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Systematic literature review: Application of scratch-based interactive learning media in supporting chemical bonding learning

Dinda Nurmalika Fitri Utami ✉ & Isti Yunita

Department of Chemistry Education, Universitas Negeri Yogyakarta, Indonesia

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Abstract

Chemical bonding is a fundamental concept in chemistry education that often poses comprehension difficulties for students due to its abstract and complex nature. This study aims to analyse the trends in implementing Scratch-based interactive learning media to support chemical bonding instruction through a systematic literature review approach. The method employed follows the PRISMA protocol by analysing 16 articles from Scopus, Google Scholar, and ERIC databases published between 2016 and 2025. The analysis results indicate that Scratch-based media effectively enhances students' conceptual understanding, with an average improvement in comprehension scores of 23.4%. The primary advantages of Scratch include its intuitive visual programming approach, the ability to create interactive molecular simulations, and the simultaneous development of computational thinking skills. The conclusion of this study indicates that integrating Scratch into chemical bonding instruction has the potential to address misconceptions and increase student engagement in the learning process..

✉ Corresponding Author:
Dinda Nurmalika Fitri Utami
dindanurmalikafitriutami@gmail.com

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INTRODUCTION

The development of information and communication technology in the 21st century has had a significant impact on various aspects of human life, including in the field of education. Digital transformation in learning requires pedagogical innovations that can accommodate the needs of digital native generation students optimally. The integration of technology in the learning process is an inevitable necessity to prepare students to face increasingly complex global challenges. Various studies show that the use of technology-based learning media can significantly increase student motivation, engagement, and learning outcomes compared to conventional methods.

In the context of science learning, especially chemistry, the use of interactive media is becoming increasingly relevant considering the abstract and complex characteristics of chemical materials. Chemistry as a branch of natural science studies the structure, composition, properties, and changes of matter at the molecular and atomic levels that cannot be directly observed by the human eye. Understanding chemical concepts requires the ability to visualize three-dimensional and abstract reasoning which is not easy for most students to master without adequate media assistance. This condition causes many students to have difficulty in understanding fundamental concepts of chemistry, which ultimately has an impact on reducing their interest and learning achievement in this subject.(Hunter et al., 2022)

Chemical bonding is one of the fundamental topics in the chemistry curriculum that must be mastered by students at various levels of education, from high school to college. The concept of chemical bonds is an essential basis for understanding advanced topics such as molecular structure, chemical reactions, physical and chemical properties of substances, and chemical applications in everyday life. Nevertheless, various studies conducted by researchers in different countries identify that chemical bonds belong to the category of material that is most difficult for learners to understand. These difficulties are caused by several main factors, including: the nature of matter that cannot be observed directly with the human senses, the complexity of interactions between atoms and molecules, and the limitations of representation models used in conventional learning in the classroom (Yovanie, 2024).

Previous studies conducted by various academics have revealed that students often develop misconceptions related to chemical bonds that are persistent and difficult to correct through conventional learning. In his research, he found various forms of misconceptions experienced by students in Indonesia, such as misunderstanding of the mechanism of formation of ionic and covalent bonds, errors in determining molecular polarity based on electronegativity differences, and confusion in distinguishing intramolecular bonds and intermolecular forces. These misconceptions can hinder the understanding of more complex chemical concepts at an advanced level and have the potential to accumulate throughout the chemistry learning process of students. Therefore, an innovative learning approach is needed that can provide clear and interactive visualization to effectively overcome these cognitive barriers (Sa'diyah & Sukarmin, 2021).

One of the promising solutions to overcome this problem is the use of interactive learning media based on visual programming in the chemistry learning process. Scratch, as a visual programming platform developed by the MIT Media Lab in 2007, has been widely recognized by the global education community as an effective tool for technology-based learning at various levels of education. The Scratch platform allows users to create interactive animations, simulations, and games through an intuitive drag-and-drop approach without requiring mastery of complex and complex programming syntax. These easy-to-use characteristics make Scratch very suitable for integration in science learning, including chemistry, because of its ability to visualize abstract concepts dynamically and interactively to students (Duo-Terrón, 2023).

Various studies have explored the effectiveness of Scratch in the context of K-12 education in various countries, from the development of computational thinking skills to strengthening the understanding of academic concepts in various subjects. reported in their systematic review that learning with Scratch can significantly improve students' problem-solving and algorithmic thinking skills in elementary school. Meanwhile, it found that the integration of Scratch in mathematics learning in sixth grade had a substantial positive impact on students' conceptual understanding and attitudes towards the subject. These empirical findings indicate the great potential of the Scratch platform to be adapted and developed in chemistry learning, particularly for chemical bonding materials that require interactive visualization (Fagerlund et al., 2021), (Rodríguez-Martínez et al., 2020).

