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Development of Neuroscience-Based Chemistry Teaching Module on Green Chemistry Material

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ABSTRACT
This study aims to (1) develop a neuroscience-based chemistry teaching module on green chemistry topics, and (2) produce a valid and practical module for use in classroom instruction. The research employed a Research and Development (R&D) approach, adopting the Thiagarajan 4-D model, comprising four stages: Define, Design, Develop, and Disseminate. The study was conducted up to the Development stage, involving module validation and practicality testing. Research activities took place at Cendana High School, Pekanbaru, with participants including material experts, media experts, a chemistry teacher, and Class X-1 students. Data were collected through interviews, validity and practicality questionnaires, and student response surveys, utilizing a Likert scale. The analysis combined qualitative descriptive methods—capturing feedback, criticisms, and suggestions—with quantitative descriptive techniques to interpret questionnaire data. Results showed that the module's content validity, assessed by material experts, reached 85.29%, categorized as very valid, while media expert validation yielded 81.25%, also very valid. Practicality tests indicated that chemistry teachers rated the module at 90% (very practical), and student responses achieved 82.96% (very practical). These findings suggest that the neuroscience-based chemistry teaching module on green chemistry is both valid and highly practical, making it suitable for enhancing chemistry instruction.

Keywords: *teaching module, neuroscience, green chemistry*

INTRODUCTION

Education serves as a foundational pillar for national development. Although advancements in the education system contribute significantly to the nation's progress, challenges persist, particularly regarding the quality of education across various levels and institutions (Nurmiati et al., 2023). In response, the Indonesian government has introduced and implemented several educational reforms, one of which is curriculum innovation (Fatmawati & Yusrizal, 2020). The Minister of Education and Culture of the Republic of Indonesia, Nadiem Makarim, introduced the "Merdeka Belajar" (Independent Learning) curriculum as a transformative initiative (Manalu et al., 2022). This curriculum is designed to foster student autonomy in the learning process by enabling learners to access knowledge not only through formal classroom settings but also via non-formal educational avenues. Furthermore, it promotes creative learning strategies for both teachers and students (Dewi & Suniasih, 2023).

Teachers, as facilitators of learning, are required to design comprehensive and structured teaching modules that foster interactive, engaging, inspiring, and student-centered learning environments. These modules should provide opportunities for students to exercise initiative, creativity, and independence, aligned with their individual interests, talents, and developmental stages (Salsabilla et al., 2023; Kemendikbudristek, 2021). Teaching modules, developed in accordance with the Independent Curriculum, are essential instructional tools that align with learning trajectories and competency standards (Siloto et al., 2023). Effective classroom instruction requires careful planning, ensuring that learning activities are systematically organized, efficient, and impactful. This is especially true in the field of chemistry education (Zakaria et al., 2020).

Chemistry is a discipline concerned with the composition, structure, properties, and transformations of matter, as well as the energy changes involved (Syukri, 1999). It is a foundational science that integrates principles from physics, biology, and geology due to its inherently macroscopic and microscopic nature (Sudarmo, 2021). One important topic introduced in the Grade X chemistry curriculum is green chemistry, an emerging field that focuses on the sustainable use and production of chemicals to minimize environmental and health-related risks (Setianingsih, 2023). It emphasizes preventive approaches in reducing hazardous chemical use from the earliest stages of design and production, aligning with environmentally conscious and health-promoting practices (Maulidiningsih et al., 2023).

To make chemistry instruction more engaging and less monotonous, teaching methods that align with how the brain naturally processes information are essential. Enjoyable and meaningful learning experiences have been shown to improve brain function and student learning outcomes (Solihat et al., 2017). Neuroscience-based learning approaches, which balance cognitive functions and stimulate brain activity, are particularly effective in creating such environments (Zakaria et al., 2020; Khafid, 2016). Neuroscience-informed instruction enables students to actively construct knowledge through meaningful interactions and problem-solving activities, thereby facilitating deeper learning and cognitive development (Danisa et al., 2015). Recognizing this potential, the present study incorporates neuroscience principles into the development of a chemistry teaching module.

Preliminary interviews with chemistry teachers at Cendana High School in Pekanbaru revealed that although the Independent Curriculum has been adopted, traditional teacher-centered instruction still predominates. This limits student engagement and autonomy, contradicting the goals of the curriculum. Consequently, there is a need for innovative instructional tools that foster active student participation and independence. Thus, this study was undertaken to develop a neuroscience-based chemistry teaching module focused on green chemistry for Grade X students at Cendana High School in Pekanbaru.

