827-Kusumawati Dwiningsih.pdf

by 1 1

Submission date: 29-May-2025 01:44PM (UTC+0700)
Submission ID: 2687299539
File name: 827-Kusumawati_Dwiningsih.pdf (1.23M)
Word count: 5715
Character count: 34556

IJORER : The Latest International Journal of Educational Research
Homepage: https://journal.ia-education.com/index.php/ijorer
Email: ijorer@ia-education.com

p-ISSN : 2721-852X ; e-ISSN : 2721-7965
IJORER, Vol. 6, No. 3, May 2025
Pages 775-788

G-Bond Development: Gamification Media to Improve Literacy, Visualization, and Numeracy in Chemical Bond Learning in High School

Kusumawati Dwiningsih[1*], Achmad Lutfi[2], Rusly Hidayah[3], Sukarmin[4], Novia Andriani[5]
Rizal Fathoni[6]
[1,2,3,4] State University of Surabaya, Surabaya, Indonesia
[5]MA Darul Ulum Tlasih, Sidoarjo, Indonesia
[6]Sekolah Indonesia Kota Kinabalu-CLC Baturong, Sabah, Malaysia

DOI: https://doi.org/10.46245/ijorer.v6i3.827

Section Info
Article Riwayat:
Posted: March 11, 2025
Last Revised: May 10, 2025
Received: May 20, 2025
Published: May 31, 2025
Keywords:
Literacy; Numeracy; Visualisation; Gamification; Chemistry Learning

ABSTRACT
Objective: This study aims to develop and evaluate G-Bond, a gamification-based learning media designed to improve students' literacy, visualisation, and numeracy skills in learning chemical bonds. **Methods:** The research uses a Research and Development (R&D) approach with a 4D (Define, Design, Develop, Disseminate) model, limited to the development stage. A total of 35 high school students in Gresik Regency participated in the pretest-posttest design of one group. Five experts carry out validation through content assessment, design, and visualisation. Practicality was tested through a student questionnaire, and effectiveness was measured using an N-Gain score. **Results:** The G-Bond application obtained a perfect validity score (average = 5), was rated very practical (95.14%), and showed moderate to high effectiveness in improving literacy (N-Gain = 0.34), numeracy (0.34), and visualisation (0.74). The most significant improvement occurs in the visualisation aspect. **Novelty:** G-Bond is the first gamification medium to simultaneously integrate three main skills in one interactive platform based on the topic of chemical bonding. Unlike previous media that focused only on a single aspect or were less connected to the curriculum, G-Bond presents relevant and adaptive game-based contextual challenges for both online and offline learning. Future integration with Augmented Reality (AR) and AI technologies is proposed to enhance immersive and personalised learning experiences.

INTRODUCTION

Chemistry learning at the secondary school level faces challenges in conveying abstract concepts such as the structure and formation of chemical bonds, which require high-level thinking skills, including submicroscopic representation, Numeracying, and spatial visualization. Unfortunately, many students have trouble understanding the relationship between theory and molecular representation. PISA 2022 data shows that Indonesian students' science literacy and numeracy scores (396 and 379) are still far below the OECD average, reflecting students' low scientific understanding and quantitative skills (Bilad et al., 2024; PISA, 2023; Wijaya et al., 2024).

This condition demands an innovative learning approach. Conventional media such as textbooks and two-dimensional simulations have not been effective in bridging students' understanding. In contrast, technology-based approaches such as gamification and augmented reality have been shown to improve understanding of abstract concepts and learning engagement (Chiu et al., 2024; Wong et al., 2021).

In response to these challenges, the study developed G-Bond—a gamification-based learning medium that integrates literacy, numeracy, and visualization in the topic of chemical bonding. Based on constructivism theory, Self-Determination Theory (SDT), and flow theory, G-Bond is designed to encourage active, interactive, and meaningful learning. This research aims to: (1) develop a valid G-Bond media in content, design, and visualization; (2) assess its practicality; and (3) analyse its effectiveness in improving students' skills (Chiu et al., 2024; Goldfarb et al., 2023; Salikhova et al., 2020).

