



Development of a Differentiated Learning-Based Chemical Bonding Teaching Module to Enhance Scientific Argumentation Skills

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Abstract

This study aimed to develop a differentiated teaching module to enhance students' scientific argumentation skills on chemical bonding material. The method used was Research and Development (R&D) with the 4D model (Define, Design, Develop, Disseminate). Validation results from experts showed that the developed differentiated teaching module was highly valid (92% and 94%), very practical (100% and 97%), and effective, with more than 80% of students achieving the minimum competency standard (KKM) and an average score of 88. The improvement in scientific argumentation skills was reflected in the average pre-test score of 64, which increased to 80 in the post-test. Specifically, the indicators of scientific argumentation showed improvement: claims increased from 62.9% to 75.4%, data from 66.3% to 84%, warrants from 67.8% to 82.1%, and backings from 68.4% to 79.4%. The increase in scientific argumentation scores from pre-test to post-test indicates that the developed teaching module was effective in helping students hone their argumentative skills. However, the ability to formulate claims and backings still requires reinforcement, as they demand a more complex understanding. Nevertheless, this improvement suggests that the differentiated teaching module created and implemented can strengthen students' scientific argumentation skills in understanding chemical bonding material, making it recommended for broader application, especially in science education.

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1. INTRODUCTION

Conventional teaching methods often failed to accommodate individual differences in students' learning characteristics. These approaches typically applied a uniform strategy to each lesson without considering variations in learning pace, preferred learning styles, or students' interests. As a result, students who had difficulty understanding the material tended to fall behind, whereas others became disengaged due to boredom. Rahmawati *et al.* (2024) reported that this one-size-fits-all approach

could reduce students' engagement and participation in the learning process. Conventional learning models had been used for a long time and were often perpetuated across generations. Accordingly, these approaches were frequently labeled as "traditional" because they tended not to incorporate contemporary strategies that positioned learners as active agents in constructing knowledge rather than as passive recipients of information.

Each student inevitably had a different starting level of ability, which was often linked to their mastery of the foundational knowledge required to follow the lessons (Rahmadani & Manullang, 2024). Differentiated learning accommodated, supported, and acknowledged students' diverse learning needs based on their readiness, interests, and learning preferences. Differentiated learning was defined as an approach that took into account variations in students' abilities (Wulandari, 2022). It emphasized diversity-based strategies that helped students meet their learning needs through key dimensions such as readiness, interest, and learning profiles (Meilina *et al.*, 2024).

The teaching and learning process, including the selection and implementation of appropriate instructional approaches, helped students understand and internalize the material presented by the teacher. Through learning assessments, students were expected to comprehend and master the subject matter so that they could apply it in real-life situations. Learning became more effective when instructional activities were aligned with children's intellectual development (Semiawan, 1990).

Every individual has characteristics that differ from others. Cognitive development theory suggests that different learning styles correspond to cognitive development levels. Heterogeneity in the classroom is a given; students possess varying abilities in terms of emotion, intelligence, social skills, academics, parental background, and other capabilities. These diverse characteristics and abilities require teachers to think creatively and provide learning activities that cater to the interests and development of each student (Asril, 2024).

Differentiated modules had the potential to support students' argumentation skills by increasing active participation, fostering interest in the content, and providing opportunities to discuss ideas and construct arguments (Liou *et al.*, 2023). The integration of adaptive technologies, such as AI, that provided different learning pathways based on students' needs further strengthened their ability to develop scientific arguments, including the effective use of evidence and reasoning (Agusta *et al.*, 2024).

High validity indicated that explicitly designed modules that included argumentation components at varying levels of difficulty could be effective. Such modules needed to incorporate all key structural

components and remain sufficiently flexible to accommodate individual learning needs (Nuzulah *et al.*, 2023). Differentiated instruction helped prevent knowledge gaps and supported the development of students' abilities and interests. Accordingly, the implementation of modules with content tailored to students' readiness, interests, and learning styles was crucial for encouraging them to construct scientific arguments while maintaining their knowledge base and motivation (Goyibova *et al.*, 2025).

Chemical bonding is a foundational topic in chemistry that often requires students to integrate abstract concepts, symbolic representations, and reasoning based on evidence. In this context, recent journal references indicated that developing a differentiated teaching module for chemical bonding material was not only innovative but also supported by strong empirical evidence. Therefore, the development of a differentiated learning-based chemical bonding teaching module was expected to make a meaningful contribution to enhancing students' scientific argumentation skills, strengthening their conceptual understanding of chemical bonding, and increasing their overall engagement in chemistry learning.