METHODOLOGY

The subjects of this study included validators of the teaching module, media experts, and material experts, as well as practicality experts consisting of chemistry teachers and students. The object of this research was a neuroscience-based chemistry teaching module focused on green chemistry material. The population for this study consisted of chemistry teachers and Grade X students at SMA Cendana Pekanbaru. The sample comprised one chemistry teacher from SMA Cendana Pekanbaru and ten students from Class X-1. The sampling was conducted using a purposive sampling technique, where participants were selected based on specific criteria. The student sample was selected based on their cognitive performance, as indicated by their daily test scores, which were categorized within the medium achievement range.

This study was designed as a Research and Development (R&D) project utilizing the 4-D development model (Define, Design, Development, and Dissemination). The research was carried out up to the development stage, which involved the validation and practicality testing of the teaching module. The stages of the model are illustrated in Figure 1

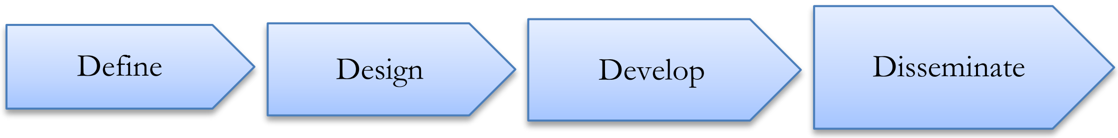

Figure 1. Stages of the 4-D Development Model

The data collection techniques employed in this study include interviews and questionnaires. Interviews were conducted as part of a preliminary study to identify and explore the challenges faced by the school. The interview was carried out with one chemistry teacher and consisted of eight questions aimed at uncovering relevant issues. The study utilized four types of questionnaires: the material expert validity questionnaire, the media expert validity questionnaire, the chemistry teacher practicality questionnaire, and the student response questionnaire. The purpose of these questionnaires was to assess the effectiveness and applicability of the developed teaching module. The data analysis for media feasibility employed the Likert scale (Hidayat, 2021). This research adapted the traditional 5-point Likert scale into a 4-point scale, consisting of the following categories: Very Good (SB), Good (B), Not Good (TB), and Very Not Good (STB). The modification of the scale was made to address certain limitations associated with the 5-point version. The standard score for each response was determined as follows to determine the number of standard scores, the highest score is calculated by multiplying the maximum score of each item by the total number of items composing the instrument. Afterward, the percentage is determined using the formula:

$$Percentage = \frac{score\ obtained}{maximum\ score}\ x\ 100\% \qquad (1)$$

The resulting percentage scores of validity and practicality are then interpreted based on the categories listed in the table below.

Table 1. Criteria for Validity and Practicality Test Results

Percentage (%)	Validity criteria
0-20%	Invalid
21-40%	Less valid
41-60%	Enough valid
61-80%	Valid
81-100%	Very valid

Source: (Karsini & Ritonga, 2021).

The inclusion of these tables allows the researchers to assess the percentage of the research outcomes, determining whether the developed module is suitable for use as an effective learning medium.

RESULT AND DISCUSSION

This study adopts a development research approach, focusing on the creation of a product. The product to be developed is a neuroscience-based chemistry teaching module on green chemistry, which is both valid and practical as assessed by material experts, media experts, chemistry teachers, and students. The research follows a Research and Development (R&D) framework, specifically the 4D model introduced by Thiagarajan. This model comprises four stages: Definition, Design, Development, and Dissemination.

Defining Stage (Define)

Definition stage is the first phase in the 4-D development model, focused on identifying and clarifying the learning requirements essential for effective teaching and learning. This stage also involves analyzing the initial problems and identifying the limitations of the media and materials to be developed. The key activities carried out during this definition process include:

Front-end Analysis

During this stage, the challenges faced by teachers in the teaching and learning process within the classroom are identified. Information was gathered through interviews with chemistry teachers at Cendana High School in Pekanbaru. It was discovered that the school had implemented Phase E of the Independent Curriculum for Grade X students, while Phase F for Grades XI and XII had not yet been applied, as the new curriculum was introduced this year, starting with Phase E for Grade X. The selection of teaching modules for this study is based on the learning objective flow (ATP) and learning achievements (CP).

