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Optimization of basic chemistry learning: Validation of stem-based problem-based learning materials for chemical equilibrium

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ABSTRACT
Background: The objective of this study is to create Basic Chemistry learning materials focused on the topic of Chemical Equilibrium using a STEM Problem-Based Learning approach. Effective learning is necessary to enhance students' understanding of complex chemistry concepts. **Method:** This study adopts the STEM Problem-Based Learning material development method, utilizing the ADDIE model, which consists of five steps: analysis, design, development, implementation, and evaluation. After the development process, the learning materials were assessed through an expert review stage. Evaluation was conducted to assess the validity of the design, pedagogical validity, and content validity using Aiken's coefficient as an indicator. **Results:** The expert review evaluation results showed high Aiken's coefficients: 0.98 for design validity, 0.95 for pedagogical validity, and 0.96 for content validity. These findings confirm that the developed learning materials comprehensively meet validity standards. **Conclusion:** Based on these evaluation results, it can be concluded that the developed Basic Chemistry learning materials, particularly on Chemical Equilibrium using the STEM Problem-Based Learning approach, meet the validity criteria. Therefore, these learning materials are considered suitable for use in the Basic Chemistry learning process. **Novelty/Originality of this study:** This study integrates the STEM Problem-Based Learning approach into developing Basic Chemistry learning materials, specifically on Chemical Equilibrium. Using the ADDIE model and comprehensive validation, this study presents a new framework for designing learning materials that simultaneously meet design, pedagogical, and content standards.

KEYWORDS: addie model; development of teaching materials; learning effectiveness; problem based learning.

1. Introduction

The 21st century serves as the cornerstone for various aspects of modern human life. This era is marked by the utilization of technology, communication, and information integrated into daily life. The reliance on technology in all aspects of life has led to changes in the qualifications and competencies of an increasingly competitive workforce (Daryanto & Karim, 2017). According to Munib et al. (2015), education is a lifelong process, meaning that educational efforts begin from the moment a person is born until the end of their life,

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as long as they are capable of receiving influence and developing themselves. Education is an essential element that cannot be separated from the progress of a nation. Education can evolve at any time, driven by globalization. Globalization and education play two critical roles in shaping the advancement of a nation. The inevitable development of globalization demands that people adopt more progressive thinking to avoid lagging behind other developed countries. The term STEM was introduced by the National Science Foundation of the United States (US) in the 1990s as the theme for the educational reform movement in these four disciplines to cultivate a workforce ready to work in STEM fields, develop STEM-literate citizens, and enhance the global competitiveness of the United States (US) in innovation, science, and technology (Hanover Research, 2011).

Mastery of Science and Technology (IPTEK) is currently a critical key to addressing future challenges. Various challenges arise, including improving the quality of life and the ability to develop human resources. For this reason, Science Education/Natural Sciences (IPA) plays a significant role in preparing students with scientific literacy, namely, the ability to think critically, creatively, logically, and proactively in responding to societal issues caused by the impact of developments in Natural Sciences (IPA) and technology (Prayekti, 2006). To enhance interconnectedness in the 21st century, a workforce equipped with science and engineering skills is essential. Several countries have implemented science- and engineering-based education, producing highly skilled graduates in these fields and improving the quality of human resources in science and engineering. Students are required to excel in scientific practices to develop an understanding of scientific endeavours. These practices include skills acquired from everyday life and systematically conducted classroom learning. Indonesia is compelled to participate in producing human resources capable of competing in the 21st century. To meet global demands, significant efforts are needed to improve human resources in Indonesia, particularly in the field of education (Jones et al., 2015).

A learning process that relies solely on textbooks and student worksheets (LKS) requiring students to solve problems is different from the demands of the 21st century, which require human resources to possess critical thinking and problem-solving skills. Teachers need to adopt a learning approach that fosters students' creative thinking abilities. One such approach is the STEM learning approach. STEM learning integrates science, technology, engineering, and mathematics and is recommended to support the development of 21st-century skills (Beers, 2011).

The Problem-Based Learning (PBL) model can be integrated with the STEM approach. STEM is an effective method to facilitate and maintain the integration of science, technology, engineering, and mathematics (Estapa & Tank, 2017). The descriptions of these four terms are as follows: (1) Science relates to concepts and laws associated with nature, (2) Technology refers to skills applied in knowledge using tools that make tasks easier, (3) Engineering involves the knowledge to design processes or steps to solve problems, and (4) Mathematics is the science that connects quantities, numbers, and space based on logic without empirical evidence (Torlakson, 2014). The integration of Problem-Based Learning with STEM enables the actualization of environmental literacy and students' creativity (Farwati, 2017). Furthermore, the implementation of STEM-integrated Problem-Based Learning can enhance students' cognitive abilities, psychomotor skills, and character development (Yulianti et al., 2018).

