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Development of a Student Worksheet Based on a Three-Dimensional Thinking Graph to Support Students' Critical Thinking Skills

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Abstract: Chemical bonding is a fundamental topic in chemistry that is often considered abstract and difficult for students to understand, resulting in low critical thinking skills. The lack of interactive and technology-based teaching materials further exacerbates this problem. Therefore, this study aims to develop an electronic student worksheet based on the Three-Dimensional Thinking Graph on chemical bonding and determine its feasibility in supporting students' critical thinking skills. This study uses the Research and Development (R&D) method with the ADDIE model limited to the analysis, design, development, implementation, and evaluation stages. Data were collected through interviews, questionnaires, expert validation sheets, teacher assessments, and student responses. The product was validated by two validators, material and media experts, and one expert in learning design and Problem-Based Learning. The product trial involved 10 students from class XII F1B at SMAN 11 Muaro Jambi, conducted through one-to-one and small-group tests. Data analysis techniques used percentage analysis and qualitative descriptive analysis. The results showed that the electronic student worksheet obtained a validation score of 92% from material and media experts and 88.57% from learning design experts, with the category of very feasible. Teacher assessments reached 91% and student responses were 86%, categorized as very good. The novelty of this research lies in the integration of concept maps, data tables, and reasoning maps in an interactive electronic student worksheet based on TDTG to systematically support the development of students' critical thinking skills. Thus, the developed electronic student worksheet is deemed feasible and has the potential to support more interactive and meaningful learning of chemical bonds.

Keywords: Chemical Bonding; Critical Thinking; E-Worksheets; Three-Dimensional Thinking Graph.

Introduction

Chemistry plays a crucial role in developing students' scientific understanding and higher-order thinking skills, particularly critical thinking. However, learning chemistry remains challenging, especially in abstract topics such as chemical bonding, which often leads to misconceptions and low levels of critical thinking. Previous studies indicate that students still face difficulties in analyzing and evaluating chemical concepts, particularly when learning is dominated by conventional methods that do not actively engage students in the learning process [1], [2]. These challenges highlight the need for more effective and student-centered learning approaches.

In the context of 21st-century education, the integration of innovative, technology-based learning media has become essential for facilitating meaningful learning. Various digital learning tools, such as virtual reality and interactive electronic student worksheets (student worksheet), have been developed to enhance students' engagement and understanding of abstract concepts [3], [4]. Among these, the student worksheet is recognized as an effective medium that supports active learning and promotes higher-order thinking skills, especially critical thinking [5], [6]. Furthermore, the integration of student worksheets with appropriate instructional models, such as Problem-Based Learning (PBL), has been proven to improve students' problem-solving abilities and learning outcomes [7], [8], [4], [9].

In addition to learning models, the use of visual and structured thinking tools is important for supporting students' reasoning processes. Multidimensional thinking diagrams have been shown to enhance students' scientific literacy, inquiry skills, and ability to organize information systematically [10], [11]. This is closely related to the development of critical thinking skills, which are considered essential competencies in modern education [12], [13]. In chemistry learning, particularly in chemical bonding, students often struggle to connect macroscopic, submicroscopic, and symbolic representations, which further emphasizes the need for structured learning support [14], [15].

One promising approach to addressing these challenges is the Three-Dimensional Thinking Graph (TDTG). TDTG integrates concept mapping, data representation, and reasoning processes into a unified visual framework, enabling students to connect knowledge, analyze data, and construct logical arguments [16]. Previous studies have demonstrated that TDTG-based learning materials are effective in supporting students' critical and scientific reasoning skills [1], [17], [18]. Moreover, the development of a student worksheet based on TDTG has been shown to be valid, practical, and effective in enhancing students' reasoning abilities [1].

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Despite these promising findings, most previous studies have focused on general science topics at the junior high school level, with limited application in specific and abstract chemistry materials such as chemical bonding in senior high school. Additionally, although student worksheet and TDTG have been widely studied, their integration in a single learning medium specifically designed to improve students' critical thinking skills remains underexplored. Previous research also emphasizes that the development of student worksheet should be preceded by a needs analysis to ensure its relevance to students' learning needs [13].