2. METHODS

This study was conducted at SMA Negeri 1 Asparaga, Bululi Village, Asparaga District, Gorontalo Regency, Gorontalo Province. The implementation period was from July to September 2024.

The research approach used combined both qualitative and quantitative approaches. The research approach that aimed to integrate both of these research methods was the Research and Development (R&D) approach. The R&D approach was used because it aligned with the goals of this study. According to (Sugiyono, 2013), this method is used to produce specific products through research that involves needs analysis (using survey or qualitative methods), and to test the effectiveness of the product so that it can function widely in society, experimental/quantitative methods are needed to test the product's effectiveness.

The research method used in this study was the development research method, focusing on the development of a differentiated teaching module. The development model used in this study was the 4D model. The use of the R&D research method with the 4D model

was chosen because it is easier to apply in learning models.

The rationale for choosing the 4D model is that each step of the development procedure is explained in detail, outlining what the researcher will do when developing products such as teaching materials, books, or other educational materials. The 4D model consists of four stages: Define, Design, Develop, and Disseminate (Sugiyono, 2013).

A literature review by I Indaryanti et al. (2025) on the application of the 4D model concluded that this model is commonly used in the development of educational materials (modules, student books, worksheets) due to its ability to integrate educational needs analysis with product evaluation procedures (validity, practicality, effectiveness). In other words, the 4D model provides an appropriate R&D framework when the research objective is to produce a module or worksheet that is proven to be effective.

The ultimate goal of this study was to produce a differentiated chemical bonding teaching module that could enhance students' scientific argumentation skills in learning.

3. RESULTS AND DISCUSSION

This study aimed to develop a differentiated teaching module on chemical bonding material that could improve students' scientific argumentation skills. The development model used was the 4D model (Define, Design, Develop, Disseminate). The research was conducted at SMA Negeri 1 Asparaga, Gorontalo Regency, in the chemistry-specialized class (Grade XI). The sample for the research trial was Grade XI students who were interested in chemistry, with a heterogeneous academic background. The module was designed to meet the needs of students with varying abilities and learning interests in the classroom. The following are the stages of development:

1. Define

This stage aimed to establish and define the criteria necessary for the learning process. Several activities were conducted during the definition phase: Task Analysis: This focused on how to adjust instructions and materials to meet the diverse needs of students with varying levels of ability, learning styles, and interests. Concept Analysis: The concept analysis conducted during the development of the teaching

module was to understand the aspects to be incorporated into the module to ensure that it would be effective in the knowledge transfer process in a structured and easily understandable manner.

Learning Objectives Analysis: Differentiated learning focuses on adjusting various aspects of teaching to create experiences that match students' diversity. The analysis of learning objectives focused on how to design objectives that accommodate this diversity. Key aspects analyzed included flexible and structured learning objectives, aligning the goals with the students' abilities, with the primary focus being to enhance scientific argumentation skills.

2. Design

The design phase involved creating a framework for the module, which included the principles of content, process, and product differentiation. In terms of content, the material was structured into three levels: basic concepts (ionic, covalent, and metallic bonds), intermediate concepts (formation of ionic, covalent, and metallic bonds), and advanced concepts (applications of chemical bonds in everyday life). Each level was tailored to students' abilities, allowing for flexibility in selecting appropriate content. The learning process was designed in various formats such as simple experiments, digital simulations, group discussions, and case studies. Regarding the product, students had the freedom to choose their final tasks, such as argumentative essays, visual presentations, and audiovisual presentations, all of which required scientific argumentation skills.

3. Develop

The develop stage involved validating the module by content, pedagogical, and media experts. The content expert validation showed that the module content was aligned with the curriculum standards and relevant for teaching chemical bonding. The pedagogical validation confirmed that the module adopted an innovative approach, supported active learning, and was easy to implement.

The validation was carried out by two lecturers from the Chemistry Education Master's Program at Universitas Negeri Gorontalo. After receiving suggestions and feedback from the validators, the researcher made revisions and resubmitted the module for validation. The revised module, based on the suggestions from the experts, was deemed ready for use.

The product validation results showed that the module received a validity score of 92% (V1) and 94% (V2), indicating that the module was highly valid according to the interpretation criteria, as the ratings from both validators were above 80% ($80 < P \leq 100$).