One of the chemistry topics that students find challenging to understand is chemical equilibrium, as the concept of chemical equilibrium is abstract and often paired with concrete examples that many students perceive as difficult (Haryani, 2014). One reason for this difficulty in understanding the material lies in the teaching resources, which still need to incorporate multiple chemical representations, resulting in a lack of comprehensive integration in the learning process. This has led to misconceptions and difficulties in understanding chemical concepts for some students (Heriyana, 2013). STEM Problem-Based Learning teaching materials have been shown to enhance students' creativity, particularly in chemistry, thereby improving learning outcomes (Hapiziah et al., 2015). Therefore, it is necessary to develop teaching materials for basic chemistry courses on chemical equilibrium topics based on STEM Problem-Based Learning. Based on this rationale, the researcher will conduct a study titled *"The Development of Basic Chemistry Teaching Materials Based on STEM Problem-Based Learning for Chemical Equilibrium Topics in the Chemistry Education Study Program."*

Several studies are relevant to this research, including one by Rahmatina (2020) on the development of STEM-based teaching materials, which were deemed feasible and could be used as an alternative in the learning process. Another relevant study was conducted by Regita et al. (2020), focusing on STEM Problem-Based Learning teaching materials for basic chemistry courses on solutions, which were found to be feasible, practical, and applicable as alternative teaching resources. Additionally, Irmita (2018) developed a chemistry learning module using the STEM approach, which was also found suitable for use as an alternative module in the learning process. The difference between this study and previous research lies in the focus on developing Basic Chemistry Teaching Materials Based on STEM Problem-Based Learning specifically for the topic of chemical equilibrium. This development is aimed at chemistry education students, ensuring the materials are both valid and practical.

Although Problem-Based Learning (PBL) is defined differently across various studies, three essential characteristics are often emphasized: problems as stimuli for learning, educators as facilitators, and learner groups as stimuli for interaction (Dolmans et al., 2005). The PBL learning process begins with selecting and designing exploratory content around a specific learning project. Next, group discussions among learners are conducted to develop project plans, explore activities, and engage in both individual and team efforts to design or implement the project. Finally, the results of their work are compiled or presented in class for evaluation and improvement (Chen, 2015).

Studies have demonstrated that STEM education offers educators opportunities for rapid and in-depth learning through various Problem-Based Learning models. It also helps learners increase their interest in studying, thereby enhancing their academic performance (Meyrick, 2011).

The aim of this study, as outlined in the problem formulation, is to develop basic chemistry teaching materials based on STEM Problem-Based Learning for the topic of chemical equilibrium that fulfill the criteria of validity. Additionally, this study seeks to produce teaching materials that meet practical standards for students in the Chemistry Education study program.

2. Methods

This study employs the development method using the ADDIE framework, which consists of five steps: analysis, design, development, implementation, and evaluation. Participants in this research include experienced educators and fourth-semester students enrolled in 2020 in the Chemistry Education Program at Sriwijaya University. The focus of this research is on the development of Basic Chemistry instructional materials based on STEM Problem-Based Learning related to the topic of Chemical Equilibrium.

The study was conducted within the Chemistry Education Program, part of the Faculty of Teacher Training and Education at Sriwijaya University, from March to April 2022. The initial stage involved a needs analysis, which included the preparation of interview guidelines for lecturers teaching Basic Chemistry courses and the development of pre-study questionnaires for students. This process also involved consultation with academic advisors, conducting interviews with lecturers, distributing questionnaires to students, and collecting and analyzing data obtained from the interviews and questionnaires.

First, an analysis of student characteristics was conducted by preparing and distributing questionnaires, followed by a curriculum evaluation that included curriculum guidelines, Semester Learning Plans (RPS), and Learning Activity Units (SAP) used in the Chemistry Education Program. The next step was the design phase, where the researchers designed the instructional material concepts according to the STEM Problem-Based Learning model, aligning the content and questions with the learning objectives, creating the visual design of the instructional materials, and producing specific prototypes evaluated by the researchers with guidance from academic advisors.