The results of the Program for International Student Assessment (PISA) 2022 show that the performance of Indonesian students in science literacy and numeracy is still far from expectations, only recording scores of 396 and 379, respectively, far behind the OECD Numeracy average, which is in the range of 489 and 492 (PISA, 2023; Wijaya et al., 2024). These findings show that Indonesian students not only experience obstacles in understanding scientific concepts but also have weaknesses in quantitative and interpretive skills that are important in the field of chemistry. These low scores indicate an urgent need for innovative learning approaches that not only address conceptual gaps but also foster the quantitative reasoning and spatial understanding that are important in chemistry. Traditional methods are not enough to bridge these shortcomings, highlighting the urgency of adopting technology-enhanced interactive strategies such as gamification and visual simulation to increase student engagement and understanding of abstract scientific concepts(Bilad et al., 2024; Wijaya et al., 2024).

Unfortunately, commonly used learning media, such as textbooks and two-dimensional static simulations, have not been fully effective in bridging students' understanding of complex chemistry concepts(Baum et al., 2021). According to Wong et al. (2021), technology-based approaches such as augmented reality (AR) and gamification can create more immersive, interactive, and enjoyable learning experiences. Additionally, the use of game-based quizzes and visual simulations has been shown to significantly improve student learning outcomes(Wong et al., 2021).

In response to this need, researchers developed G-Bond, a gamification-based learning app designed to integrate three essential competencies in 21st-century chemistry learning: science literacy, spatial visualization, and quantitative numeracy. This media leverages interactive features and game-based narratives to facilitate the real-time exploration of chemical bond concepts. With a points system, challenge level, and instant feedback, G-Bond encourages active student engagement and supports autonomous and continuous learning (Abukari et al., 2022).

Theoretically, G-Bond's gamification approach refers to the Theory of Self-Determination (SDT), which states that motivation to learn will increase if students feel autonomy, competence, and connectedness. In addition, the app also refers to the Csikszentmihalyi scheme theory, which emphasises the importance of challenge and focus in building an optimal learning experience. This combination is expected to be able to overcome low student involvement and make the learning process more meaningful (Feriyanto & Anjariyah, 2024; van Dinther et al., 2023).

The novelty of this research lies in the development of G-Bond as a digital-based gamification media that integrates literacy, visualization, and numeracy simultaneously in one interactive learning platform. The uniqueness of this approach compared to previous research is the integration of cross-domain competencies in a single game-based application tailored to a specific chemical topic, namely chemical bonds. Previously, many studies focused only on one aspect of skills, such as literacy or visualization, or used educational games without a deep alignment with chemical numerical competence. This research offers a holistic approach based on constructivism theory and Self-Determination Theory (SDT) in designing gamification that not only facilitates conceptual understanding but also builds students' intrinsic motivation simultaneously. Additionally, the use of challenge-based scenarios, contextual numerical quizzes, and 3D animation makes G-Bond superior to similar learning media because it combines substantive content with pedagogically relevant interactive elements (Dwiningsih et al., 2022; Lutfi et al., 2021; Wijanarko et al., 2023; Wijanarko & Solikhin, 2023).

Therefore, this study aims to develop and evaluate the effectiveness of G-Bond learning media in the context of technology-based chemistry learning. This research specifically aims to: (1) develop G-Bond learning media that is valid in content, design, and visual display; (2) assess the practicality of G-Bond based on student responses; and (3) analyse the effectiveness of G-Bond in improving students' literacy, numeracy, and visualization skills on the topic of chemical bonding.

RESEARCH METHODS

Research Design

This research uses a Research and development (R&D) approach with a 4D (Define, Design, Develop, and Disseminate) model developed by Thiagarajan (Thiagarajan et al., 1974). However, this research has only been carried out until the development stage, namely the development and testing of the application of G-Bond in chemistry learning. The research design used is the One Group Pretest-Posttest Design, where one group of students is given a pretest before treatment (using the G-Bond application) and a posttest after treatment. This design was chosen to measure the effectiveness of the G-Bond application in improving students' literacy, numeracy, and visualization in understanding the concept of chemical bonding. However, it does not allow for direct comparisons with conventional learning methods