Learner Analysis

The next step in the Definition stage is to conduct an analysis of the learners. This analysis is crucial for understanding the characteristics of the students, ensuring that the design and development of the media align with their needs. The results of the learner analysis for Grade X-1 at Cendana High School in Pekanbaru reveal that many students express a lack of interest in chemistry. This disinterest in the subject may lead to a reduced motivation to engage with the material, potentially affecting their academic performance negatively.

Concept Analysis

The formulation of concepts involves identifying the information to be presented in the learning module being developed, ensuring it aligns with the applicable standards or guidelines, and follows the flow of learning objectives (ATP) for Phase E 10.21. This process includes explaining the definition of green chemistry, the principles of green chemistry, the application of green chemistry principles, natural phenomena, and their connection to green chemistry.

Task Analysis

Task analysis involves a series of procedures aimed at determining and detailing the content of the teaching module on green chemistry material. The purpose of this analysis is to identify and evaluate the learning outcomes and the flow of learning objectives (ATP) required for the learning process, subsequently breaking them down into more specific achievement indicators. This analysis focuses on elaborating the learning outcomes (CP) and the flow of learning objectives (ATP) for green chemistry material. Furthermore, one of the key topics in Phase E includes concepts that will be integrated into the learning media, such as the definition of green chemistry, the principles of green chemistry, the application of green chemistry principles, natural phenomena, and their connection to green chemistry.

Specifying Instructional Objectives

The learning objectives at this stage are aligned with both the concept analysis and task analysis. The outcomes of the learning objectives analysis form the basis for designing the teaching module on green chemistry. The goal is for learners to actively engage in the learning process and gain a comprehensive understanding of green chemistry concepts, in accordance with the independent curriculum.

Design

Selection of Media

Following the needs analysis, it was determined that new learning media are required to enhance the chemistry learning process. The selected media are designed based on the results of the learning objectives analysis, concept analysis, task analysis, and the characteristics of the students as end users. The media include images and videos, created using applications such as Microsoft Word 2016, Canva, and Capcut. Each of these applications serves a specific function that supports the effective development of the teaching module.

Selection of format

The selection of format is an important step in the application of the media used in the teaching module. This includes choosing the appropriate material format, strategies or approaches, and learning resources. The selected material is green chemistry, a relatively new subject introduced in the independent curriculum. The chosen instructional approach is neuroscience-based, aimed at optimizing students' learning experiences. In this design, the learning resources or references utilized include textbooks commonly used in schools as well as additional resources focused on green chemistry.

Planning the Teaching Module Design

The product design planning is aligned with the learning material selected by the researcher, which focuses on the concept of moles. This teaching module, based on the independent curriculum, is designed to include several key components: the module cover, general information, core competencies, and appendices. The neuroscience-based learning design is outlined in Table 2 below:

Table 2. Neuroscience-Based Learning Design

Activity Details	Description
Preparation	In this activity, the teacher provides an initial explanation of the material to be taught and connects it with everyday life contexts. This stage aims to stimulate students' curiosity in learning.
Acquisition	In this activity, the teacher divides the students into several discussion groups to work on a task. The task consists of completing the LKPD.
Elaboration	This activity allows the brain to explore, analyze, test, and gain a deeper understanding in learning. Students are also asked to present the results of their group discussions in front of the class, while other students listen and provide feedback or questions. Through this discussion, it is hoped that students can find answers to the problems presented in the LKPD.
Memory Formation	At this stage, students engage in stretching exercises while watching a motivational video designed to encourage learning. In this phase of the research, brain gym exercises were implemented
Functional Integration	At this stage, the teacher checks students' understanding of the material that has been taught. Students also need to assess the extent of their understanding of the material. The teacher can provide more complex and challenging exercises. If students have not completed these exercises, the teacher usually assigns them to be completed at home. Next, students summarize the material they have just learned with the guidance of the teacher. The teacher also informs students about the material that will be studied in the next meeting. As a conclusion, the teacher appreciates the students who have participated in the learning by applauding and ends with a greeting.

Based on Table 2**,** the details of the neuroscience-based learning activities are presented in a more structured manner, ensuring alignment with the objectives outlined in the teaching module. The primary goal is for students to understand and explain the concepts of green chemistry, including the principles of green chemistry, the application of these principles, natural phenomena, and their connection to green chemistry.