Additionally, interviews were conducted with lecturers of Basic Chemistry courses to identify problems and needs as an initial step in this research. Questionnaires were distributed to students of classes A and B, 2020 cohort, in the Chemistry Education Program at FKIP Sriwijaya University, Indralaya, during the pre-study phase and development process. The pre-study questionnaire contained a series of questions answered by the students, which were then used as preliminary data for this research. During the instructional material development process, questionnaires were also given to expert validators to evaluate the validity of the developed materials. This validation process involved assessments by expert validators in the fields of education, content, and design, using a Likert scale with four categories: very good (VG), good (G), poor (P), and very poor (VP) (Sugiyono, 2018). The collected data included validation sheets containing the validators' assessments of various pedagogical, content, and design aspects of the developed instructional materials.

The researchers used specific data analysis techniques in their study to evaluate the validity at the expert review stage by utilizing Aiken's V formula. The formula proposed by Aiken can be detailed as follows:

V = $\Sigma s\ [n(c-1)]$

with : (Aiken, 1985)

s = r – lo

lo = low validity assessment number (for example 1)

c = highest validity assessment number (e.g. 4)

r = the score given by the assessor

The Aiken's V coefficient value ranges from 0-1. Here is the interpretation Koefisien Aiken's V :

Table 1. Aiken V score categories

No	Range of aiken's V coefficient values	Category
1	0,68 – 1,00	High
2	0,34 – 0,67	Medium
3	0 – 0,33	Low

(Aiken, 1985)

3. Results and Discussion

This research resulted in a product in the form of Basic Chemistry instructional materials that adopt the STEM Problem-Based Learning approach on the topic of chemical equilibrium. By utilizing the ADDIE development model combined with Tessmer's formative evaluation, the development outcomes holistically consider the needs and characteristics of students. Through a comprehensive analysis phase, including a needs analysis, student characteristics analysis, and curriculum analysis, efforts were made to ensure that the resulting materials effectively meet learning needs.

The needs analysis revealed several findings underlying the development of these materials. Students were identified as needing a deeper understanding of chemical equilibrium and the necessity for instructional materials to relate to everyday life and natural phenomena. Additionally, the need for supplementary teaching materials was highlighted to facilitate comprehension of the content. Meanwhile, the analysis of student characteristics emphasized the importance of active student engagement in learning, both through real-life connections and collaboration in completing tasks.

Table 2. Data from pre-research questionnaire results

No	Questions	Number of students		Percentage	
		Yes	No	Yes	No

1	I feel enthusiastic about participating in Basic Chemistry learning, particularly on the topic of Chemical Equilibrium.	45	6	88.20%	11.80%
2	I enjoy seeking references from other sources to gain a better understanding of the Chemical Equilibrium learning material.	45	6	88.20%	11.80%
3	I am more accustomed to using the internet rather than books when studying the Chemical Equilibrium material.	34	17	66.70%	33.30%
4	I prefer it when the learning of Chemical Equilibrium is related to real-life problems.	47	4	92.20%	7.80%
5	I prefer working with my friends to complete assignments, exercises, or chemistry problems.	41	10	80.40%	19.60%
6	I prefer active, independent learning over theoretical explanations from the lecturer in Basic Chemistry courses.	28	23	54.10%	45.10%
7	I have teaching materials (books/LKPD/modules) to study the topic of Chemical Equilibrium.	33	18	64.70%	35.30%
8	I still need additional teaching materials to study the topic of Chemical Equilibrium.	47	4	92.20%	7.80%
9	I need illustrations or images to understand the topic of Chemical Equilibrium.	49	2	96%	4%
10	My teaching materials already meet the needs for understanding the concepts of Chemical Equilibrium.	32	19	62.70%	37.30%
11	My teaching materials already meet the needs for understanding the concepts of Chemical Equilibrium.	26	25	51%	49%
12	The teaching materials for the topic of Chemical Equilibrium that I use present problems relevant to natural phenomena in everyday life.	21	30	41.20%	58.80%
13	The teaching materials for the topic of Chemical Equilibrium allow me to study independently without the need for the instructor's presence.	18	33	35.30%	64.70%
14	The teaching materials for the topic of Chemical Equilibrium guide me towards an approach that integrates science, technology, engineering, and mathematics.	32	19	62.70%	37.30%
15	The teaching materials for the topic of Chemical Equilibrium that I use already incorporate STEM-PBL (STEM Problem-Based Learning).	17	34	33.30%	66.70%
16	The teaching materials for the topic of Chemical Equilibrium that I use encourage me to be creative and innovative in solving problems in everyday life.	15	36	29.40%	70.60%
17	I need teaching materials in the form of a module to easily understand Basic Chemistry learning on the topic of Chemical Equilibrium.	47	4	92.20%	7.80%