G-Bond Application Flowchart

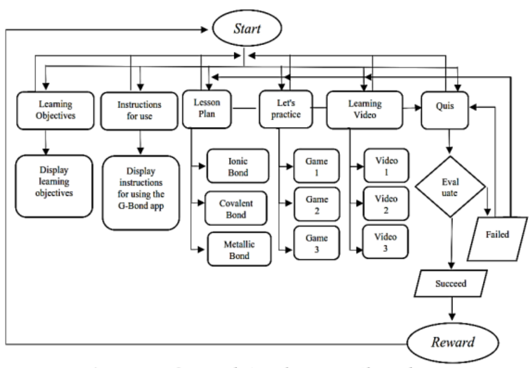


Figure 1. G-Bond Application Flowchart

To provide a comprehensive overview of the G-Bond application workflow, this section presents a flowchart that represents the sequence of processes, key features, and user interactions during learning. This flowchart aims to show how G-Bond is designed to facilitate a gamification-based learning experience systematically, from initial access to challenge-based quiz completion. By understanding these flows, developers and educators can gain a better understanding of the logical structure of the app, as well as how each component supports the development of literacy, visualization, and numeracy skills in an integrated manner. The G-Bond Application Flowchart is illustrated in Figure 1.

Sample Population and Research

The population in this study consists of grade XI students majoring in Natural Sciences (IPA) at one of the secondary schools in Gresik Regency during the 2023/2024 school year. A total of 35 students were selected using purposive sampling techniques based on specific criteria that are in line with the research objectives, including: (1) the availability of technology-based learning facilities, such as computer laboratories and stable internet access to ensure optimal use of the G-Bond application; (2) heterogeneous student levels of understanding, determined through pretest scores and teacher observations, categorised as low (<50), medium (50–75), and high (>75) to represent diverse academic abilities; and (3) institutional support from the school, which includes infrastructure readiness, permits for research activities, and students' willingness to engage in G-Bond interventions. This intended sampling approach is aligned with developmental research principles, ensuring that product testing takes place in a realistic and varied educational context

Research Instruments

The instruments used in this study include three main aspects: validity, practicality, and effectiveness of the G-Bond application.

1. **Instruments of Validity**

The validity of the media was tested through expert assessments from five validators, consisting of expert lecturers in the fields of chemistry education, learning technology, and learning media. The validation process includes aspects of content validity, construction, and visual display, as recommended by Nieveen (1999), who emphasises the importance of validation in the development of learning tools to ensure the appropriateness of instructional content and design. A 5-point Likert scale is used in this process, with categories 1 = Invalid to 5 = very valid. G-Bond Media is declared valid if it obtains an average score of ≥ 4, which falls into the valid category or very valid category.

2. **Instruments of Practicality**

The practicality of the application was measured using a student response questionnaire, which included three main indicators: (1) Ease of use of the application, (2) Readability and presentation of the material, and (3) Student involvement in learning. This concept of practicality refers to the usability theory put forward by Nielsen (1994), where ease of use and efficiency are the main benchmarks in the assessment of educational digital media. Practicality data are analysed using the following percentage formula:

The practicality category is determined based on the evaluation standards of learning media as follows:

- 81 – 100% = Very Practical
- 61 – 80% = Practical

- 41 – 60% = Quite Practical
- 21 – 40% = Less Practical
- 0 – 20% = Impractical

3. Effectiveness Instruments

The effectiveness of the G-Bond application was evaluated through a pretest and posttest, which were designed based on literacy, numeracy, and visualization indicators in chemistry learning. Better analysis of learning outcomes is carried out using the Normalised Gain (N-Gain) method, as introduced by, which is the standard method in measuring the effectiveness of pretest and posttest-based learning interventions.

The N-Gain formula used is Effectiveness data analysis was carried out by calculating the N-Gain score for each literacy, numeracy, and visualization indicator, referring to Hake (1998). To test the significance of the difference in pretest and posttest results, a paired sample t-test is performed. All of these statistical analyses used IBM SPSS Statistics software version 23.0. The consistent use of a single version of the software aims to guarantee transparency and ease of replication.

