Designing a Green Chemistry Integrated Separation and Purification Textbook Using the Four Steps Teaching Material Development (4STMD) Method: Selecting and Structuring Steps

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Abstract. This research aims to develop a university chemistry textbook in the Separation and Purification course by integrating the principles of Green Chemistry through the Four Steps Teaching Material Development (4STMD) method. Several separation and purification techniques are designed in this textbook, including sublimation, recrystallisation, chromatography, and distillation techniques, which are packaged in a presentation that focuses on the principles of Green Chemistry. The textbook development uses the 4STMD method which includes the steps of selecting, structuring, characterisation, and didactic reduction. The 4STMD is a teaching material development method characterised by a well-organized and straightforward sequence of steps. The research is limited to the selecting and structuring steps so that the research results are more focused and in-depth. The instrument used in this study was a review sheet of the suitability of concepts, indicators, and core competencies; as well as the suitability of concept maps, macro structures, and textbook systematics. The instrument used in this study was a review sheet of the suitability of concepts, indicators, and core competencies; as well as the suitability of concept maps, macro structures, and textbook systematics. This research was motivated by the limited number of college textbooks with a Green Chemistry perspective, especially for prospective chemistry teachers in coastal areas. Separation and purification are basic skills that must be mastered before synthesising and isolating a compound. However, the synthesis and isolation process usually involves the use of relatively hazardous solvents. Therefore, a separation and purification textbook that integrates Green Chemistry is needed so that students can master specification and concentration materials that are oriented towards environmental sustainability.

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1 Introduction

Separation and purification are basic skills that must be mastered by chemistry or chemistry education students before synthesising and isolating a compound, either organic or inorganic. In universities, the separation and purification of compounds are included in advanced chemistry courses, one of which is the Separation Chemistry course. Along with the development of technology, the techniques employed for the separation and purification of organic molecules are subject to ongoing development and refinement over time [1-3]. The purification technique also follows the concept of sustainable development, one of which begins with the reduction of solvents [2-4]. The use of solvents plays an important role in the purification process, where it is known that solvents commonly used in organic chemistry are relatively hazardous solvents, hence the need to develop purification techniques that are sustainable, especially in the field of education [5].

Sustainable development in education, especially in the Separation Chemistry course can be obtained through experimental activities in the laboratory. Laboratory experiments have long had a special and central role in the science curriculum and science educators have stated that many advantages are gained by involving students in laboratory activities [6]. Chemistry education students are required to be able to master skills in the laboratory as a provision when teaching at school.

Green Chemistry refers to the deliberate and systematic approach employed in the development of chemical goods and processes with the aim of minimising or completely eradicating the utilisation and production of compounds that pose a threat to human health and the environment [7]. The essential aspect of Green Chemistry is the design concept consisting of twelve Green Chemistry principles which are design criteria or guidelines that provide a framework for sustainable design [7-9]. Green Chemistry embodies two main components, which concern the efficient utilisation of raw materials and relate to the issue of chemical waste removal [10]. The integration of Green Chemistry into the undergraduate curriculum is a necessity to prepare students for a sustainable future [11]. Green Chemistry can be realised through teaching materials that are in accordance with curriculum criteria and can be a learning resource for students in the classroom [12].

Teaching materials encompass a wide range of materials that are structured and systematically in accordance with the demands of the curriculum and become learning resources for students, as well as materials or materials for teachers in carrying out teaching and learning activities [12]. Teaching materials have an essential part in facilitating effective learning experiences. Teaching materials can be a guide for educators in carrying out the learning process. One of the teaching materials that are commonly used in learning is a textbook. The textbook can be interpreted as a composition of teaching materials that can make it easier for students and students to learn well. The textbook is one of the effective curricular material dissemination strategies [13].