After reviewing the curriculum, several findings were noted, including; the curriculum used by the Chemistry Education students at FKIP Sriwijaya University, from 2017 to 2022, is the 2017 curriculum, which has undergone revisions, the Basic Chemistry course carries 3 credit units and is taught in the odd semester, with the prerequisite that students have completed the previous Basic Chemistry course, the instructional materials for the Basic Chemistry course cover 8 main topics, including Chemical Equilibrium, in the context of chemical equilibrium, there are 7 learning indicators linked to everyday life situations, enabling the resolution of real-world problems relevant through the STEM Problem-Based Learning approach.

In the design phase, the researcher began developing the initial concept of the product, including both the content and the appearance of the teaching materials. During this phase, the researcher also conducted a literature review from one of the journals, namely the *Chemical Connection: A Problem-Based Learning STEM Experience* journal, as a reference for understanding the syntax of STEM Problem-Based Learning, which will become the distinctive feature of the teaching materials. Additionally, the researcher consulted books such as the *General Chemistry: Principles, Patterns, and Application* textbook, which is commonly used by lecturers in the learning process, *Kimia Dasar Konsep-Konsep Inti Edisi Ketiga Jilid 2*, *Kimia Untuk Universitas Edisi Keenam Jilid 1*, and *Kimia Dasar 1 Berdasarkan Prinsip-prinsip Kimia Terkini* and *Prinsip-prinsip Kimia Modern Edisi Keempat Jilid 1* to gather supporting material and problems to be included in the STEM Problem-Based Learning-based Basic Chemistry teaching materials on the topic of Chemical Equilibrium.

The structure of the instructional materials to be developed consists of the following elements: the title of the material is "Basic Chemistry Instructional Materials Based on STEM Problem-Based Learning on the Topic of Chemical Equilibrium." The introductory section includes a brief description, learning objectives of the course, sub-learning objectives, learning indicators, learning targets, instructions for using the instructional materials, a guide to STEM learning, and symbols used. The learning activities are divided into three activities, each focusing on a relevant sub-topic of Chemical Equilibrium. Additionally, there is a student worksheet in the third learning activity, which aims to design an engineering product related to the Chemical Equilibrium material. The instructional materials are also supplemented with sample problems and exercises to be worked on in groups. The concluding section of the instructional materials includes a summary, evaluation questions, answer keys, a glossary, and a list of references.

3.*1 Design validation*

In the analysis and design phase, the results are still in the form of a specific prototype that will later be evaluated by the researchers themselves through consultations with academic advisors, a process referred to as self-evaluation. Comments and revisions from this self-evaluation can be found in Table 3. below:

Table 3. Self evaluation with supervisor

No	Recommendation	Revision
1	Before Revision: There are no instructions for teaching materials regarding STEM and the STEM learning process	After Revision: There are already instructions for teaching materials regarding STEM and the STEM learning process
2	Before Revision: There is still material that has not been explained clearly and is not in accordance with learning indicators	After Revision: The material displayed in the teaching materials is clear and in accordance with learning indicators
3	Before Revision: There are still several images in teaching materials whose sources have not been included	After Revision: All images in the teaching materials have been corrected by including the source in the teaching materials
4	Before Revision: The sentences used in teaching materials still use book language which makes the teaching materials difficult to understand	After Revision: The sentences used in teaching materials have been replaced with language that is easier to understand

The results of the product revision from this self-evaluation are further developed using Tessmer's Formative Evaluation, starting with an expert review, followed by one-to-one and then small group evaluations.

In the Development phase, further expansion was conducted on the design and content of the previously prepared instructional materials, along with an evaluation aimed at producing valid STEM Problem-Based Learning-based instructional materials. During the expert review process, the revised product from the self-evaluation was endorsed for assessing the validity of its development. Validation was carried out by a validator who is a lecturer from the Chemistry Education Program at Sriwijaya University. This validation process comprised three aspects: design validation, content validation, and pedagogical validation. Each expert was provided with validation tools to assess the validity of the instructional materials. Assessment was conducted quantitatively through the completion of validity questionnaires using a Likert scale. In addition to providing assessments, validators also offered feedback and suggestions as a basis for the researchers to revise the developed product. The validation process continued until the validators confirmed that the developed product was valid for testing. Evaluation of design validity was performed with the involvement of a single validator. The researcher received a number of notes and recommendations from this design expert, documented in Table 4 below:

Table 4. Comments/suggestions and results of design validation revisions

Validator	Comments/Revision	Suggestions
MS	The illustrations in teaching materials are unattractive and too monotonous	The image illustration has been changed into an animated video so it's been interesting.
	The picture illustrations in the teaching materials do not match the information provided.	The image illustration has been changed according to the information is in the teaching materials.
	The pictures on the teaching materials are still some are blurry and unclear.	All images are clear and no longer blurry
	There are still picture illustrations and animated videos in teaching materials for which the sources and descriptions have not been written.	All animated image illustrations and videos have their source and description.