The practicality analysis, based on the feedback from the teacher observers and the percentage obtained during the dissemination phase, showed scores of 100% (V1) and 97% (V2), indicating that the module was highly practical according to the interpretation criteria, as the ratings exceeded 76%.

The effectiveness of the module was evaluated based on the average scores of students and their achievement of the Minimum Competency Criteria (KKM) in the chemical bonding material. The average score was 88, with more than 80% of students achieving the KKM. According to the effectiveness criteria, a teaching module is considered very effective if more than 80% of students meet the learning completion criteria ($P > 80$), indicating that the module was effective in helping students achieve the target competencies.

The validation of the scientific argumentation instrument, reviewed by two validators, showed that the instrument was categorized as "Eligible with Revisions" (LDP). This means that the instrument generally met the criteria for measuring students' scientific argumentation skills but still required some refinement for optimal use.

4. Disseminate

The final stage, Disseminate, involved creating a manual for using the module as a guide for teachers. The manual included steps for implementing the module in the classroom, strategies for adapting the module to various needs, and a rubric for assessing scientific argumentation.

The module not only improved students' scientific argumentation skills but also enhanced their motivation to learn. Students felt more confident in presenting scientific arguments because the module provided clear, step-by-step guidance. Additionally, the flexibility in selecting activities and tasks allowed students to learn in a way that suited their individual styles and abilities.

The success of this module aligns with previous research, which showed that differentiated approaches can significantly improve learning outcomes. Furthermore, the development of scientific argumentation skills through this module is relevant to the demands of

21st-century learning, which emphasizes critical thinking and scientific communication. Therefore, this module represents a valuable contribution to the innovation of chemistry education, aligning with current educational needs.

The analysis of pre-test (Figure 1) and post-test (Figure 2) results demonstrated a significant improvement in students' scientific argumentation skills after the implementation of the differentiated learning-based teaching module. The pre-test average score for students' scientific argumentation skills was 64, which increased significantly after the post-test.

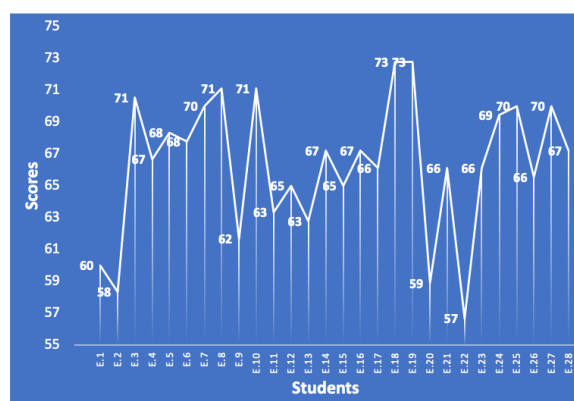


Figure 1. Pretest of scientific argumentation analysis

After the implementation of the teaching module, a significant improvement was observed in the students' average post-test score, which increased to 80. This indicates the effectiveness of the module in helping students develop their scientific argumentation skills.

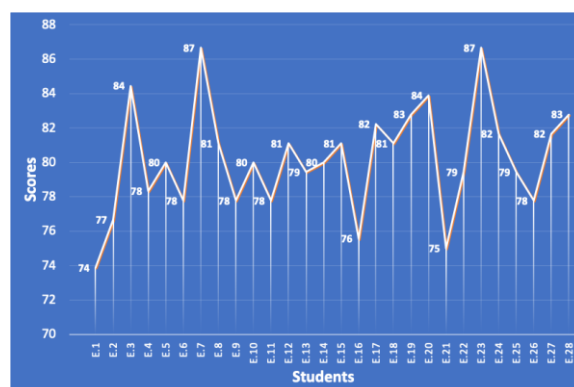


Figure 2. Posttest of scientific argumentation analysis

Further analysis of each indicator of scientific argumentation claims, data, warrants, and backings

revealed a significant improvement in students' ability to construct more structured and logical scientific arguments.

In the pre-test, students showed relatively low average scores across all indicators, with claims at 62.9%, data at 66.3%, warrants at 67.8%, and backing at 68.4%. These scores indicated that students were still at an early stage in developing their skills in constructing scientific arguments. The claims they made were often unclear or insufficiently supported, the data used to back up their claims was often irrelevant or poorly organized, and they were not yet able to connect claims with data through strong reasoning (warrants) or provide further support (backing) to strengthen their arguments.