Acquisition of high-quality teaching materials necessitates a systematic approach that takes into consideration the requirements of the relevant curriculum [14]. The lack of theory about development that specialises in teaching materials makes a difficult to develop science teaching materials [15], in this research, the teaching materials developed are in the form of textbooks on the topic of separation and purification. The Four Steps Teaching Material Development (4STMD) is a method for developing teaching materials that offer distinct advantages when compared to other methodologies or models used in product development. The 4-step method for text mining and document analysis (4STMD) comprises four distinct stages, which are selecting, structuring, characterization, and didactic reduction. This method offers several advantages. Firstly, it enables the selection of subject matter from diverse sources. Additionally, it facilitates the exploration of the values acquired by students throughout the study of the chosen subject matter. Furthermore, the processes outlined in the

Four-Step Teaching Model for Developing Material (4STMD) have the capacity to enhance cognitive abilities, construct conceptual frameworks, and classify material concepts according to their level of complexity, hence facilitating students' comprehension of the supplied content [16].

The problems obtained by researchers when conducting observations in the field are that there are no teaching materials, both in the form of textbooks and practicum guidelines that support sustainability during the Separation Chemistry lecture process. Consequently, students have encountered challenges in applying the concepts and theories they have acquired in the classroom, resulting in suboptimal development of essential abilities and values that are expected to be cultivated among students. Hence, it is imperative to create educational resources, specifically textbooks, that can effectively address the requirements of a sustainable future. This can be achieved by developing textbooks that adopt the principles of Green Chemistry and focus on the subject of Separation and Purification. The incorporation of the 4STMD method in the textbook development process is recommended.

2 Research Methods

This research uses a research and development design that focuses on the development of teaching materials processes and products. The objectives of this study were to develop a Green Chemistry integrated Separation and Purification textbook for the university level; identify the suitability to the demands of the curriculum, ensure the correctness of the concept, and develop the context of the developed material; and identify the suitability of the concept map, macro structure, and three levels of representation.

2.1 Data collection techniques

The development of textbooks in this study used the Four Steps Teaching Material Development (4STMD) method [12] because it has several advantages over other teaching material development models or methods. The 4STMD method offers the development of teaching materials with detailed stages and steps accompanied by clear criteria according to the demands of the applicable curriculum [12, 14]. In addition, the stages and steps used are work that can be followed easily by teaching material developers by following the established criteria [12]. Textbook development using the Four Steps Teaching Material Development (4STMD) method consists of the steps of selecting, structuring, characterisation, and didactic reduction [12]. However, this research is restricted to the selecting and structuring steps, and the other two steps will be continued in the subsequent research. The steps of 4STMD are illustrated in Figure 1.