Recent studies have highlighted the importance of innovative and interactive learning media in support students' engagement and conceptual understanding in chemistry learning. Game-based learning media, particularly board game–based learning in chemical bonding, can create interactive learning environments that support meaningful knowledge construction and increase student participation in the learning process [19]. Similarly, the use of interactive PowerPoint-based learning media has been shown to enhance students' chemical literacy by presenting abstract concepts in a more visual, structured, and accessible manner [20]. These findings indicate that integrating appropriate digital learning media plays an important role in facilitating meaningful learning experiences and supporting higher-order thinking skills.

In addition, electronic student worksheets have been widely recognized as effective digital learning media capable of promoting active learning and critical thinking skills [5], [6]. The integration of electronic student worksheets with Problem-Based Learning (PBL) has also been reported to improve students' problem-solving abilities, creativity, and learning outcomes through meaningful and student-centered learning activities [4], [7]–[9]. Furthermore, the use of structured thinking tools such as the Three Dimensional Thinking Graph (TDTG) enables students to connect concepts, organize information systematically, analyze data, and construct logical arguments effectively [16]. Previous studies have demonstrated that TDTG-based learning materials can support students' critical reasoning and scientific reasoning skills [1], [17], [18].

Critical thinking is considered one of the essential competencies in chemistry education because it enables students to analyze, evaluate, and construct scientific arguments effectively [12], [21]. However, students' critical thinking skills in chemistry are still relatively low and require support from innovative instructional strategies and well-designed learning media [21]. In chemical bonding learning, students often experience difficulties in understanding abstract concepts and connecting macroscopic, submicroscopic, and symbolic representations [14], [15]. Therefore, integrating technology-based learning media, such as electronic student worksheets, combined with structured thinking tools like TDTG and Problem-Based Learning, is a relevant approach to support meaningful learning and facilitate students' critical thinking skills in chemistry.

Therefore, this study aims to develop a student worksheet based on the Three-Dimensional Thinking Graph (TDTG) for the chemical bonding material and to analyse its feasibility in supporting students' critical thinking skills. This research is expected to contribute to the development of innovative digital learning materials and provide an effective solution for enhancing students' critical thinking in chemistry. Furthermore, the findings of this study are expected to serve as a reference for future research on the development of technology-based learning media integrated with higher-order thinking skills.

Research Methods

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation [22].

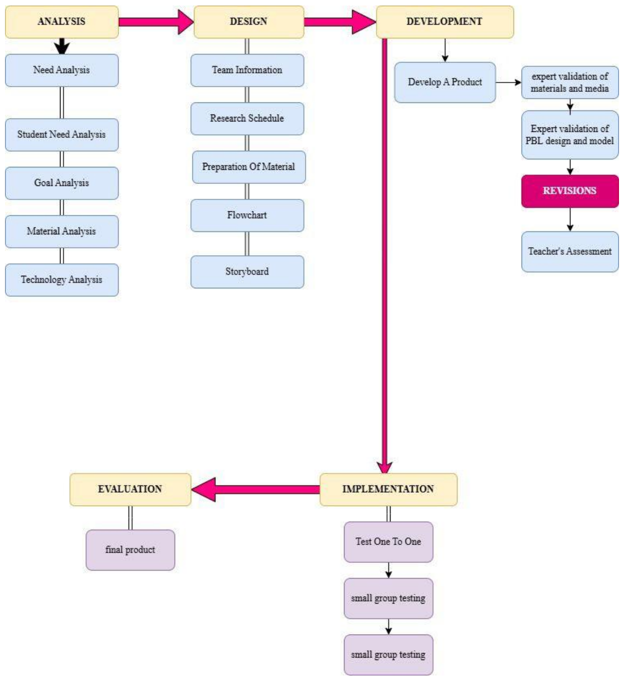

Figure 1. Electronic Student Worksheet Development Procedures

Analysis

A needs assessment was conducted to identify learning problems, students' characteristics, and the availability of learning media. Data were collected through interviews with teachers and questionnaires distributed to students at SMAN 11 Muaro Jambi. The data obtained were then analyzed to serve as the basis for developing appropriate and relevant learning media.