The interpretation criteria for the N-Gain score refer to the research of Hake (Hake, 1998), namely:

- $g \geq 0.7$ = High
- $0.3 \leq g < 0.7$ = Medium
- $g < 0.3$ = Low

Furthermore, N-Gain data was processed using Software Statistical Package for Social Science (SPSS) version 23.0. Based on the descriptive data, the normalised gain data obtained the maximum value, minimum value, average, and standard deviation of the final test in the experimental class and control class, and then continued by calculating the normality test

RESULTS AND DISCUSSION

Result

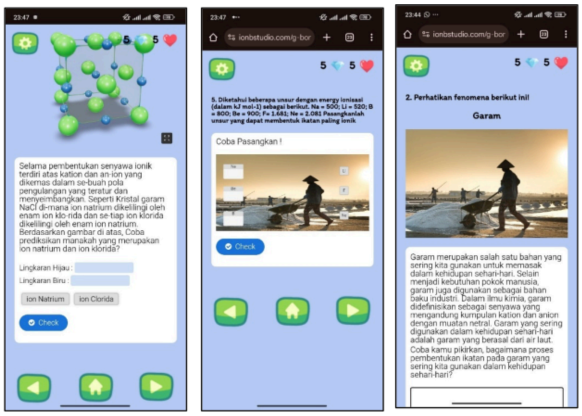
Validity Results

Five experts in chemistry education and learning technology validated the G-Bond application. This validation process includes three main aspects: content validity, construction validity, and visual validity. Based on the results of the assessment, an average score was obtained, as listed in Table 1.

Table 1. Classification of Interpretation of Validity Coefficients

Validation Aspects	Average score	Category
content	4.8	Highly Valid
Construction	4.6	Highly Valid
Visual	4.7	Highly Valid

The results of the study showed that the G-Bond application met excellent standards of academic validity in every aspect assessed. This high validity signifies that the app can present learning materials that are aligned with the curriculum, intuitive navigation, and visualizations that support concept understanding. This is in line with Azizah and Ardhana's research, which confirms that technology-based learning media can increase chemical effectiveness if it has strong academic validity.



(a) (b) (c)

Figure 2. G-Bond Application Design (a) Visual skills, (b) Numeracy skills, (b) Literacy skills

Practical Results

The practicality of the G-Bond app is measured through a student response questionnaire after they use it to learn. The results of the analysis showed that 95.14% of respondents stated that this application is very practical and easy to use. Details of the practical results are shown in Table 2.

Table 2. Practical Results

Practical Aspects	Percentage (%)	Category
Ease of Use	96.5	Very Practical
Material Readability	91.3	Very Practical
Student Engagement	97.8	Very Practical

These findings show that G-Bond is not only designed to present materials effectively but also considers the factors of ease of access and user convenience. In line with the results of Christina, Selamat, and Sanjaya's research, interactive and game-based learning media have been proven to be able to improve students' learning experiences in a more flexible and interesting way.

Effectiveness Results

At this stage of the effectiveness test, pretest and posttest sheet instruments consisting of Literacy, Visual, and Numeracy skills were reviewed from several aspects.

Literacy and Numeracy data results

The results of Literacy and Numeracy data are presented through the Normality Test, as shown in Table 3.

Table 3. Literacy and Numeracy Normality Test

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistics	**Df**	**Sig.**	**Statistics**	**Df**	**Sig.**
Prates	.188	23	.035	.889	23	.015
Post-tests	.145	23	.200*	.961	23	.490

The normality test was carried out using the IBM SPSS Statistics application version 23.0. Based on the Table, the normality test found that the mark. For the pretest, it is 0.15, and for the posttest, it is 0.490. The Shapiro-Wilk test indicated that the pretest and posttest scores were normally distributed ($p > 0.05$).

The results of the normality test are then used to perform the t-test. The t-test aims to determine if there is a significant difference between the pretest and the posttest.

Table 4. T-test on the difference in pretest and posttest scores of literacies and numeracy

	Mean Difference							
	Mean	Standard Deviation	Std. Standard Error	95% Difference Confidence Interval		t	Df	Sig. (2-tailed)
Pretest - Pastates	-6.478	7.757	1.617	-9.833	-3.124	-4.005	22	.001

Table 4 shows the significance value (2-tailed) is 0.001 (< 0.05), indicating that Ho is rejected and Ha is accepted, which means that there is a significant difference between pretest and posttest scores. In addition, the effect size calculated using Cohen's d was 0.84, categorised as large, suggesting that G-Bond had a strong impact on improving students' literacy and numeracy skills. In addition, qualitative feedback from participants supported these quantitative findings. Some participants stated that:

- *"The bond energy calculation quiz feature in G-Bond helped me understand faster how to calculate bond strength without feeling bored like I would during regular class exercises." (Participant 7)*
- *"The explanation of the types of chemical bonds in G-Bond is easier to understand because it is presented through interactive stories and images, not just textbook definitions." (Participant 5)*
- *"When working on problems about covalent and ionic bonds, I became more excited because there were points and animations when my answers were correct. So, I read the questions and calculated more carefully." (Participant 16)*

Thus, the integration of gamification in G-Bond not only improves learning outcomes quantitatively but also strengthens motivation and understanding of the concept of chemical bonding through an interactive and fun learning experience.