Develop

Validation test

At this stage, the researchers seek validation from experts who are competent in their respective fields to obtain feedback and recommendations, ensuring the quality of the module. The modules designed during the design phase are reviewed by experts in learning modules, materials, and media. Following the validation, the product is evaluated and revised based on the feedback provided by the validators, as outlined in the validation instrument sheet. The validation results are presented below:

Table 3. Materials Validity Results on Teaching Module

No	Aspects of Assessment	Scores Obtained	Maximum Scores
1.	Content Completion Aspects	19	20
2.	Neuroscience Aspects	18	20
3.	Presentation Qualification Aspects	12	16
4.	Language Qualifications Aspects	9	12
	Total	**58**	**68**
	Validation Percentage (%)	**85,29%**	
	Categories	**Very Valid**	

Table 4. Media Validity Results on Teaching Module

No	Aspects of Assessment	Scores Obtained	Maximum Scores
1.	Graphic Aspects	6	8
2.	Cover Aspects	17	20
3.	Picture and Illustration Content	13	16
4.	Aspects Content Design	16	20
	Total	**58**	**52**
	Validation Percentage (%)	**81,25%**	
	Categories	**Very Valid**	

The results presented in the table above indicate the validity level of the developed teaching module: 1) the material expert rated it as very valid, with a percentage of 85.29%, and 2) the media expert rated it as highly valid, with a percentage of 81.25%. These validity results fall within the very valid criteria, suggesting that the neuroscience-based chemistry module on the mole concept can be used in group or limited trials.

Test of Practicality

The modules that have been revised by the validators were tested on the subject of the research, namely one chemistry teacher and 10 students of the X class of Cendana Pekanbaru High School. The practicality test of the teaching module is obtained from the teacher's response which consists of five aspects of the assessment, namely content completeness, Neuroscience, presentation validity, language validity and display.

Table 5. Practicality Results of Teaching Modules

No	Aspects of Assessment	Scores Obtained	Maximum Scores
1.	Content Accessory Aspects	15	16
2.	Neuroscience Aspects	14	16
3.	Presentation Qualification Aspects	14	16
4.	Language Qualification Aspects	14	16
5.	View Aspect	23	24
	Total	**80**	**88**
	Validation Percentage (%)	**90%**	
	Categories	**Very practical**	

Based on the data shown in the table above, a percentage result was obtained against the practicality test by the chemistry teacher on a teaching module of 90% that meets the practical criteria.

Table 6. Student Response Results to Teaching Module

No	Question	Percentage (%)	Description
1.	The instructions for the use of LKPD are easy to understand	82%	Very practical
2.	The material is presented in a concise manner so that it is easy for me to understand	82%	Very practical
3.	The LKDP cover on the learning module is interesting	92,8%	Very practical
4.	The LKPD on the teaching module has a color display design and an interesting picture	82%	Very practical
5.	The characteristics in the LKPD are clear and complete	85,7%	Very practical
6.	The combination of colors and images of the LKPD is interesting	96,4%	Very practical
7.	The letters are clearly used and easy to read	89,2%	Very practical
8.	The language used is interesting and easily understood	78,5%	Practical
9.	Using this Neuroscience LKPD in learning makes it easy to comprehend the material of the green chemistry	78,5%	Practical
10.	The learning stages provided by the LKPD can help me in understanding the material and answering the questions	75%	Practical

No	Question	Percentage (%)	Description
11.	This Neuroscience chemistry LKPD can enhance my interest and motivation to study the materials of molecules concepts	85,7%	Very practical
12.	The Neuroscience LKPD can help me learn to be active	75%	Practical
13.	Using a Neuroscience LKPD can make learning chemists not boring.	75%	Practical

Based on the results of the student response questionnaire in the table above, it shows that the LKPD in the teaching module that has been developed and taught to students has a percentage level of 82.96%, indicating that it is very practical to use and can make students enthusiastic and eager to participate in chemistry learning, so that students do not feel bored and tired in studying green chemistry.

The developed teaching module is a neuroscience-based module, structured to meet the specific needs of both teachers and students at Cendana High School in Pekanbaru. The discussion of the research results covers two key aspects: 1) the development of the neuroscience-based teaching module, and 2) the validity and practicality of the designed chemistry teaching module.