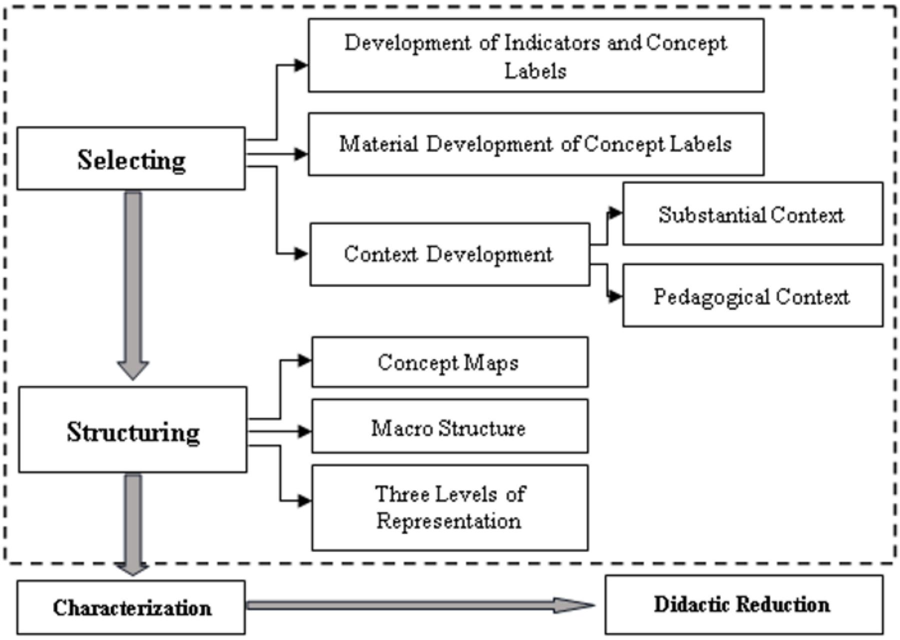

Fig.1. Four Steps Teaching Material Development (4STMD)

The data collection techniques used in this research are literature studies of the syllabus and curriculum applicable to the Separation Chemistry course; and expert judgement on the suitability of predetermined criteria. The research instrument for the selecting step consists of instruments: 1) suitability of indicators or sub-course learning outcome with course learning outcomes; 2) suitability of concept labels with indicators or sub-course learning outcome; 3) suitability of values with material concepts. In the structuring step, the draft of teaching materials that have been prepared need to be reviewed independently by the developer of teaching materials by developing, inserting, refining, and adjusting [12].

2.2 Data analysis techniques

Analyse the data in the selecting step using Content Validity Index (CVI). In this step, three experts (raters) were involved. The categorisation of the results of the CVI calculation is adjusted to the number of validators used based on certain criteria [17]. The rating scale for content validation in this step uses a Guttman scale with two alternative answers "Yes" and "No" [18] to get a firm and clear answer to a questioned problem. With 3 experts, a category or statement will be declared valid or accepted if V = 1 [19].

$$V = \frac{\Sigma s}{n\,(c-1)}$$

V = agreement index
s = r - lo
r = the score given by the validator/rater
lo = lowest number of judgements
n = number of raters
c = the number of categories that the rater can choose

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3 Results and discussion

3.1 Selecting Step

The development of the Separation and Purification textbook has been conducted using the 4STMD method. This research is limited to the selecting and structuring steps to obtain in-depth results according to the criteria. There are three stages in the selecting step, namely 1) development of indicators and concept labels; 2) development of material from concept labels; and 3) development of context (substantial context and pedagogical context).

The selecting step was carried out by analysing the syllabus and curriculum for the Separation and Purification course. After the syllabus and curriculum analysis process were carried out, four course learning outcomes were obtained that were suitable for the development of separation and purification textbooks. Furthermore, developing indicators or sub-course learning outcome derived from the Course Learning Outcome (CLO) of the course that is the target of development. The selection of CLO is based on its suitability for the textbook to be developed. The CLO that has been selected, is then developed into indicators or sub-course learning outcome. After that, based on the indicators, the concept labels were developed. There were 17 indicators or sub-course learning outcome and 11 concept labels that were considered in accordance with the learning outcomes that had been previously determined.

The next step is to collect information related to the concept or material according to the concept label that has been agreed upon previously. Concept/material descriptions are sourced from textbooks that have been used by many scientists around the world to ensure the correctness of the concepts used [12] and can be added with other relevant secondary sources. Table 1 shows the relationship between indicators and concept labels that form the basis for textbook development in the next stage.

Table 1. The relationship between indicators and concept labels.