Table 5. N-Gain score for literacy and numeracy

Pretest	Pascates	N-Gain	Category
82,13%	88,60%	0,34	Medium

Based on Table 5, the N-Gain score shows 0.34, meaning that the N-Gain score is≥ 0.7 in the medium category. Thus, the G-Bond application that has been developed is effectively used to improve Literacy and Numeracy.

Visual Data Results

Table 6. Normality Test for students' visual comprehension

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistics	**Df**	**Sig..**	**Statistics**	**Df**	**Sig..**
Pretest	.151	23	.189	.897	23	.022
Post-tests	.387	23	.000	.645	23	.000

The normality test was carried out using the IBM SPSS Statistics application version 23.0. Based on Table 6, the normality test found the mark. For the pretest, it is 0.022, and for the posttest, it is 0.000. From the data, pretest scores, and posttests are usually distributed in the Shapiro-Wilk test, with a mark. >0.05. A t-test was carried out based on the results of the normality test.

Table 7. T-test on the difference in pretest and posttest scores visualization

	Mean Difference					t	Df	Sig. (2-tailed)
	Mean	Standard Deviation	Std. Standard Error	95% Difference Confidence Interval				
				Lower	Above			
Pretest - Pastates	-12.783	15.142	3.157	-19.330	-6.235	-4.049	22	.001

Based on Table 7, the significance value (2-tailed) is < 0.001, indicating that Ho is rejected, and Ha is accepted, which means that there is a significant difference between pretest and posttest scores. This confirms that the G-Bond application is very effective in improving students' visual comprehension.

Table 8. N-Gain score for visualization

Pretest	Post-tests	N-Gain	Criterion
79,82%	92,60%	0,74	Tall

Based on Table 8, the N-Gain score shows 0.74, meaning that the N-Gain score is≥ 0.7 in the high category. Thus, the developed G-Bond app effectively improves students' visual comprehension. To measure the effectiveness of the application, an N-Gain Score test was conducted to compare students' pretest and posttest results after using G-Bond in chemical bonding learning. The results of the analysis are shown in Table 9.

Table 9. Recap of the Effectiveness of G-Bond Media Based on N-Gain

Category	Pre-test (%)	Posttest (%)	N-Gain	Category N-Gain
Literacy	62.5	81.2	0.50	Medium
Many	58.7	79.3	0.45	Medium
Visualization	64.2	90.5	0.74	Tall

The data showed that the most significant improvements occurred in the visualization aspect, which reached the highest category. This shows that using simulations and interactive animations in G-Bond is essential in helping students understand abstract chemical bonding concepts. These findings are in line with Hasanah's research, which states that interactive visual-based learning media can improve students' understanding of complex chemical concepts.

Discussion

Validity Analysis

Five experts in chemistry education and learning technology evaluated the validity of the G-Bond application. This validation includes three main aspects: content validity, construction, and visualization. The results showed that the app obtained an average score of ≥ 4 (a very valid category), which shows that G-Bond has met academic standards in presenting learning materials according to the curriculum. According to Johnstone's Triangle Theory, understanding chemistry must consider the relationship between macroscopic, symbolic, and submicroscopic representations. G-Bond successfully provides a visualization-based approach to bridge the difficulties in understanding abstract chemical bond concepts. This suggests that technology-based media can improve understanding of chemistry through more intuitive visual representations (Coduto et al., 2024; Lutfi et al., 2021; Nurviandy & Dwiningsih, 2021)