After providing feedback and suggestions, the validator evaluated the instructional materials using a validation evaluation form prepared by the researcher. The evaluation form assessed by the validator was subsequently analyzed by the researcher using the V Aiken method to obtain validation evaluation scores. Details regarding the design validation evaluation scores can be found in Table 5 below.

Table 5. Design validation test assessment results

Inisial	Mean	Category
MS	0.98	High

From the pedagogical validation test evaluation in Table 5 above, it is evident that the average V Aiken score for pedagogical validation is 0.95, indicating a high level of validity. This indicates that the pedagogical aspect of the developed instructional materials has been proven valid.

3.2 Pedagogical validation

The evaluation of pedagogical validity involved the participation of one validator. The researcher received several inputs and suggestions from this pedagogical expert, documented in Table 6 below:

Table 6. Comments/suggestions and results of revised pedagogical validation

Validator	Comments/Revision	Suggestions

MS	Grammatical provisions and standard terms in teaching materials are not in accordance with EYD.	Grammatical provisions and standard terms in teaching materials are in accordance with EYD.
	There are still some uses of punctuation in teaching materials it is not in accordance with.	All punctuation in teaching materials is appropriate.
	There are still several errors in writing teaching materials.	It's no longer there error in writing on teaching materials.
	There are still errors and inappropriate writing of compound formulas in teaching materials.	There are no longer errors in writing compound formulas in teaching materials.
	The column for ticking answers on the comprehension test does not yet exist.	There is already a column for checking comprehension tests on teaching materials.

After providing feedback and suggestions, the validator evaluated the instructional materials using a validation evaluation form prepared by the researcher. The evaluation form assessed by the validator will be examined by the researcher using the V Aiken method to generate validation evaluation scores. Detailed information regarding the design validation evaluation scores can be found in Table 7 below.

Table 7. Pedagogical validation test score results

Initial	Average value	Category
MS	0.95	High

From the results of the pedagogical validation test in Table 7 above, it is noted that the average V Aiken score for pedagogical validation is 0.95, indicating a high level of validity. This signifies that the pedagogical aspect of the developed instructional materials has been proven valid.

3.3 Material validation

The evaluation of material validity involved the participation of one validator. The researcher received several inputs and suggestions from this pedagogical expert, recorded in Table 8 below:

Table 8. Comments/suggestions and results of revision of material validation

Validator	Comments/Revision	Suggestions
MS	The material presented on teaching materials are adjusted again with RPS and indicators learning	The material presented in the teaching materials is in accordance with the RPS and learning indicators.
	The final evaluation questions on the teaching materials do not yet contain a description of STEM.	The final evaluation questions already contain a description of STEM.
	There are still practice questions in the teaching materials that are not appropriate in relation to the material being discussed	The practice questions in the teaching materials are in accordance with the material discussed
	The final report on activities in teaching materials does not contain any elaboration or collaboration.	The final activity report on the teaching materials already contains elaboration and collaboration.

After providing feedback and suggestions, the validator assessed the instructional materials using a validation evaluation form prepared by the researcher. The evaluation form assessed by the validator will be analyzed by the researcher using the V Aiken method to obtain validation evaluation scores. Details regarding the material validation evaluation scores can be found in Table 9 below.

Table 9. Material validation test score results

Initial	Average value	Category
MS	0.96	High

From the material validation test evaluation in Table 9 above, it is evident that the average V Aiken score for material validation is 0.96, indicating a high level of validity. This demonstrates that the material aspect of the developed instructional materials has been proven valid. Overall Average Validation Score Results

Table 10. Overall average validation score results

Validator	Aiken coefficient value	Category
Design	0.98	High
Pedagogik	0.95	High
Materials	0.96	High

The research conducted is developmental research utilizing the ADDIE development model combined with Tessmer's formative evaluation. The stages of research in the ADDIE development model include analysis, design, and development. Tessmer's formative evaluation is limited to the small group stage. The evaluation stages consist of expert review, one-to-one, and small group evaluations. Tessmer's formative evaluation is employed because, at each stage of the development model, evaluation is immediately conducted to identify product weaknesses so they can be revised. This approach is more effective than using the evaluation stage of the ADDIE model.