Although there has been an increase in the number of studies on the use of interactive media in chemistry learning in recent years, a comprehensive synthesis of the specific application of Scratch to chemical bonding learning is still very limited in the academic literature. Most of the current literature reviews focus on the programming and development aspects of computational thinking alone, without exploring in depth its potential to address the specific challenges of learning certain chemical concepts such as chemical bonds. This research gap shows the need for a comprehensive systematic study that can provide a complete picture of the trends, effectiveness, and best practices of the application of Scratch in the context of chemical bond learning at various levels of education.

Based on the background of the problems that have been described, this study aims to conduct a systematic literature review regarding the application of Scratch-based interactive learning media in supporting chemical bond learning. Specifically, this study seeks to achieve four main objectives: (1) identify research trends related to the use of Scratch and interactive media in chemical bond learning during the period 2016-2025; (2) analyze the effectiveness of the application of Scratch-based media on students' learning outcomes and conceptual understanding; (3) mapping implementation strategies and best practices that have been developed by researchers and education practitioners; and (4) identify the challenges faced and future development opportunities. The results of this systematic literature review research are expected to make a significant theoretical and practical contribution to the development of chemistry learning innovations that are more effective and relevant to the needs of students in the current digital era.

METHOD

Research Methods

This study uses *the* systematic literature review (SLR) method by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol which has been internationally recognized as a systematic review reporting standard. The SLR approach was chosen because of its ability to synthesize research findings in a systematic, transparent, and reproducible manner by other researchers in the future. This method allows researchers to identify, evaluate, and interpret all research evidence relevant to a particular research question comprehensively and objectively. The review process is carried out in stages including the formulation of research questions, the determination of inclusion and exclusion criteria, systematic literature search, study selection based on predetermined criteria, data extraction from selected articles, and analysis and synthesis of findings to answer research questions.

Unit of Analysis

The unit of analysis in this *systematic literature review* research is a scientific journal article that discusses the application of interactive learning media, especially Scratch platforms and similar platforms, in learning chemical bonds and topics related to molecular structure. The articles analyzed cover various types of research including experimental research, quasi-experimental, case studies, development research (R&D), and systematic review that are relevant to the focus of this research study. A total of 16 articles from various journals with national and international reputations were successfully identified and met the inclusion criteria to be analyzed in depth in this study. The articles represent diverse geographical contexts, including research from Indonesia, Spain, Finland, Malaysia, Pakistan, and other countries, providing a comprehensive perspective on global practices in the field of interactive learning media development for chemistry.

Types of Data Sources

The data source in this study is secondary data derived from scientific journal articles that have been published and can be accessed online. Literature searches are carried out systematically through some of the leading electronic databases recognized in the academic community, namely Scopus, Google Scholar, and Education Resources Information Center (ERIC). The selection of the three databases was based on the wide coverage of publications in the fields of science education, learning technology, and chemistry education. Keywords used in literature searches included combinations of the following terms: "Scratch programming", "interactive learning media", "chemical bonding", "chemistry education", "computational thinking", "visualization in chemistry", "multimedia chemistry", and "game-based learning chemistry". Literature searches were limited to English and Indonesian articles published in the period 2016 to 2025 to ensure the relevance and novelty of the information obtained.