Design

The student worksheet was systematically planned, including the formulation of learning objectives, the preparation of materials on chemical bonding, and the design of learning activities based on the Three-Dimensional Thinking Graph (TDTG). The design also incorporated Problem-Based Learning (PBL) syntax to support students' critical thinking processes. Furthermore, research instruments such as validation sheets and response questionnaires were prepared.

Development

The product was developed using the Canva and Liveworksheet platforms. The validators involved in this study consisted of two material and media experts and one instructional design and Problem-Based Learning (PBL) expert. The selection of validators was based on their expertise, academic background, and experience in chemistry education, instructional media development, and learning model implementation. In addition, the chemistry teacher who assessed the product had experience teaching chemical bonding material at the senior high school level.

The research instruments used in this study included interview guidelines, needs analysis questionnaires, validation sheets, teacher assessment sheets, and student response questionnaires. Instrument validity was established through expert judgment conducted by material, media, and instructional design experts to ensure the appropriateness and relevance of each assessment indicator. Meanwhile, the reliability of the instruments was supported by the consistency of the assessment criteria and indicators developed in line with the research objectives and product feasibility.

The data analysis techniques used in this study consisted of qualitative and quantitative analyzes. Qualitative data, in the form of comments and suggestions from experts and users, were analyzed descriptively to improve the product. Meanwhile, quantitative data obtained from the validation sheet, teacher assessments, and student response questionnaires were analyzed using percentage calculations. This stage aimed to assess the practicality of the developed electronic student worksheets and students' responses to them. The results were then interpreted against predetermined feasibility criteria to assess the product's feasibility level. To calculate the percentage of student responses, the feasibility percentage was used using the formula:

$$K = \frac{F}{N \times I \times R} \times 100\%$$

The feasibility percentage (K) was determined based on the total number of responses received. In this formula, F denotes the total score across all respondents' answers, N denotes the maximum possible score for each questionnaire item, I denotes the number of items in the questionnaire, and R denotes the total number of respondents. These variables were used to calculate and interpret the overall feasibility level of the developed product.

Table 1. Student Response Questionnaire Assessment Criteria

No.	Score Range (%)	Criteria
1	>81 – 100	Very Good
2	>61 – 80	Good
3	>41 – 60	Fair
4	>21 – 40	Poor
5	0 – 20	Very Poor

Implementation

The sampling technique used in this study was purposive sampling based on the recommendations of the chemistry teacher at SMAN 11 Muaro Jambi. The subjects involved in the implementation stage consisted of students from class XII F1B. The one-to-one trial involved three students representing high, medium, and low academic abilities to identify initial usability issues and students' understanding of the developed electronic student worksheet. Meanwhile, the small-group trial involved 10 students to evaluate the practicality, readability, and students' responses toward the product during the learning process.

The selection of trial subjects was based on students' academic abilities and their participation in chemistry learning activities. This was intended to elicit diverse responses and to ensure that the developed electronic student worksheet could be used effectively by students with varying levels of understanding and learning abilities.

This stage aimed to determine the level of practicality and their response to the developed electronic student worksheet. During this stage, students used the electronic student worksheet in learning activities, and data were collected through a response questionnaire to measure user acceptance and product practicality. In addition, the collected data were used to evaluate the quality of the developed electronic student worksheet, and the results became the basis for revising and supporting the product.

Evaluation

The evaluation phase was conducted in both formative and summative ways. Formative evaluation was conducted at each development stage through expert validation and product revision, while summative evaluation was conducted based on teacher assessment results and student responses to the product. The research instruments used included interview guidelines, a student needs questionnaire, an expert validation sheet, a teacher assessment sheet, and a student response questionnaire. Instrument validity was established through expert validation prior to use in the research. Instrument reliability was assessed by examining the consistency of assessment indicators developed to align with the research objectives and product feasibility.