In the analysis of student characteristics, based on a pre-research questionnaire distributed to students, it was found that 80.4% of students felt enthusiastic about learning Basic Chemistry when it was connected to real-life problems. Additionally, 92.2% of students preferred working in groups with their peers on Basic Chemistry assignments rather than completing them independently. The researcher also conducted interviews with lecturers teaching Basic Chemistry courses, revealing that students still exhibit a high dependency on the presence of lecturers during the learning process. Therefore, there is a need for additional engaging teaching materials to foster student creativity.

In the curriculum analysis, the curriculum used by Chemistry Education students at FKIP Universitas Sriwijaya is the 2017 revised curriculum, which directs students to conduct independent learning activities. There are seven learning indicators related to everyday life related to the topic of Chemical Equilibrium, making them suitable for design using the STEM Problem-Based Learning approach.

STEM is an acronym for Science, Technology, Engineering, and Mathematics. Moore et al. (2014) stated that STEM is an approach and effort to integrate several or all four STEM components into a single lesson based on the interrelation between subjects and real-world problems. Kelley and Knowles (2016) explained that STEM serves as an authentic approach that enhances students' learning interests. Sanders (2009) described STEM as an approach that explores two or more STEM subjects along with one or more school subjects.

STEM Problem-Based Learning is a learning approach that integrates the Problem-Based Learning model with the STEM approach. STEM encompasses disciplines that are closely interconnected. Science requires mathematics as a tool for data processing, while technology serves as the application of science itself (Afriana et al., 2016). Learning science also necessitates the engineering design process, which involves knowledge for operating or designing a procedure to solve a problem (Torlakson, 2014). STEM Problem-Based Learning is a learning system based on the philosophy that students can absorb lessons effectively when they find meaning in the academic materials they acquire and school assignments by connecting new information with the knowledge and experiences they already possess (Karim & Normaya, 2015).

Reeve (2013) stated that STEM education is defined as an interdisciplinary approach to learning in which students utilize science, technology, engineering, and mathematics in real-world contexts. This approach connects school, the workforce, and the global environment, fostering STEM literacy that enables students to compete in the new knowledge-based economy. Kelley and Knowles (2016) outlined five steps in STEM learning: (1) Learning begins with questions and the process of problem definition, (2) Learning activities involve the development and use of products as well as the formulation of steps for problem investigation, (3) Analyzing and interpreting materials studied by applying knowledge in mathematics and technology, (4) Constructing explanatory texts that lead to solutions and group opinions based on evidence gathered through collaborative investigations, and (5) Concluding, evaluating, and discussing the outcomes of the discussions.

Abbot (2016) proposed six steps in the STEM Problem-Based Learning process: (1) The PBL Scenario, where the plan of activities to be carried out by students in each session is laid out. At this stage, students are presented with everyday phenomena that prompt questions. They can observe surrounding phenomena, which serve as the initial topics for problem-solving. (2) Introducing Students to the Task, where students' thinking frameworks are directed, encouraging them to think critically in solving a given problem. (3) The Learning Board, which guides students to comprehensively understand the problem, including identifying the key issues that need to be addressed. Students are encouraged to question the presented phenomena to provide appropriate solutions. (4) Researching the Problem, where students investigate the problem and identify solutions. During this phase, students gather and analyze information from learning resources to gain a complete understanding of the problem and potential solutions. (5) Engaging Students in EDP (Engineering Design Process), where students are involved in the engineering phase by creating prototype designs to address the problem. (6) An Interdisciplinary Approach with Writing, the final stage in STEM Problem-Based Learning, where students compile a final report summarizing the activities and solutions developed during the process.

The next stage conducted by the researcher was the design phase. During this stage, the researcher began developing the initial concept design of the product. The first step involved designing a STEM Problem-Based Learning-based teaching material for basic chemistry on the topic of chemical equilibrium. The researcher planned chemistry learning activities, formulated competency achievement indicators, learning objectives, and evaluation instruments, and compiled the chemical equilibrium material to be included in the teaching material. In the design process, the researcher sought reference materials from books, modules, and journals to gather content for the product design. At this stage, the design was still in the form of a specific prototype, which the researcher then self-evaluated by seeking input from a supervising lecturer, a process referred to as self-evaluation.