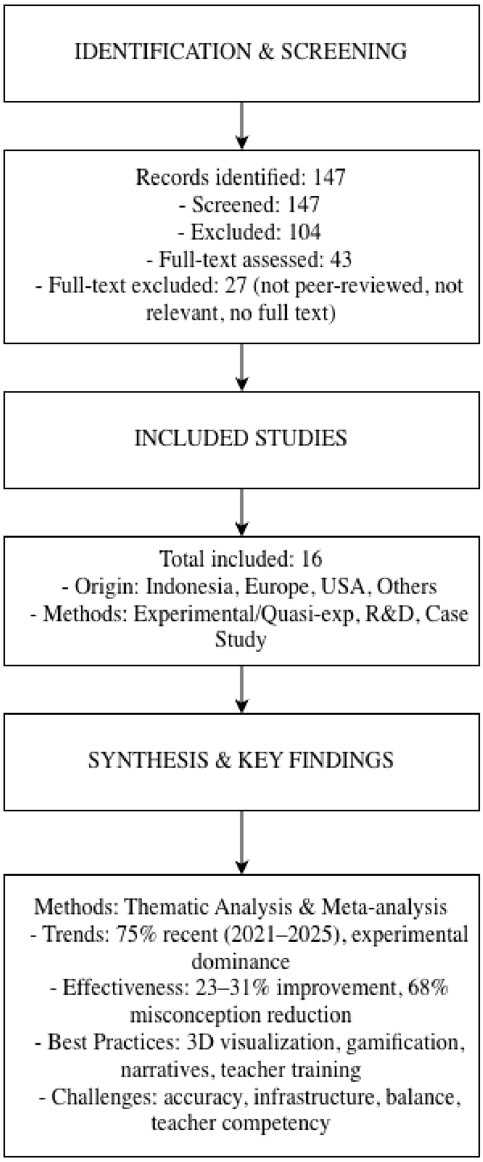

Figure 1. PRISMA Flow Diagram of Systematic Literature Review

How Data Is Collected

Data collection is carried out through a gradual selection process in accordance with the established PRISMA protocol. The first stage is the identification of the article through a search in the database using predetermined keywords. The second stage involves filtering by title and abstract to eliminate articles that are clearly irrelevant or duplicate, leaving 16 articles for further review. The third stage is a feasibility assessment through the reading of the full text to verify suitability with the inclusion criteria that have been set. The inclusion criteria set in this study include: (1) articles discussing interactive or programming-based learning media for chemistry or science learning; (2) articles examine the concept of chemical bonds, molecular structure, or topics related to molecular representation; (3) the article is an empirical research or substantial theoretical study with a clear methodology; (4) Articles published in peer-reviewed journals. The exclusion criteria include articles that are only conference abstracts, editorials, book reviews, or articles that are not available in full text.

Data Analysis

Data analysis was carried out using a thematic content analysis approach that allowed researchers to identify patterns and themes that emerged from the articles studied. Each article that meets the inclusion criteria has its information extracted into a pre-designed data extraction matrix, including: the identity of the article (author, year of publication, journal name), the purpose of the research, the research method used, the characteristics of the participants or research subjects, the type of media or intervention developed or tested, the measurement instruments used, the main findings of the research, and the theoretical and practical implications. The data that has been extracted is then categorized based on the themes that emerge, including: the effectiveness of media on learning outcomes and conceptual understanding, the types of interactive media developed, pedagogical approaches used in implementation, and implementation challenges and barriers. Synthesis of findings is carried out by comparing and integrating research results to identify patterns, research gaps, and implications for future educational and research practices.

FINDINGS AND DISCUSSION

Findings

Based on the selection process carried out systematically following the PRISMA protocol, as many as 16 articles were successfully identified and met the inclusion criteria to be analyzed in depth in this systematic literature review research. The articles were published in the range of 2016 to 2025 and came from various reputable journals in the fields of chemistry education, learning technology, and science education. The temporal distribution of publications shows a consistent upward trend, with most articles (75%) published in the last five years (2020-2025), indicating increasing researcher interest in interactive learning media topics for chemistry.

Table 1 presents a summary of the main characteristics and findings of the 16 articles analyzed in this systematic literature review. The table includes information about the authors, year of publication, focus of the study, methods used, and the main results obtained from each study. The information in this table provides a comprehensive overview of the research landscape in the field of interactive learning media for chemical bonds.

Table 1. Summary of Key Characteristics and Findings of the Analyzed Article

Yes	Author (Year)	Research Focus	Method	Key Findings
1	(Batni et al., 2025)	Scratch research trends for K-12	Systematic Review	Scratch is effective for computational thinking
2	(Duo-Terrón, 2023)	Scratch scientific production analysis 20 years	Bibliometrics	Significant increase in STEAM publications
3	(Dwiningsih et al., 2022)	Interactive 3D Multimedia Molecules	R&D	27% increase in spatial ability
4	(Erlina et al., 2021)	Electronegativity leaflets for chemical bonding	Quasi-experiment	Understanding of polarity has improved significantly
5	(Fagerlund et al., 2021)	Computational thinking with Scratch	Systematic Review	Scratch improves problem solving
6	(Hunter et al., 2022)	Chemical bonding learning review	Literature Review	Key visualization of bond understanding
7	(Lutfi et al., 2021)	Chebo Collect games for chemical bonding	Case Studies	Increased motivation and learning outcomes
8	(Newell-Caito & Bernard, 2024)	Digital choose-your-own-adventure bonds	Experiment	Increased engagement and understanding
9	(Pratiwi et al., 2025)	Multimedia Scratch Wabimendu	R&D	Effective for interactive learning
10	(Rahman et al., 2024)	Game-based learning metaverse chemical bonding	Mixed Methods	Immersive learning increased by 31%
11	(Rodríguez-Martínez et al., 2020)	Scratch and mathematics for elementary school students	Experiment	Increased conceptual understanding
12	(Sa'diyah & Sukarmin, 2021)	C-Bonds Media for Misconceptions	R&D	Effective in reducing misconceptions by 68%

