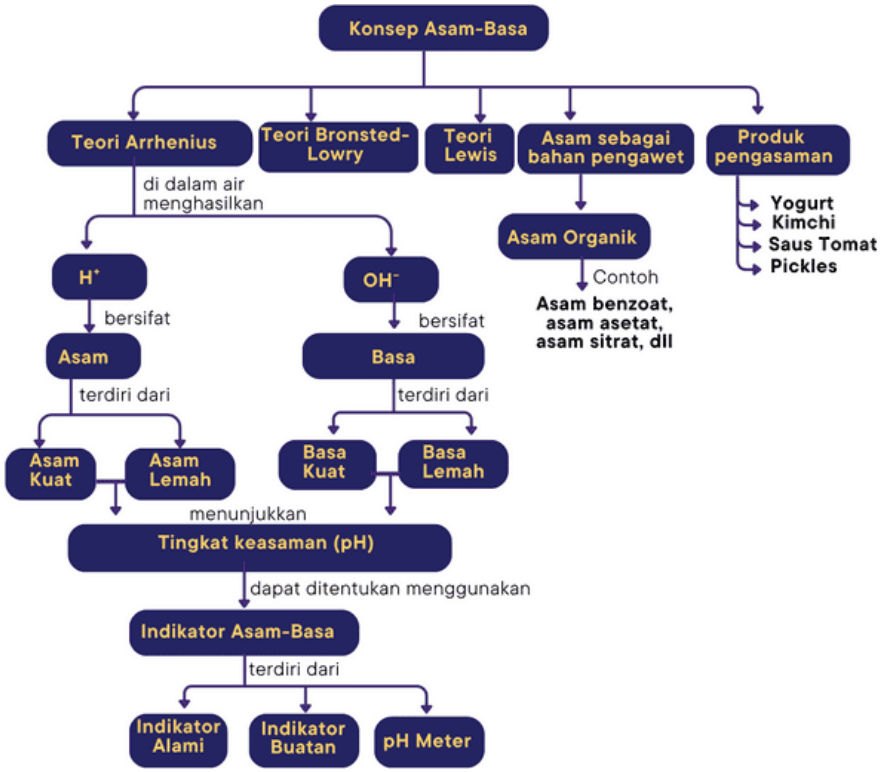

Figure 6. Concept map of acid-base material for APHP vocational school students.

The compiled draft of the teaching material undergoes a self-review by the developer through processes of refinement, such as content development, insertion, refinement, and adjustment. Development is conducted when additional elements (such as student worksheets) are needed, especially to support the contextual aspects outlined in the selection stage. Insertion is done when two paragraphs are not well connected and require linking sentences. Additional images, illustrations, graphs, or tables may also be inserted to further clarify the concepts being explained. Refinement is needed when sentences are ambiguous, ineffective, or unclear in meaning. Adjustments are made when scientific terminology or language is inappropriate or not easily understood by the target audience. This is particularly necessary when the source materials are adapted from international textbooks intended for university students, while the developed teaching material is designed for vocational high school students. Therefore, the language and presentation must be simplified. The appearance of the structured draft can be seen in Figure 7 and 8.

(a) (b)

Figure 7. (a) The cover of the developed teaching material draft, (b) an example of the draft content presenting the acid-base context in kimchi

DID YOU KNOW

Mengapa pH Harus Dikendalikan dalam Pembuatan Yoghurt?

Sumber: canva

Gambar 4. Asam laktat menurunkan pH, membentuk tekstur khas yoghurt

Yoghurt adalah produk olahan susu yang dibuat melalui proses fermentasi. Dalam proses ini, susu difermentasi oleh bakteri baik, seperti *Lactobacillus bulgaricus* dan *Streptococcus thermophilus*. Bakteri tersebut mengubah laktosa (gula susu) menjadi asam laktat, yaitu asam lemah yang berperan penting dalam proses pembuatan yoghurt. Asam laktat ini menyebabkan penurunan pH susu. Saat pH turun hingga sekitar 4,5, protein susu (kasein) akan menggumpal dan membentuk tekstur kental khas yoghurt. Oleh karena itu, pH menjadi faktor penting yang harus dikendalikan selama proses fermentasi.

Menurut penelitian oleh Anwar dkk. (2025), yoghurt yang difermentasi dari susu domba menunjukkan kualitas terbaik pada pH sekitar 4,2, dengan fermentasi selama 6 jam. Pada pH ini, yoghurt memiliki rasa yang seimbang, tekstur yang baik, dan kandungan probiotik yang tinggi.