Results and Discussion

Analysis

The analysis stage was conducted through interviews with chemistry teachers and the distribution of needs-analysis questionnaires to students in class XII F1B at SMAN 11 Muaro Jambi. This stage aimed to collect data on the problems students face during the learning process and the challenges teachers encounter in teaching. The collected data were analyzed based on several aspects, including learning needs, students' characteristics, learning objectives, subject matter, and educational technology.

Needs Analysis

Based on interviews with the chemistry teacher, the learning process primarily relied on textbooks and direct practical activities. However, these learning resources were considered insufficient for facilitating students' critical thinking skills, as many students still had difficulty understanding chemical bonding concepts. This was mainly due to the limited depth of the material and the lack of visualization of abstract concepts. In addition, students had difficulty distinguishing among types of chemical bonds, and the teacher had not previously used a student worksheet during instruction.

The results of the student questionnaire further supported these findings. Approximately 55% of students reported difficulty understanding the material on chemical bonding due to limited learning resources. Meanwhile, around 80% of students expressed interest in more interactive learning media that include videos, images, and three-dimensional thinking graphs to support their understanding. Therefore, it can be concluded that students need interactive electronic teaching materials that integrate various media to support their critical thinking skills. Using a student worksheet is an appropriate alternative for supporting independent and meaningful learning.

Students' Characteristics Analysis

The product developed in this study was intended for students of class XII F1B at SMAN 11 Muaro Jambi. Based on the questionnaire results, smartphone use was not permitted during the learning process. However, the school provided computers to support learning activities. This condition indicates a strong potential to implement digital learning media, such as student worksheets, especially since they have not been used previously in learning chemical bonding.

Learning Objectives Analysis

The analysis of learning objectives was conducted in accordance with the Merdeka Curriculum. The learning outcomes indicate that students are expected to analyze the tendency of atoms to achieve stability as the basis for ionic and covalent bonding and to represent Lewis structures by integrating macroscopic, submicroscopic, and symbolic representations through the Three-Dimensional Thinking Graph (TDTG). Furthermore, the specific learning objectives include students' ability to analyze atomic stability, explain the formation of chemical bonds, represent Lewis structures, and integrate multiple representations logically and critically.

Material Analysis

The material analysis was conducted by considering the difficulties students experienced in learning chemical bonding. The results showed that many students had not yet achieved the minimum learning criteria (KKTP). This was due to the use of less engaging teaching materials, mainly textbooks. As a result, students perceived the material as difficult and uninteresting. Chemical bonding material involves complex and abstract concepts, such as atomic stability, types of chemical bonds, and Lewis structures, which require a deeper understanding and visualization. Therefore, the material was designed and organized as an interactive student worksheet, integrated with the Three-Dimensional Thinking Graph, to facilitate students' understanding and promote critical thinking through discussion and exploration.

Educational Technology Analysis

Based on direct observations at SMAN 11 Muaro Jambi, the school facilities were found to be adequate to support the learning process, including the availability of computers, projectors, and internet access. These facilities indicate that there are no significant obstacles to implementing digital learning media. Therefore, developing a student worksheet as a technology-based teaching material is highly feasible and supported by the existing infrastructure.

Design

At the design stage, the structure of the student worksheet was developed by integrating the Three-Dimensional Thinking Graph (TDTG) approach. The student worksheet consisted of several components, including learning objectives, instructional materials, learning activities, and evaluation tasks. The learning activities were designed using Problem-Based Learning (PBL) principles to encourage active student participation and critical thinking. The TDTG components, such as concept maps, data tables, and reasoning maps, were systematically embedded in each activity to help students organize information, analyze relationships, and construct logical reasoning. In addition, research instruments, such as validation sheets and response questionnaires, were designed at this stage.