No.	Indicators/Sub-Course Learning Outcomes	Concept Labels
1	Analyse the principles of separation and purification of organic compounds.	Principles of Separation and Purification of Organic Compounds
2	Identify the types of laboratory equipment related to the separation of organic compounds.	Introduction to Equipment, Safety, and Security in the Organic Chemistry Laboratory
3	Describe the properties and characteristics of solvents in organic chemistry laboratories.	
4	Identify the maintenance and handling of glassware in the organic chemistry laboratory.	
5	Identify specialised handling of hazardous materials in organic laboratories	
6	Analyse the basic techniques of separation and purification of organic compounds.	Basic Techniques of Separation and Purification of Organic Compounds
7	Analyse various techniques for testing the purity of an organic compound.	Purity Testing of Organic Compounds
8	Analyse the principles of Green Chemistry in the practicum of separation and purification of organic compounds.	Principles of Green Chemistry and Microscale in Separation and Purification of Organic Compounds Practicum
9	Analyse the Microscale criteria in the practicum of separation and purification of organic compounds.	
10	Design practical procedures for the separation and purification of compounds based on aspects of Green Chemistry-Microscale.	Practicum Project Proposal
11	Implement the principles of purification and separation through practicum by sublimation techniques.	Principles of Separation and Purification by Sublimation Technique
12	Implement the principles of purification and separation through practicum by recrystallisation techniques.	Principles of Separation and Purification by Recrystallisation Technique

No.	Indicators/Sub-Course Learning Outcomes	Concept Labels
13	Implement the principles of purification and separation through practicum by paper chromatography techniques.	Principles of Separation and Purification by Chromatographic Techniques
14	Implement the principles of purification and separation through practicum by thin-layer chromatography technique.	
15	Implement the principles of purification and separation through practicum by simple distillation techniques.	Principles of Separation and Purification by Simple Distillation Techniques
16	Identify information and data from the results of the separation and purification practicum project.	Scientific Articles based on Research Results
17	Synthesise information and data to describe the results of the separation and purification practicum project.	

The last stage in the selecting step is to develop values that are referred to as substantial and pedagogical contexts. Substantial context contains the context of the textbook that is connected to phenomena, symptoms, facts, data, and benefits in various fields of life [12]. The substantial context integrated into the textbook is related to the principles of Green Chemistry and Microscale criteria in practicum. Next is to develop a pedagogical context in the textbook, namely exploring the values, attitudes, and skills related to the material [12-18]. The pedagogical context inserted in this textbook is related to science process skills and sustainability awareness.

The collection of information in this selecting step is referred to as Draft 1 of the textbook. As a guarantee that indicators of competency achievement, concept labels, concept/material descriptions, and contexts represent the learning outcomes demanded by the curriculum, a review was conducted by three experts in chemistry and chemistry education. This review process aims to determine 1) the suitability of indicators or sub-course learning outcome with learning outcomes; 2) the suitability of indicators or sub-course learning outcome with concept descriptions; and 3) the suitability of concept descriptions with related substantial and pedagogical contexts. Table 2 shows the agreement index (V) on the aspects reviewed based on the calculation using the Conten Validity Index [21].

Table 2. Results of the selecting step review.

Raters	Agreement Index (V)		
	Indicator/Sub-Course Learning Outcome with Learning Outcome	Concept Label with Indicator	Value with Concept
R1	1,00	1,00	1,00
R2	1,00	1,00	1,00
R4	1,00	1,00	1,00
Category	Valid	Valid	Valid

3.2 Structuring Step

The structuring step aims to make the book develop to have an orderly arrangement of concepts according to the cognitive structure of students [22]. There are three important parts to this structuralisation step: the concept map, the macro structure, and the three levels of representation [12]. First, the concept map aims to provide a relationship between concepts in the textbook so that readers are able to relate new knowledge to their cognitive structure [12, 21]. In addition, concept maps can also give learners the opportunity to think deeply about science by helping them to better understand and organise what they are learning, and to store and retrieve information more efficiently [23].

Furthermore, the macro structure form describes the systematic presentation in the textbook by considering didactic elements in teaching materials so that readers can more easily understand the textbook developed [12]. In other words, the macro structure in the development of this textbook serves to show the order and arrangement of the material to be studied in the textbook. An example of a macro structure in one of the chapters is shown by Figure 2.