The implementation of the differentiated teaching module, which was designed to accommodate students' learning styles and levels of understanding, led to a significant improvement in the post-test results. The score for claims increased to 75.4%, showing that students were now better able to formulate clear, precise, and understandable claims. This improvement reflected a stronger understanding of how to formulate statements or hypotheses that can be tested through scientific evidence. The score for data soared to 84%, indicating that students were now more skilled in finding, organizing, and using relevant data to support their claims. This demonstrated the success of the module in introducing concepts that helped students link scientific data to claims more accurately.

For the indicator of warrant, which measures students' ability to logically connect claims and data, the post-test score reached 82.1%, showing that students now had a better understanding of how to reason rationally and support claims with strong explanations. Finally, the score for backing increased to 79.4%, indicating that students were now able to provide additional support for their warrants by using evidence or references to strengthen their scientific arguments.

Supporting and inhibiting factors in the implementation of the model also provided insights into how the model could be improved. For example, to address time constraints, the module could be supplemented with brief guides or tutorial videos to help teachers understand and implement the learning steps more easily. Additionally, developing a digital application-based version of the module could provide a solution to overcome infrastructure limitations in some schools.

In terms of strengths and weaknesses, this analysis showed that while the model has great potential to improve the quality of education, a well-thought-out strategy is needed to address existing challenges. Continuous support from the government and educational institutions is also crucial to ensure the sustainability and broader dissemination of this model to more schools.

Integrating STEM approaches and problem-based learning significantly enhances students' understanding of chemical bonding. For example, the Chem-A Module, which presents problems through real-world scenarios, has proven effective in improving student comprehension and engagement (Bang). Additionally, a force-based teaching approach, grounded in quantum mechanical principles and Coulombic interactions, has helped students grasp complex concepts and improve their academic performance (Arvidsson, 2025). Incorporating multiple representations and ICT tools, such as augmented reality (AR) applications like QuimiAR, has further enhanced students' cognitive abilities and their understanding of chemical bonding processes (Hoai *et al.*, 2024). The integration of ICT with valence bond theory also simplifies complex ideas, making them more accessible to students (Stašević *et al.*, 2025).

Guided inquiry-based learning has also been shown to significantly improve learning outcomes, particularly in topics like chemical bonding, where student performance increased notably with this approach (Putra, 2021). In addition, incorporating local socio-scientific issues (SSI) has proven more effective than traditional methods in fostering high-quality scientific arguments (Saija *et al.*, 2023). To enhance scientific argumentation skills, electronic modules based on the ASICC learning model have shown to be both effective and valid, leading to significant improvements in students' argumentation abilities (Afifah *et al.*, 2023). Furthermore, interactive educational games like the Valence Bond© game, which combine scientific visualization with manipulation challenges, provide an engaging and effective tool for developing deeper understanding and argumentation skills (Lin *et al.*, 2015).

The development and implementation of a differentiated teaching module is indeed a complex process, yet it offers numerous significant benefits. First, this approach supports inclusive learning and is responsive to the diversity of students—differences in

learning readiness, interests, learning styles, and learning profiles—thus providing each student with a fairer opportunity to develop according to their capacity and needs (Asriadi et al., 2023). Second, through differentiation in content, process, product, and learning environment, the teaching module can be adjusted so that students remain actively engaged and have meaningful learning experiences (Gheysens et al., 2023). Empirical results show that the application of differentiated instruction (DI) improves student learning outcomes compared to traditional teaching models (Wicaksono et al., 2024).

Differentiated modules not only assist in academic aspects but also support students' social-emotional well-being and sense of inclusion, particularly in heterogeneous classrooms (Fitria, 2023). By enhancing motivation, self-confidence, and participation in learning, this module helps create a learning environment that supports students' holistic development (Suharti, 2023).

With appropriate improvements and adaptations including teacher training, contextual module development, and institutional support. This model has the potential to be implemented more widely. It can strengthen the quality of education and better prepare students with the scientific and cognitive skills necessary for the 21st century (Zahra, 2023).

4. CONCLUSION

Based on the research findings, the differentiated learning-based chemical bonding teaching module was proven to be highly valid, practical, and effective. Expert validation exceeded 90%, practicality reached over 97%, and effectiveness was demonstrated by more than 80% of students achieving the Minimum Competency Criteria (KKM) with an average score of 88. The improvement in scores from pre-test (64) to post-test (80) indicates that this module was effective in developing students' abilities to make claims, present data, use warrants, and support arguments with backing. Therefore, this teaching module has proven to be an innovative alternative in chemistry education to enhance both the quality of the learning process and student outcomes.

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