Practical analysis

The practicality of the G-Bond application is measured through a student response questionnaire, which includes ease of use, readability of the material, and student involvement in learning. The analysis showed that 95.14% of respondents stated that the app is practical and easy to use. This is in line with previous research that showed that the use of technology-based media can increase student engagement. According to Self-Determination Theory, students' engagement in learning increases when they feel they have control over their learning experiences. G-Bond enables interactive exploration, provides game-based challenges, and provides hands-on feedback, supporting students' needs for autonomy, competence, and connectedness in the learning process. The practicality of this application is also supported by a gamification-based design that utilises the Flow theory of Csikszentmihalyi. This theory states that students are more motivated when they are in a state of "flow," where they are fully engaged in activities without external barriers. G-Bond uses this principle by providing a system of points, challenge levels, and instant feedback to enhance the student learning experience (Anisa Lailatul Azizah & Ardhana, 2023; Chiu et al., 2024; Goldfarb et al., 2023; Mills & Allen, 2020; Rohman & Fauziati, 2022; Salikhova et al., 2020).

Analysis of Effectiveness in Literacy, Numeracy, and Visualization

Literacy

Literacy in chemistry learning includes students' ability to read, understand, and interpret chemical texts, graphs, and symbols. A good understanding of chemical literacy is essential in improving analytical and scientific problem-solving skills. G-Bond helps improve students' literacy by providing narrative-based content and interactive discussions that connect theory with real-life applications. This allows students to see how their concepts are applied in everyday situations, such as using chemical bonds in the pharmaceutical industry and environmental contextual-based learning theories. students' understanding is enhanced when they can directly relate chemical concepts to the phenomena they experience. G-Bond supports this approach by providing problem-based scenarios that require students to analyse and interpret data before making scientific decisions. Thus, the app not only improves reading skills and understanding of chemical symbols but also trains students' critical thinking skills in applying concepts in various fields.

In addition, based on Vygotsky's theory of constructivism, learning will be more effective when students interact with the material actively and socially. At G-Bond, interactive discussions facilitated by the game-based learning feature allow students to exchange understandings, build arguments, and build their concepts through collaborative reflection and problem-solving. This interaction strengthens science literacy as students not only read and understand but also communicate their scientific ideas in a more structured way Overall, the gamification approach implemented in G-Bond improves students' chemistry literacy in a more contextual, collaborative, and actively exploration-based way The main effect of this literacy increase is the increased ability of students to read experimental data, understand the relationship between chemical concepts, and translate the theory into more tangible scientific practice. These difficulties are often caused by students' inability to relate mathematical concepts to the chemical context and limitations in quantitative understanding of the relationship between molarity, reaction equations, and mass conservation.

Numeracy

G-Bond provides a numerical practice feature that allows students to practice number-based problem-solving gradually, with immediate feedback. Based on cognitive load theory, students have difficulty in Numeracying due to excessive mental workload when they have to simultaneously understand the relationship between numbers, chemical concepts, and mathematical equations. G-Bond reduces this burden by implementing a phased approach in which students are given practice questions that start with basic concepts before moving on to more complex calculations. Although the increase in numeracy in this study is still in the moderate category, gamification-based methods have shown positive results in improving students' analytical skills. In the study by Anisa Lailatul Azizah and Ardhana, students who studied with a gamification approach and greater involvement in solving chemical calculations compared to conventional methods (Anisa Lailatul Azizah & Ardhana, 2023).

In addition, Vygotsky's scaffolding principle suggests that students will have an easier time understanding numeracy if given gradual support that matches their level of cognitive development. In G-Bond, students are given step-by-step instructions in solving bond energy calculations and stoichiometric problems before finally being asked to solve the problem independently. Overall, the gamification-based approach at G-Bond not only increases students' interest in numerical problems but also facilitates a more systematic process of understanding numeracy concepts. Integrating interactive and scenario-based features allows students to connect chemical calculations with their real-life applications, improving their analytical abilities and quantitative problem-solving skills.

Visualization

The most significant improvement in this study was observed in the visualization aspect (N-Gain = 0.74, high category), highlighting the important role of interactive 3D models in improving students' understanding of complex molecular structures. According to Dual Coding Theory (Paivio) and Cognitive Load Theory, combining visual and verbal information reduces cognitive load and improves retention, which explains why G-Bond's dynamic simulation effectively supports conceptual mastery.