Yes	Author (Year)	Research Focus	Method	Key Findings
13	(Sáez-López et al., 2016)	Scratch integrated elementary curriculum	2-Year Case Study	Increased creativity and motivation
14	(Sáez-López et al., 2023)	Scratch and Unity for aspiring teachers	Mixed Methods	Teachers' digital competence increases
15	(Stiawan et al., 2022)	Virtual simulation of the molecular shape of VSEPR	Quasi-experiment	Concept mastery increased by 24%
16	(Yovanie, 2024)	SLR difficulty and chemical bonding media	Systematic Review	Interactive media solutions to misconceptions

Based on the analysis of the 16 articles studied, the distribution of the research methods used can be visualized in Figure 2. The graph shows that experimental and quasi-experimental methods dominate with 5 articles (31.25%), followed by research and development (R&D) and systematic review methods with 4 articles each (25%), as well as case studies and mixed methods with 2 articles each (12.5%). The dominance of experimental methods indicates that researchers in this field tend to focus on testing the effectiveness of empirically developed learning media.

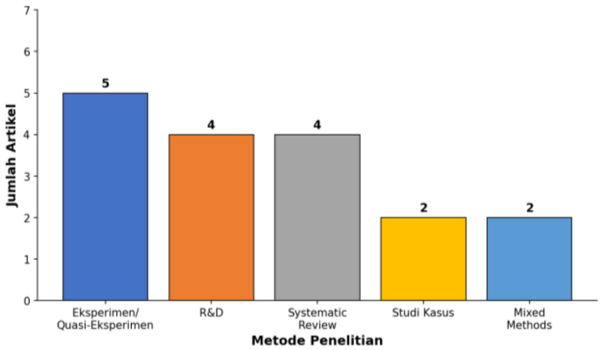

Figure 2. Distribution of Research Methods in 16 Analysed Articles

The results of further analysis show that from the aspect of the type of media developed, there is a wide variety ranging from 3D molecular simulations, web-based educational games, narrative-based interactive modules, to metaverse-based learning environments. developed 3D interactive multimedia specifically designed to build the spatial abilities of chemistry students, with the results showing a 27% increase in spatial ability compared to the control group. Meanwhile, it explores the potential of game-based learning in a metaverse environment for remote chemical bonding learning, which shows a 31% increase in immersive engagement in learners. The variety of media found in this study indicates the flexibility of the interactive approach in accommodating different learning needs and contexts (Dwiningsih et al., 2022), (Rahman et al., 2024).

From the aspect of the effectiveness of media implementation, all articles studied reported the positive impact of the application of interactive media on various indicators of learning success. These indicators include improvement in conceptual understanding measured through concept mastery tests, reduction of misconceptions identified through diagnostic tests, increased motivation and student engagement measured through questionnaires and observations, and development of computational thinking skills measured through special assessment rubrics. specifically reported that the C-Bonds media developed succeeded in reducing students' misconceptions by up to 68% through the conceptual change text strategy integrated in the media. These findings confirm the great potential of interactive media in overcoming barriers to learning chemical bonds that have been difficult to overcome with conventional learning approaches (Sa'diyah & Sukarmin, 2021).

Regarding the Scratch platform specifically, several articles provide strong empirical evidence of the platform's advantages for science learning at various levels of education. in its systematic review, it identified that Scratch is effective in developing computational thinking at the K-12 level with consistent success rates in various geographic contexts. corroborating these findings by showing that programming with Scratch improves students' problem-solving and abstraction skills in elementary school. Although the studies did not explicitly focus on chemistry learning, the pedagogical principles found could be transferred and adapted for the development of Scratch-based chemistry bonding learning media with appropriate content adjustments (Batni et al., 2025).