Process of Developing the Teaching Module

This research results in a final product in the form of a learning module, developed through a Research and Development (R&D) approach utilizing the 4-D development model (Four-D Models). The stages implemented include definition, design, development, and dissemination. During the definition stage, the problems are identified and analyzed through preliminary analysis, teacher analysis, student analysis, concept analysis, task analysis, and the formulation of learning objectives. The findings from this stage highlight the need for the development of a chemistry teaching module, leading to the design, creation, and development of a neuroscience-based green chemistry module in line with the specified format. This format includes general information, core competencies, and appendices.

The developed teaching module is then reviewed in consultation with a supervising lecturer to gather feedback and suggestions for improvement. In the development stage, the goal is to produce a finalized teaching module, which is revised by experts in teaching modules, materials, and media. Validation is performed to identify any weaknesses or areas for improvement in the module. Following the validation and feedback from material and media experts, the module undergoes revisions to enhance its quality. Once the revisions are complete, the module is tested with students

Validity and Practicality of the Teaching Module

The feasibility results of the Neuroscience-Based Teaching Module show that the module is overall suitable for use as teaching material. This feasibility is evidenced by the validity results from teaching module experts, material experts, and media experts. Then, based on the practicality results from the trial of the developed teaching module and the overall average score. Based on the data analysis results, the assessment results can be described in the discussion as follows:

Teaching Module Experts

The feasibility of the teaching module on green chemistry is divided into aspects of the completeness of teaching module components, clarity of learning objective achievement indicators, clarity of learning objectives, learning material, selection of learning models, media and learning resources, learning activities, and the suitability of learning activities with neuroscience-based learning models for assessing learning outcomes. Based on the assessment results of the teaching module, an average total score of 124 out of a maximum score of 132 was obtained, with a percentage of 93.93%. This can be interpreted that the teaching module expert states "very valid," meaning it is suitable for use as a teaching device.

Material Experts

The feasibility of the teaching module on green chemistry is divided into 4 aspects: content completeness, graphic aspects, presentation feasibility, and language feasibility. Based on the assessment results of the teaching module, an average total score of 59 out of a maximum score of 72 was obtained, with a percentage of 81.94%. This can be interpreted that the material expert for the LKPD in the teaching module states that the neuroscience-based chemistry LKPD on green chemistry is categorized as "very valid," meaning it is suitable for use as a learning medium.

Media Experts

The feasibility of the teaching module on green chemistry is divided into 4 aspects: graphics, cover, images and illustrations, and content design aspects. Based on the assessment results, the teaching module achieved an average total score of 59 out of a maximum score of 64, with a percentage of 81.25%. This can be interpreted that the media expert for the LKPD in the teaching module states that the neuroscience-based chemistry LKPD on green chemistry is categorized as "very valid," meaning it is suitable for use as a learning medium.

Testing Development

The assessment questionnaire for users was divided into three aspects: media, material, and learning. Based on the assessment results from students during the development trial, the module received a total average score of 302 out of a maximum possible score of 364, which falls into the "Very Practical" category, representing a percentage value of 82.96%.

This indicates that the neuroscience-based Green Chemistry LKPD is categorized as "Very Practical," with a percentage of 82.96%, confirming that it can be effectively used by students as a learning medium in chemistry. These findings align with previous research, such as the study conducted by Ayuningsih et al. (2022), titled "Development of Physics Learning Devices with a Neuroscience Approach to Improve High School Students' Concept Understanding", which also yielded valid and practical results for learning chemistry topics, specifically physical and chemical changes.

Based on the results of both the validity and practicality assessments, it is concluded that the neuroscience-based chemistry teaching module on green chemistry material is deemed feasible and suitable for use in supporting teaching activities, offering an effective tool for chemistry education.

CONCLUSION

Based on the research conducted on the development of a neuroscience-based chemistry teaching module for green chemistry material for grade X at Cendana High School in Pekanbaru, the following conclusions can be drawn: The developed teaching module, designed using Canva and Microsoft Word, includes components such as the cover, general information, initial competencies, and appendices, with the appendices primarily consisting of neuroscience-based LKPD (Student Worksheets). The validity of the module was assessed by experts, with material experts rating it as very valid (85.29%) and media experts rating it as very valid (81.25%). The practicality of the module, as assessed by teachers, was rated at 90%, while students rated it at 82.96%. Both scores fall within the very practical category, indicating that the developed neuroscience-based chemistry teaching module is valid and highly practical for use in the learning process

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