These findings are consistent with studies by Wong et al. (2021) and Dwiningsih et al. (Isaloka & Dwiningsih, 2020; Nisa & Dwiningsih, 2021), which shows that technology-based visual tools significantly reduce misconceptions in abstract chemistry concepts by offering manipulable representations. Traditional 2D methods often fail to convey the spatial relationships that are essential for understanding covalent and ionic bonds.

In addition, based on the Spatial Intelligence Theory, direct interaction with visual models enhances students' ability to mentally manipulate molecular geometry, fostering a deeper understanding. G-Bond integrates gamification tasks that require the exploration of molecular structures, thus promoting active engagement and conceptual clarity.

In contrast, the increase in literacy and numeracy is moderate due to their reliance on textual and mathematical reasoning, which requires different cognitive strategies and longer engagement for mastery. Overall, these results underscore the importance of embedding interactive visual simulations within gamification frameworks to effectively address the abstractions inherent in chemistry learning and to develop students' spatial reasoning skills that are essential for mastering molecular concepts.

CONCLUSION

Key Findings: This study shows that G-Bond is a valid, practical, and effective gamification-based learning medium in improving students' skills in literacy, numeracy, and especially the visualization of chemical bond concepts. Through a narrative-interactive approach and game-based challenges, G-Bond has succeeded in creating a more engaging and participatory learning experience. **Implications:** The results of the study confirm that gamification can be an effective instructional strategy to overcome difficulties in understanding abstract concepts of chemistry. The use of G-Bond can support learning that is more contextual, motivating, and aligned with the needs of 21st-century learning. **Theoretical Contribution:** G-Bond contributes to the development of cross-domain gamification models in chemistry education, integrating literacy, visualization, and numeracy simultaneously. This integration is based on constructivism theory, Self-Determination Theory, and Flow Theory, which strengthens the pedagogical framework of technology-based interactive learning. **Limitations:** The single-group pretest-posttest design without the control group limits the generalisation of results. Research has also not evaluated the long-term impact on student learning retention. **Recommendation:** Follow-up research is recommended using an experimental design with a control group. G-Bond also needs to be further developed by integrating AI technology for adaptive learning paths, as well as AR simulations and analytics dashboards to improve personalisation, engagement, and effectiveness of monitoring students' learning processes.

REFERENCE

Abukari, M. A., Marifa, H. A., Samari, J. A., Dorsah, P., & Abudu, F. (2022). Senior High School Students' Difficulties In Learning Hybridisation in Chemistry. *Problems of Education in the 21st Century*, *80*(5), 630–651. https://doi.org/10.33225/pec/22.80.630

Anisa Lailatul Azizah, & Ardhana, I. A. (2023). Pengembangan Elektronik Modul (E-Modul) Interaktif Berbasis Web dengan Pendekatan Saintifik pada Materi Ikatan Kimia. *JRPK: Jurnal Riset Pendidikan Kimia*, *13*(1), 8–15. https://doi.org/10.21009/JRPK.131.02

Baum, Z. J., Yu, X., Ayala, P. Y., Zhao, Y., Watkins, S. P., & Zhou, Q. (2021). Artificial Intelligence in Chemistry: Current Trends and Future Directions. *Journal of Chemical Information and Modeling*, *61*(7), 3197–3212. https://doi.org/10.1021/acs.jcim.1c00619

Bilad, M. R., Zubaidah, S., & Prayogi, S. (2024). Addressing the PISA 2022 Results: A Call for Reinvigorating Indonesia's Education System. *International Journal of Essential Competencies in Education*, *3*(1), 1–12. https://doi.org/10.36312/ijece.v3i1.1935

Chiu, T. K. F., Falloon, G., Song, Y., Wong, V. W. L., Zhao, L., & Ismailov, M. (2024). A self-determination theory approach to teacher digital competence development. *Computers and Education*, *214*. https://doi.org/10.1016/j.compedu.2024.105017

Coduto, J. R., Lazicki, A., & Leddy, J. (2024). Visualizing 3D Objects in Analytical Chemistry. *Journal of Chemical Education*, *101*(1), 77–87. https://doi.org/10.1021/acs.jchemed.3c00821