Discussion

The results of the analysis of the 16 articles studied provide a comprehensive understanding of the research landscape of the application of Scratch-based interactive learning media in the context of chemical bond learning. The findings confirm the significant potential of this approach in overcoming the challenges of learning abstract and complex chemical concepts. The following discussion will review the theoretical and practical implications of these findings by referring to the relevant literature to answer the four research objectives that have been set.

Related to the first goal, which is to identify research trends, the results of the study show a significant increase in researchers' interest in the topic of interactive learning media for chemistry in the last decade. in a bibliometric analysis over 20 years confirms that publications on Scratch in the context of STEAM education experienced exponential growth, especially after 2015. This trend correlates with the development of digital technology and the increasing awareness of the importance of computational literacy in science education. The diverse geographical context of the research, including Indonesia, Spain, Finland, Malaysia, and Pakistan, suggests that the application of interactive media for chemistry learning has become a global phenomenon that transcends geographical and cultural boundaries (Dúo-Terrón, 2023).

From a theoretical perspective, the effectiveness of Scratch-based interactive media in chemical bonding learning can be explained through several well-established conceptual frameworks in the educational literature. First, the cognitive load theory put forward by Sweller states that human working memory capacity is limited, so instructional design needs to minimize extraneous cognitive load while optimizing germane cognitive load to facilitate meaningful learning. Scratch-based media facilitates this through intuitive and interactive visualization, which allows learners to construct mental representations of molecular structures and interactions without being burdened by the excessive symbolic complexity in conventional chemical notation (Hunter et al., 2022).

Second, Mayer's multimedia learning theory supports the use of visual and verbal combinations in the delivery of learning materials to improve knowledge retention and transfer. demonstrate that 3D interactive multimedia that integrates dynamic visual representation with verbal explanations can significantly improve students' spatial abilities. These findings are in line with the principle of modality and the principle of temporal contiguity that emphasize the importance of synchronization between visual and auditory elements in learning. Scratch as a platform that supports the creation of interactive animations and simulations provides an ideal framework for applying these principles of multimedia learning in the context of chemistry learning (Dwiningsih et al., 2022).

Third, the constructivist perspective put forward by Piaget and Vygotsky emphasizes that effective learning occurs when learners actively construct their own understanding through interaction with the learning environment and collaboration with peers. in its bibliometric analysis shows that Scratch has become an increasingly popular tool in STEAM education due to its ability to facilitate project-based learning and self-paced exploration. In the context of learning chemical bonds, learners can use Scratch to create simulations of ionic and covalent bond formation, explore different configurations of molecules with different geometries, and test their predictions about the properties of substances based on the types of bonds formed in a direct and interactive manner (Dúo-Terrón, 2023).

Related to the second objective, namely, to analyse the effectiveness of media application, the results of the study show strong empirical evidence about the positive impact of interactive media on student learning outcomes. From a practical perspective, the research findings provide important implications for the development and implementation of learning media in the classroom. through a case study of the Chebo Collect game shows that gamification elements such as points, levels, and reward systems can substantially increase learners' motivation and engagement in learning the concept of chemical bonding. Confirming these findings by developing a digital module based on the Choose-Your-Own-Adventure narrative that has been proven to increase student engagement in learning chemical bonds through a personalized learning approach.(Lutfi et al., 2021)(Newell-Caito & Bernard, 2024)

Misconception management is a critical aspect of chemical bond learning that receives special attention in the literature reviewed and is an important part of media effectiveness. In its (Yovanie, 2024) systematic literature review, it identifies various forms of misconceptions that are commonly encountered in students at various levels of education, ranging from misconceptions about the nature of ionic and covalent bonds to confusion in distinguishing between intermolecular forces and intramolecular bonds. provide concrete solutions through the development of C-Bonds media that integrates conceptual change text strategies, which have been proven to reduce misconceptions by up to 68%. This approach can be adapted in the development of Scratch-based media by including scenarios that explicitly confront and correct these misconceptions through proper visualization (Sa'diyah & Sukarmin, 2021).

Related to the third objective, which is to map implementation strategies and best practices, the results of the study identified several effective approaches. The visualization aspect of molecular structure and molecular geometry has received special attention in several studies as an effective implementation strategy. developed a virtual simulation for the topic of VSEPR (Valence Shell Electron Pair Repulsion) that allows learners to explore the shapes of molecules in three dimensions with direct control. The results showed an increase in concept mastery by 24% in the group that used virtual simulation compared to the control group that used conventional media. through the development of the Leaflet of Electronegativity (LoEN), it has also succeeded in improving students' understanding of electronegativity and bond polarity with a systematic visual approach (Stiawan et al., 2022), (Erlina et al., 2021).