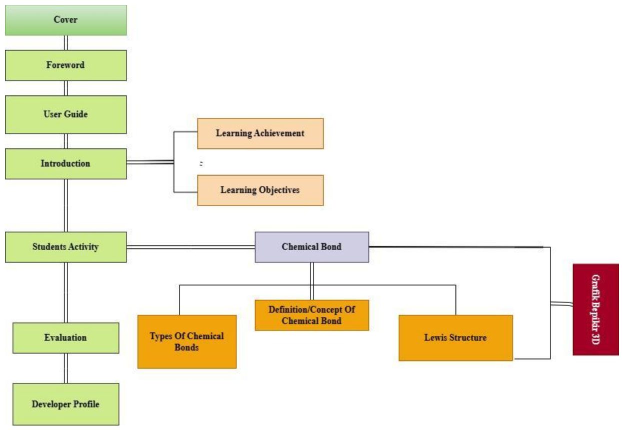

Figure 2. Three-Dimensional Thinking Graph-Based Electronic Student Worksheet Flowchart

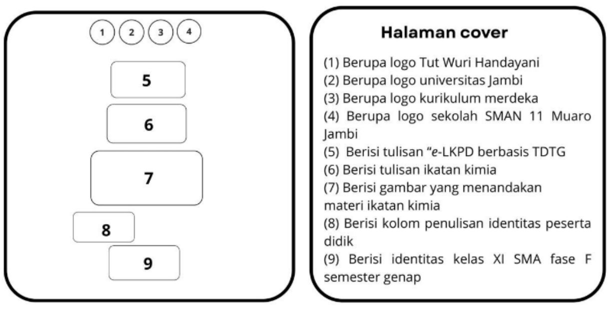

Figure 3. Electronic Student Worksheet Cover Page Storyboard

Figure 2. Electronic Student Worksheet Product Cover

The storyboard was developed based on the formulated flowchart. It involved collecting relevant materials such as images and videos, preparing instructional text, selecting appropriate animations, and organizing content from reference sources for the student worksheet. The storyboard served as a guideline for developing the product.

Development

In the development stage, the student worksheet was created using Canva and Liveworksheet platforms. The product was then validated by experts to determine its feasibility. The validation results showed that the student worksheet obtained a score of 92% from material and media experts, categorized as very feasible. Meanwhile, validation from learning design and PBL experts reached 88.57%, also categorized as very feasible. In addition, the teacher's assessment indicated a score of 91%, which falls into the very good category. This result shows that the developed student worksheet is appropriate and applicable for classroom use. These results indicate that the developed student worksheet meets the criteria of validity in terms of content, design, and instructional aspects. Revisions were made based on expert suggestions to improve the product's quality, particularly the clarity of instructions, visual design, and the alignment between activities and learning objectives.

Implementation

The implementation stage was conducted through limited trials to determine the practicality and user response to the developed student worksheet. The trials included one-to-one and small group trials involving students. Student responses reached 86%, also categorized as very good, showing that students found the student worksheet interesting, interactive, and helpful in understanding chemical bonding concepts.

During the implementation stage, students actively participated in learning activities using the electronic student worksheet. Students were able to complete concept maps, data tables, and reasoning maps integrated within the Three-Dimensional Thinking Graph (TDTG). The interactive features, such as videos, visual representations, and Liveworksheet-based activities, helped students understand abstract chemical bonding concepts more easily. In addition, students showed enthusiasm and engagement during discussions and problem-solving activities. These findings indicate that the developed electronic student worksheet has the potential to support meaningful and student-centered learning.

Figure 5. Small Group Trial

Table 2. Student Response Results

No.	Respondents										Score
	1	2	3	4	5	6	7	8	9	10	
1	4	5	4	4	4	4	4	4	4	4	41
2	4	4	5	4	4	4	4	4	4	5	42
3	4	5	4	4	4	5	5	5	4	4	44
4	5	5	4	4	4	5	4	4	4	4	43
5	5	5	4	4	4	5	4	5	4	5	45
6	4	4	5	5	4	4	4	5	4	4	44
7	4	4	4	4	4	4	4	4	4	4	40
8	4	5	4	4	5	4	4	4	4	4	42
9	4	5	4	5	4	4	5	4	5	5	45
10	4	5	5	4	4	4	4	5	4	4	43
11	4	4	4	4	5	4	4	4	4	5	42
12	4	5	4	4	5	5	5	4	5	4	45
13	4	4	4	5	4	4	4	5	4	4	40
14	3	4	3	5	4	4	4	5	4	5	41
15	5	5	5	4	4	4	5	4	5	4	45
16	4	5	4	4	5	5	4	5	4	4	44
17	4	4	4	4	4	5	4	4	5	5	43
18	5	4	4	4	5	4	4	5	4	5	45
19	4	5	4	4	4	4	4	4	5	4	42
20	4	5	4	5	5	4	4	5	4	4	44
21	4	5	5	5	5	4	4	5	4	5	46
22	5	5	4	5	4	5	4	4	4	5	45
23	4	5	4	4	5	5	5	5	5	5	47
24	4	5	4	4	4	4	4	4	4	4	41
25	4	5	5	5	4	4	4	5	5	4	45
Total Score											1075
Percentages											86%
category											Very Good