Jika pH terlalu rendah, yoghurt bisa terasa sangat asam dan bertekstur terlalu keras. Jika pH terlalu tinggi, yoghurt bisa menjadi encer, kurang asam, dan tidak awet. Maka dari itu, mengontrol pH sangat penting agar yoghurt yang dihasilkan memiliki rasa, tekstur, dan daya simpan yang sesuai.

Melalui contoh ini, kalian bisa melihat bahwa pH bukan hanya angka dalam pelajaran kimia, tetapi juga memiliki peran nyata dalam pengolahan hasil pertanian, khususnya produk susu seperti yoghurt.

INDIKATOR ASAM-BASA

Indikator asam-basa adalah zat yang memiliki warna berbeda dalam larutan asam dan larutan basa. Indikator asam-basa di antaranya sebagai berikut.

1. Indikator Alami

Indikator alami merupakan pigmen yang diekstraksi dari tumbuhan seperti kol ungu, kunyit, bunga telang, atau bahan alam lain, yang menunjukkan berbagai warna pada pH berbeda. Misalnya ekstrak kunyit dalam larutan asam berwarna kuning dan berwarna cokelat dalam larutan basa.

Sumber: Dokumen pribadi

Gambar 5. Perubahan warna beberapa indikator alami pada larutan dengan pH 1-14 dari kiri ke kanan.

Figure 8. An example of the draft content presenting the acid-base context in yogurt.

After the product from the structuring stage (draft of the teaching material) was reviewed by subject matter experts, the process should have continued to the third stage, characterization, and the fourth stage, didactic reduction. However, in this development, the process was only carried out up to the structuring stage. If the development is continued, the characterization stage will be implemented with the aim of identifying which parts of the text are easy or difficult for students to understand.

According to Anwar (2023), difficult texts can be categorized into three types: complex, complicated, and abstract. A text is considered complex if it contains many components; it is considered complicated if it contains many interrelationships between components; and it is considered abstract if it is not concrete or is difficult to visualize. To identify these parts, a characterization instrument in the form of a comprehension test will be used, in which students are asked to determine the main idea of each text and explain the difficulties they encounter in understanding it.

The results of the characterization stage will then serve as the basis for the next step, which is didactic reduction. Didactic reduction is the process of simplifying difficult material, either qualitatively or quantitatively, to make it easier for students to understand without removing its scientific essence (Anwar, 2023). This is done by reducing the complexity, intricacy, and abstractness of the material into forms that are simpler, more concrete, and communicative. Anwar (2023) outlines several strategies that can be used to reduce the difficulty level of teaching materials during didactic reduction, including: (1) presenting texts qualitatively; (2) omission; (3) using illustrations such as images, symbols, sketches, experiments, animations, simulations, and videos; (4) the use of analogies; (5) incorporating historical development levels; (6) generalization; (7) particularization; (8) omitting conceptual statement differences; and (9) reformulating sentences and using familiar terminology.

Didactic reduction enables teaching materials to become more communicative, contextual, and applicable, especially for vocational students who require learning that is practice-based and grounded in real-world phenomena. Once the reduction process is complete, the materials will be restructured and compiled into the final draft of the teaching material. Subsequently, this final draft will be evaluated through comprehension and feasibility tests, covering aspects such as content, language, presentation, and visual layout. The evaluation will be conducted by subject matter experts and chemistry teachers to ensure the developed teaching material is truly appropriate for instructional use.

Although this study has only reached the selection and structuring stages, the two subsequent stages (characterization and didactic reduction) play a vital role in perfecting the final product. The characterization stage allows developers to understand students' learning difficulties, while didactic reduction helps bridge complex material into content that is easier to understand and more contextual. This is particularly crucial, considering the characteristics of vocational school students who need learning that is more visual, applied, and connected to real-life experiences.

The application of characterization and didactic reduction stages in the 4-STMD method has been proven to significantly improve students' comprehension and produce highly feasible teaching materials (Oktasari et al., 2021; Marfu'ah et al., 2022; Ashari et al., 2025). Therefore, it is projected that if these final two stages are optimally carried out in the development of acid-base teaching materials, the result will be instructional content that is not only scientifically accurate and well-structured but also contextually relevant and easy to understand for vocational high school students. Hence, further research is essential to complete all four stages as an effort to improve the quality of chemistry education in vocational schools, particularly in the agricultural product processing agribusiness expertise area.

Conclusion

This study developed acid-base teaching materials for vocational students in the agricultural product processing agribusiness program using the 4-STMD method. The development was carried out up to the selection and structuring stages. The selection stage produced indicators, concept labels, and concept explanations that were scientifically valid and contextual to agricultural product processing, such as pH control in fermentation. The structuring stage produced concept maps, macro structures, and three levels of representation that linked chemical theory to vocational practices. The results show that the developed teaching materials are systematic, relevant to the curriculum, and contextual to the needs of vocational students.

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