At the self-evaluation stage, the researcher conducted several rounds of guidance and improvements with the supervising lecturer. The self-evaluation process involved reviewing and repeatedly understanding every piece of writing and presentation of the content in the teaching material, as well as correcting any mistakes found in the material. Initially, the researcher needed help in determining how to integrate the content of science, technology, engineering, and mathematics (STEM) with the topic of chemical equilibrium in the teaching activities. The supervisor provided several suggestions and feedback. One of the suggestions was to ensure that the problems presented in the teaching material were related to real-world issues that would spark creativity in students. The issue presented in the teaching material was the creation of a bathroom scale cleaner, which was clearly related to the topic of chemical equilibrium. This problem was introduced in learning activity 3, so students could discuss and solve the problem with the creativity they possessed.

The supervisor also provided feedback on both the content and presentation of the teaching material. Regarding the content, the supervisor suggested organizing the material clearly and aligning it with the learning indicators, as the initial material needed to meet these indicators. The supervisor also advised ensuring that every image was clear and not blurry and that each image included its source. Any unclear or ambiguous sentences in the material had to be corrected, as they could confuse students in understanding the content. Additionally, the supervisor suggested adding the stages of the STEM learning process in the introduction of the teaching material. The guidance and feedback from the supervising lecturer became the basis for the researcher to refine the specific prototype. The revised specific prototype was then developed in the development stage using the Tessmer formative evaluation, starting from the expert review, one-to-one, and small group stages.

The expert review stage was conducted to assess the validity of the developed teaching material. This stage involved one validator who validated the design, pedagogy, and content. The researcher met with the validator offline to discuss the product developed. The validation process was carried out by providing the initial product from the self-evaluation to the validator for review. After reading the initial product, the validator filled out a validation form and provided comments or suggestions. These comments or suggestions from the validator served as a reference for the researcher to improve the developed teaching material. This stage received numerous constructive comments, feedback, and suggestions from the expert, which greatly contributed to the further development of the teaching material.

First, the researcher evaluated the design. The design validator provided comments and suggestions regarding the design of the developed teaching material. The comments and suggestions from the validator included concerns about the illustrations in the material, stating that they could have been more appealing and more varied. Additionally, some illustrations did not match the descriptions provided, and some images needed to be clearer or clearer. There were also illustrations and animated videos that needed to have their sources or captions indicated. These comments and suggestions were used as a reference for the researcher to make improvements to the teaching material. For the design validation, the researcher used a validation instrument developed by Diar Arum Trianda, a student of the Chemistry Education program, class of 2017, University of Sriwijaya. This design validation instrument consists of 20 indicators, with each indicator having four descriptors. The results of the design validation by the validator showed an Aiken coefficient value of 0.98, indicating a high level of validity. Therefore, the design aspect of the STEM Problem-Based Learning teaching material can be considered valid.

Next, after evaluating the design, the researcher conducted a pedagogical evaluation. In this pedagogical evaluation, the validator provided comments and suggestions to the researcher regarding the developed teaching material. The comments and suggestions from the validator included concerns about the correctness of the grammar and the standardization of terms in the material, which needed to align with the Indonesian spelling system (EYD) fully. Additionally, there were issues with the use of punctuation in the material, and some errors in writing were identified. The formulae for the compounds in the material were found to be incorrect and inconsistent, and there needed to be more checkboxes in the comprehension test section. The pedagogical validation used a validation instrument developed by Novani, a student of the Chemistry Education program, class of 2017, University of Sriwijaya. This pedagogical validation instrument consists of 22 indicators, with each indicator having four descriptors. The results of the pedagogical validation by the validator showed an Aiken coefficient value of 0.95, indicating a high level of validity. Therefore, the pedagogical aspect of the STEM Problem-Based Learning teaching material can be considered valid.

Next, after evaluating the design and pedagogy, the researcher evaluated the content. In this content evaluation, the validator provided comments and suggestions to the researcher regarding the material in the developed teaching resource. The comments and suggestions from the validator included the need to align the material presented in the teaching resource with the Course Learning Plan (RPS) and the learning indicators. Additionally, the final evaluation questions in the material still needed to include STEM elaboration, some practice questions were not fully relevant to the topics discussed, and the final report in the material lacked elaboration and collaboration. The content validation used a validation instrument developed by Nur Afifah, a student from the Chemistry Education program, class of 2017, University of Sriwijaya. This content validation instrument consists of 21 indicators, with each indicator having four descriptors. The results of the content validation by the validator showed an Aiken coefficient value of 0.96, indicating a high level of validity. Therefore, the content aspect of the STEM Problem-Based Learning teaching material can be considered valid.