These findings are consistent with the principles of Problem-Based Learning (PBL), which emphasize active learning, problem-solving, and the development of higher-order thinking skills through meaningful contexts [23]. The positive student responses indicate that integrating PBL into the student worksheet successfully facilitated student engagement and encouraged critical thinking. In line with cognitive and constructivist learning theories, learning becomes more effective when students actively construct knowledge through experience and interaction [24], [25]. Furthermore, the use of visual elements such as images, videos, and three-dimensional representations supports the dual coding theory, which suggests that combining verbal and visual information can enhance understanding and memory retention.

The integration of the Three-Dimensional Thinking Graph (TDTG) also plays a significant role in supporting students' reasoning. TDTG helps students connect macroscopic, submicroscopic, and symbolic representations, which are essential in understanding complex scientific concepts such as chemical bonding [16]. This finding is supported by previous studies, which reported that TDTG-based learning materials can support students' critical reasoning and conceptual understanding [1], [17].

Compared to previous studies, the novelty of this research lies in integrating TDTG into an interactive student worksheet and combining it with a PBL approach using digital platforms such as Canva and Liveworksheet. This combination not only enhances visualization but also provides interactive learning experiences that are aligned with 21st-century learning demands. Therefore, the developed student worksheet offers a more comprehensive learning solution by integrating pedagogy, technology, and content to effectively support students' critical thinking skills.

Evaluation

The evaluation stage involved both formative and summative evaluation processes. Formative evaluation was conducted throughout each stage of development, particularly during expert validation and product revision. Summative evaluation was conducted based on teacher assessments and student responses. The overall findings indicate that the developed student worksheet is highly feasible and has strong potential to support students' critical thinking skills. The integration of TDTG within the student worksheet provides a structured approach that supports students in connecting concepts, analyzing data, and developing reasoning skills. These findings are consistent with previous studies, which highlight that the use of visual and interactive learning media can significantly support students' critical thinking abilities.

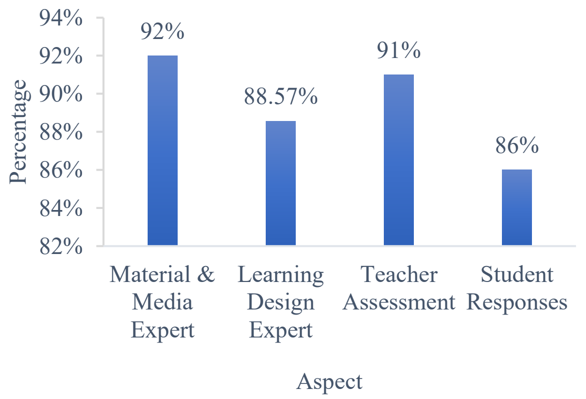

Figure 6. Validation and Response Results of the Developed Electronic Student Worksheet

The results of this study indicate that the developed student worksheet based on the Three-Dimensional Thinking Graph (TDTG) is feasible and effective in supporting students' critical thinking skills on chemical bonding material. This finding is consistent with previous studies that reported the effectiveness of student worksheets in promoting active learning and higher-order thinking skills [5], [6]. In particular, the integration of Problem-Based Learning (PBL) within student worksheets has been shown to enhance students' problem-solving abilities and learning outcomes [7], [8], [4], [9]. Compared with those studies, the present research extends prior work by incorporating TDTG as a structured thinking tool that not only facilitates problem-solving but also supports deeper reasoning.