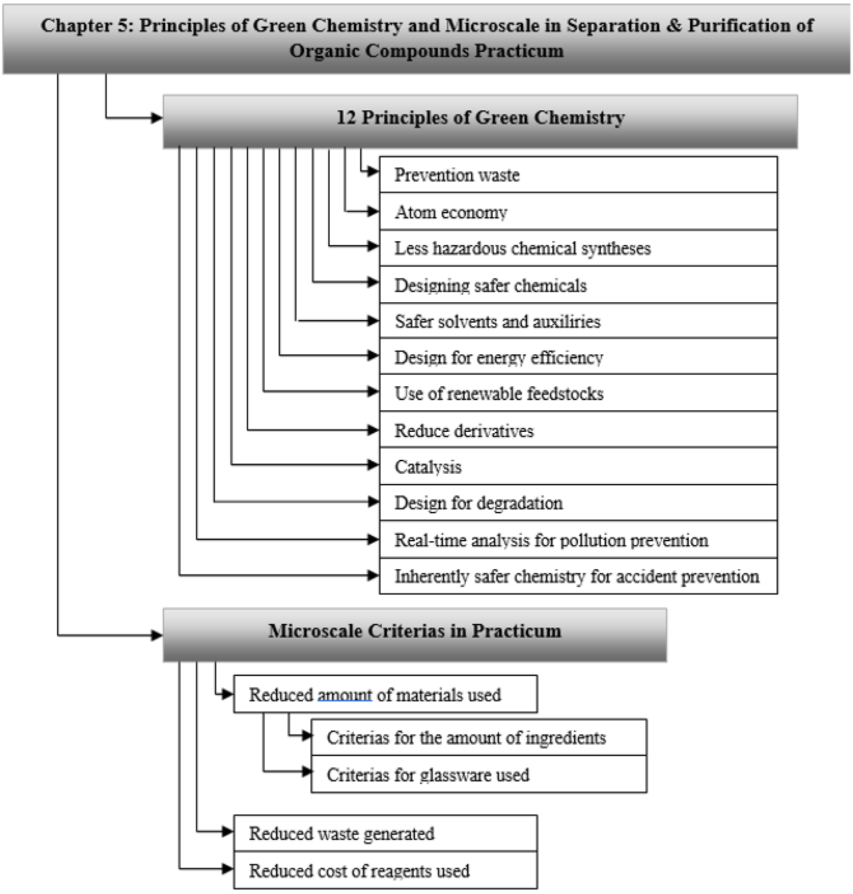

Fig. 2. Macro structure of chapter 5 of green chemistry-integrated separation and purification textbook.

Subsequently, three levels of representation consisting of macro, sub-micro, and symbolic levels were determined [24]. With these three representation models, teaching material will help students create the mental models that they should have correctly [12]. However, at this stage, it is not a must to use, so it needs to be considered and adjusted to the characteristics of the concept or material [12]. Table 3 shows an example of the three levels of representation of one of the concepts in the developed textbook.

The final product of this structuring step is the development of a draft textbook according to the macro structure and three levels of representation. The systematic presentation of textbooks is adjusted to the macro structure, while the presentation of concepts in the textbooks follows the three levels of representation. The concept map can be included at the beginning of each teaching material, the chapter, if the purpose of using the concept map is as a guideline to find out the scope of discussion in each chapter. However, if the concept map aims as a summary of the discussion in the textbook, it should be included at the end of each chapter.

Table 3. An example of three levels of representation of one of the textbook concepts developed.

Material Concept	Macroscopic	(Sub) Microscopic	Symbolic
Sublimation is the direct change of a solid phase substance into the vapour phase of the substance without going through the liquid phase. It has been proven that the vapour pressure of a liquid increases as the temperature increases. Since the boiling point of a liquid occurs when its vapour pressure is equal to the applied pressure (usually atmospheric pressure), the vapour pressure of a liquid is equal to 760 mmHg at its boiling point. The vapour pressure of a solid also varies with temperature. Because of this behaviour, some solids can go directly into the vapour phase without going through the liquid phase. One example of separation that is often encountered in everyday life is the process of sublimation of camphor from its impurities, such as car fragrances that emit fragrance even though it is invisible to the naked eye.	A cupboard with mothballs in it will emit a strong fragrance when opened.		Naphthalene has the chemical formula $C_{10}H_8$