After completing the expert review phase, the researcher proceeded with the one-to-one phase, which is a pre-pilot test of the practicality of the teaching material with three students selected based on their different levels of ability. Data collection in this study was conducted through walkthroughs and by using six variables with 21 indicators, each indicator having four descriptors. The three students who participated as informants in this phase were MUA, AM, and AH. These students were first provided with the initial product and asked to read it. After reading, they answered the walkthrough sheet, filled out the practicality questionnaire, and provided comments or suggestions.

The comments/suggestions from the student MUA were that the provided teaching material was engaging, which made it easier to understand the material. However, there were still some things that needed to be corrected in writing. The comments/suggestions from student AM were that the material had an attractive appearance and was full of colours, making it less monotonous. However, some images needed to be clearer and clearer. The comments/suggestions from student AH were that the STEM Problem-Based Learning chemistry material with the topic of chemical equilibrium was excellent because it encouraged critical thinking, motivation, and systematic learning. The flexible learning system requires critical thinking, perseverance, and comprehensive reading of literature.

After receiving the research results from the three students, the researcher revised the teaching materials and analyzed the practicality of the materials based on the obtained results. The quantitative assessment process in the one-to-one phase was conducted by distributing the practicality sheet for the teaching materials. After the students provided scores for each indicator, the scores were then accumulated using the practicality formula. Based on the assessment by the students of the developed teaching materials, the average practicality score obtained was 0.95, which falls into the very high category. The product developed in the expert review phase, which was deemed valid, and the one-to-one phase, which was deemed practical, is referred to as prototype 1.

Next, prototype one was tested again through the small group phase to assess its practicality in a small group of students using the developed teaching materials. Prototype 1 was tested for practicality on nine students. Similar to the one-to-one phase, data collection was conducted using a walkthrough technique and by employing six variables with 21 indicators, each with four descriptors. Based on the results of the walkthrough, it can be concluded that the developed teaching materials meet the criteria. The materials presented in the module are engaging and unique, encourage students to think critically, are relevant, and have clear and easily understandable explanations. The materials also stimulate students to engage in discussions to solve problems and help them generate varied ideas or answers from the tasks given. However, there are still several comments/suggestions from students that need to be addressed, such as writing errors in the materials, unclear and blurry images, lack of example problems, and an unattractive cover.

After obtaining the results from the nine students, the researcher revised the teaching materials and analyzed their practicality based on the results received. The researcher analyzed the practicality of the teaching materials using the practicality formula, obtaining an average score of 0.95, which falls under the very high practicality category. Therefore, the product developed by the researcher can be considered practical. The outcome of the small group phase is referred to as prototype 2, which represents the teaching materials that have met the criteria of being both valid and practical.

Previous research that aligns with this study includes research conducted by Rahmatina (2020), titled Pengembangan Bahan Ajar Berbasis Science, Technology, Engineering and Mathematics (STEM) di SMA/MA. Rahmatina's study employed the ADDIE development model, which was limited to the development (development) stage. The difference between Rahmatina's research and the current study lies in the produced teaching materials and the subject matter developed, specifically chemical equilibrium. In addition to Rahmatina, another researcher, Irmita (2018), conducted a study titled

Pengembangan Modul Pembelajaran Kimia Menggunakan Pendekatan Science, Technology, Engineering and Mathematics (STEM) pada Materi Kesetimbangan Kimia. The difference between Irmita's development and the current research lies in the implementation of STEM Problem-Based Learning. Irmita's development was limited to a STEM-based module, whereas the current study developed teaching materials incorporating STEM Problem-Based Learning. A distinguishing feature of this development is the relevance of the content in the teaching materials to real-life situations.

5. Conclusions

Based on the results of the development research conducted, it can be concluded that the Basic Chemistry teaching materials for the topic of Chemical Equilibrium based on STEM Problem-Based Learning developed in this study meet the criteria for validity. The validity obtained during the expert review stage, calculated using the Aiken coefficient, showed a design validation score of 0.98, a pedagogical validation score of 0.95, and a material validation score of 0.96. Based on these quantitative data, the teaching materials produced are categorized as highly valid, making them feasible and appropriate for use.

Furthermore, based on qualitative walkthrough data and practicality calculations during the one-to-one stage, the practicality score was 0.95, which is classified as very high. During the small group stage, the practicality score was also 0.95, again classified as very high. These results indicate that the teaching materials are practical and suitable for use.

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