Furthermore, the findings align with studies on the application of the Three-Dimensional Thinking Graph (TDTG), which demonstrate its effectiveness in supporting students' critical and scientific reasoning skills [1], [17], [18]. However, while previous research mainly focused on general science topics at the junior high school level, this study specifically applies TDTG in chemical bonding material at the senior high school level. This difference highlights the contribution of this study in addressing more abstract and complex chemistry content, where students often struggle to connect macroscopic, submicroscopic, and symbolic representations [14], [15].

The observed support for students' critical thinking skills in this study can be explained by several factors. First, the use of TDTG provides a visual and structured framework that helps students organize information, analyze relationships, and construct logical arguments. This is consistent with findings that multidimensional thinking diagrams can enhance students' ability to process information and support inquiry-based learning [10], [11]. Second, the integration of student worksheets with interactive features encourages students to actively engage in the learning process, which is essential for developing higher-order thinking skills [5]. Third, the implementation of PBL allows students to learn through real-world problem contexts, thereby stimulating critical thinking and meaningful learning [7], [25-27].

From a theoretical perspective, the results of this study can be explained through constructivist learning theory, which emphasizes that knowledge is actively constructed by learners through interaction and experience [28]. The use of student worksheets, combined with TDTG and PBL, provides opportunities for students to explore concepts, discuss ideas, and reflect on their understanding, thereby supporting the construction of meaningful knowledge. In addition, cognitive learning theory also supports these findings, as structured visual representations such as TDTG can facilitate information processing and support students' understanding of complex concepts [24].

Moreover, the findings are also supported by previous research on innovative learning media, which shows that interactive and engaging media can significantly enhance students' motivation and conceptual understanding [3], [29]. Similarly, game-based and technology-supported learning environments have been proven to create more interactive learning experiences and support students' engagement, which ultimately contributes to better learning outcomes [19].

However, this study was limited to product development and feasibility testing through one-to-one and small-group trials. The effectiveness of the developed electronic student worksheet in improving students' critical thinking skills was not directly measured through experimental methods such as a pretest-posttest design. This limitation was due to time constraints and the scope limitations of undergraduate-level research, which focused primarily on product development and limited implementation trials. Therefore, further studies with larger sample sizes and experimental designs are recommended to quantitatively assess the effectiveness of the developed electronic student worksheet in supporting and improving students' critical thinking skills in chemistry learning.

Overall, the findings of this study confirm that integrating TDTG into student worksheets provides a comprehensive learning approach that combines visual representation, problem-solving, and active learning. This combination not only supports students' critical thinking skills but also addresses the challenges of learning abstract chemistry concepts. Therefore, this study contributes to the development of innovative and effective instructional media in chemistry education.

Conclusion

This study developed an interactive electronic student worksheet on chemical bonding, based on the Three-Dimensional Thinking Graph (TDTG), using the ADDIE model through the stages of analysis, design, development, implementation, and evaluation. The developed electronic student worksheet was categorized as very feasible based on expert validation, teacher assessments, and student responses, indicating that the product is practical and suitable for classroom use. The integration of TDTG, Problem-Based Learning (PBL), and interactive digital features within the electronic student worksheet supports meaningful and student-centered learning activities. The developed product also has the potential to support students' critical thinking by helping them understand abstract chemical bonding concepts through visual representations, concept maps, data tables, and reasoning maps integrated into the learning process. The novelty of this study lies in integrating TDTG, Problem-Based Learning, and interactive electronic student worksheets into a single digital learning medium specifically designed for chemical bonding instruction at the senior high school level. Therefore, this study contributes to the development of innovative chemistry learning media that support 21st-century learning and higher-order thinking skills.

Author's Contribution

N. Dinati: responsible for conceptualization, methodology, investigation, data curation, formal analysis, product development, and writing the original draft. Afida and Asmiyunda: contributed to supervision, validation, and review of the manuscript. Kriswantoro: contributed to validation as a material and media expert. F. Romundza: contributed to validation as a learning design and Problem-Based Learning (PBL) expert. All authors have read and approved the final manuscript.

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