4 Conclusion

The development of the separation and purification textbook was carried out using the 4STMD (Four Steps Teaching Material Development) method which consists of selecting, structuring, characterisation, and didactic reduction steps. In this research, it is limited to the selecting and structuring steps to get in-depth research results. As many as 4 course learning outcomes, 17 indicators of sub-course learning outcomes, and 11 concept labels were obtained so that it became a systematic material which consists of 10 chapters and 30 sub-chapters in the developed textbook. Green Chemistry and microscale principles are integrated as a substance context, while science process skills and sustainable awareness are integrated as pedagogical contexts in the development of separation and purification textbook.

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References

1. M. Pena-Abaurrea, V. S. García de la Torre, and L. Ramos, J. Chromatogr. A **1317**, 223 (2013)
2. V. M. Vorotyntsev, V. M. Malyshev, and A. N. Petukhov, Theor. Found. Chem. Eng. **52**, 819 (2018)
3. J. Zeng, W. Wang, J. Lin, Y. Zhang, H. Li, J. Liu, C. Yan, Y. Gu, and Y. Wei, J. Chromatogr. A **1674**, 1 (2022)
4. D. A. Vosburg, ACS Symp. Ser. **1345**, 63 (2020)
5. M. Chen, E. Jeronen, and A. Wang, Int. J. Environ. Res. Public Health **17**, (2020)
6. K. Tobin, Sch. Sci. Math. **90**, 403 (1990)
7. P. Anastas and N. Eghbali, Chem. Soc. Rev. 301 (2010)
8. E. S. Beach, Z. Cui, and P. T. Anastas, Energy Environ. Sci. **2**, 1038 (2009)
9. R. Boethling and A. Voutchkova, *Handbook of Green Chemistry Green Processes*

Designing Safer Chemicals (2012)
10. S. Ravichandran, Int. J. ChemTech Res. **3**, 1046 (2011)
11. F. A. Etzkorn and J. L. Ferguson, Angew. Chemie - Int. Ed. **62**, (2023)
12. S. Anwar, *Metode Pengembangan Bahan Ajar: Four Steps Teaching Material Development (4STMD)*, I (Indonesia Emas Group, Bandung, 2023)
13. J. A. Haack and J. E. Hutchison, ACS Sustain. Chem. Eng. **4**, 5889 (2016)
14. Arifin and S. Anwar, J. Pendidik. Fis. Indones. **12**, 8 (2016)
15. D. Lotaningrat, Didakt. J. Pendidik. **V**, 80 (2019)
16. S. Suryaningsih, B. Muslim, and N. A. Wati, TARBIYA J. Educ. Muslim Soc. **7**, 78=87 (2020)
17. F. R. Wilson, W. Pan, and D. A. Schumsky, Meas. Eval. Couns. Dev. **45**, 197 (2012)
18. A. Saifuddin, *Penyusunan Skala Psikologi* (Kencana, Jakarta, 2020)
19. L. R. Aiken, J. Artic. Reports - Res. Numer. Data **45**, 131 (1985)
20. A. Hasyim, Pros. Simp. Nas. Inov. Dan Pembelajaran Sains 2015 (SNIPS 2015) **2015**, 605 (2015)
21. C. H. Lawshe, Pers. Psychol. **28**, 563 (1975)
22. N. I. Syar and N. Meriza, Kwangsan J. Teknol. Pendidik. **08**, 190 (2020)
23. J. Vanides, Y. Yin, M. Tomita, and M. A. Ruiz-Primo, Teach. Strateg. **28**, 27 (2005)
24. J. K. Gilbert and D. Treagust, *Models and Modeling in Science Education: Multiple Representations in Chemical Education* (Springer, Netherlands, 2009)