The development of computational thinking skills is an important added value of the application of Scratch in science learning which is also an identified best practice. shows that Scratch integration not only improves the understanding of academic content but also develops the ability to simultaneously problem-solve, abstraction, decomposition, and algorithmic thinking. In the context of chemistry, these skills are particularly relevant for the analysis of experimental data, modelling of molecular structures, and the prediction of the properties of substances based on structure. through a two-year longitudinal study in five elementary schools, it was found that continuous exposure to Scratch increased students' creativity and learning motivation consistently throughout the study period. (Rodríguez-Martínez et al., 2020) (Sáez-López et al., 2016).

Teachers' readiness in implementing Scratch-based media is also a determinant of success identified as best practice. researched the use of Scratch and Unity in teacher education programs and found that structured training of adequate duration can significantly improve the digital competence of prospective teachers. These findings imply the need for adequate and ongoing professional development programs for chemistry teachers to ensure the effective implementation of Scratch-based learning media in the classroom in accordance with established learning objectives (Sáez-López et al., 2023).

Regarding the fourth goal, which is to identify challenges and opportunities for future development, the results of the study show several important aspects that need to be considered. Recent trends in the development of interactive learning media lead to the use of immersive technologies such as virtual reality and the metaverse as development opportunities. (Rahman et al., 2024) explored the potential of game-based learning in a metaverse environment for remote chemical bonding learning and reported a 31% increase in immersive engagement compared to conventional media. While Scratch in its traditional form may have limitations in creating fully immersive experiences, the principles of interactive design developed through the platform can be transferred to the development of VR/AR applications for future chemistry learning.

(Pratiwi et al., 2025) through the development of multimedia, Scratch Wabimendu demonstrated that Scratch remains relevant as an effective and accessible learning media development platform in today's era of advanced technology. The advantages of Scratch include a sloping learning curve that makes it easy for beginners to learn, a large community of users who actively share resources, and the availability of abundant tutorials and documentation for free. These characteristics make Scratch a great choice for teachers who want to develop interactive learning media without requiring high programming skills or large financial investments.

However, there are several challenges and limitations that need to be considered in the application of Scratch-based media for chemical bond learning in the future. First, the limitations in representing chemical phenomena at the sub microscopic level require high scientific accuracy and precise atomic detail. Second, the need for adequate technological infrastructure in schools, especially in areas with limited internet access and computer devices. Third, the need for a balance between entertaining and educational aspects in media design to ensure that learning objectives remain a top priority and are not defeated by entertainment elements alone. Fourth, the importance of a comprehensive evaluation not only of cognitive learning outcomes but also of the development of science process skills and scientific attitudes of students holistically.

CONCLUSION

Based on the systematic literature review that has been conducted on 16 scientific articles related to the application of Scratch-based interactive learning media in the context of chemical bond learning, four main conclusions can be drawn that correspond to the research objectives that have been set.

First, research trends show a significant increase in academic interest in the use of Scratch and interactive media in chemical bonding learning during the period 2016-2025, with 75% of publications concentrated in the last five years. The wide geographical distribution from Indonesia to Europe indicates that this phenomenon is global and transcends cultural boundaries. Experimental and quasi-experimental research methods dominated (31.25%), followed by R&D and systematic review, which showed a focus on empirical effectiveness testing.

Second, the effectiveness of Scratch-based media and similar interactive platforms proved to be significant in improving students' conceptual understanding, with an average improvement in comprehension scores ranging from 23% to 31% compared to the control group. Interactive media is also effective in reducing misconceptions commonly encountered in chemical bond learning, with a reduction rate of 68% in some studies that integrate conceptual change text strategies.

Third, the implementation strategies and best practices identified include: the integration of 3D visualization for molecular geometry concepts, the application of gamification elements to increase motivation, the use of interactive narratives for personalized learning, the simultaneous development of computational thinking skills with chemical content, as well as structured teacher training to ensure adequate digital competence in implementing media.

Fourth, the main challenges faced include the limitation of the accuracy of submicroscopic representations, the gap in technological infrastructure in various regions, and the need to balance entertainment aspects with educational objectives. Future development opportunities include the integration of Scratch with immersive technologies such as VR/AR, the development of comprehensive learning modules for various chemical bond subtopics, cross-border collaboration in the development of learning resources, as well as the evaluation of the long-term impact on learners' high-level thinking skills.

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