Dwiningsih, K., Fauziatul Fajaroh, Parlan, P., Munzil, M., & Habiddin, H. (2022). 3D Molecular Interactive Multimedia for Building Chemistry Students' Spatial Ability. *International Journal of Emerging Technologies in Learning*, *17*(14), 253–262. https://doi.org/https://doi.org/10.3991/ijet.v17i14.30339

Feriyanto, F., & Anjariyah, D. (2024). Deep Learning Approach Through Meaningful, Mindful, and Joyful Learning: A Library Research. *Electronic Journal of Education, Social Economics and Technology*, *5*(2), 208–212. https://doi.org/10.33122/ejeset.v5i2.321

Goldfarb, Y., Golan, O., & Gal, E. (2023). A Self-Determination Theory Approach to Work Motivation of Autistic Adults: A Qualitative Exploratory Study. *Journal of Autism and Developmental Disorders*, *53*(4). https://doi.org/10.1007/s10803-021-05185-4

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Isaloka, I., & Dwiningsih, K. (2020). The Development of 3D Interactive Multimedia Oriented Spatial Visually on Polar and Nonpolar Covalent Bonding Materials. *JTK (Jurnal Tadris Kimiya)*, *5*(2), 153–165. https://doi.org/10.15575/jtk.v5i2.8688

Lutfi, A., Hidayah, R., Sukarmin, S., & Dwiningsih, K. (2021). Chemical Bonding Successful Learning Using The "Chebo Collect Game": A Case Study. *Journal of Technology and Science Education*, *11*(2). https://doi.org/10.3926/JOTSE.1265

Mills, D. J., & Allen, J. J. (2020). Self-determination theory, internet gaming disorder, and the mediating role of self-control. *Computers in Human Behavior*, *105*. https://doi.org/10.1016/j.chb.2019.106209

Nisa, A., & Dwiningsih, K. (2021). Efektivitas Pembelajaran Geometri Molekul Menggunakan Mobile Virtual Reality (MVR) untuk Meningkatkan Kemampuan Visuospasial. *Kwangsan: Jurnal Teknologi Pendidikan*, *9*(2), 220. https://doi.org/10.31800/jtp.kw.v9n2.p220--236

Nurviandy, I., & Dwiningsih, K. (2021). The Effectiveness of Interactive Multimedia 3D Modeling of Metallic Bondings to Optimize Visual-Spatial Intelligence. *JTK (Jurnal Tadris Kimiya)*, *6*(1). https://doi.org/10.15575/jtk.v6i1.9704

PISA. (2023). Programme for International Student Assessment (PISA) 2022 : Insights and Interpretations. *Oecd 2023*.

Rohman, D., & Fauziati, E. (2022). Gamification of Learning in the Perspective of Constructivism Philosophy Lev Vygotsky. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *5*(1).

Salikhova, N. R., Lynch, M. F., & Salikhova, A. B. (2020). Psychological aspects of digital learning: A self-determination theory perspective. *Contemporary Educational Technology*, *12*(2). https://doi.org/10.30935/cedtech/8584

Thiagarajan, Sivasailam, & others. (1974). *Instructional Development for Training Teachers of Exceptional Children: A Sourcebook.*

van Dinther, R., de Putter, L., & Pepin, B. (2023). Features of Immersive Virtual Reality to Support Meaningful Chemistry Education. *Journal of Chemical Education*, *100*(4). https://doi.org/10.1021/acs.jchemed.2c01069

Wijanarko, A., & Solikhin, F. (2023). Efektivitas Pembelajaran Geometri Molekul Menggunakan Mobile Virtual Reality (MVR) untuk Meningkatkan Kemampuan Visuospasial. *Rabit : Jurnal Teknologi Dan Sistem Informasi Univrab*, *7*(1). https://doi.org/10.36341/rabit.v7i1.2150

Wijanarko, A., Solikhin, F., Antoni, E., & Fadhil, H. N. (2023). Implementasi Metode Lean UX dan Efek Positifnya Pada Pengembangan Game Edukasi Berbasis Android Materi Ikatan Kimia. *JTKSI (Jurnal Teknologi Komputer Dan Sistem Informasi)*, *6*(1). https://doi.org/10.56327/jtksi.v6i1.1394

Wijaya, T. T., Hidayat, W., Hermita, N., Alim, J. A., & Talib, C. A. (2024). Exploring Contributing Factors to Pisa 2022 Mathematics Achievement: Insights from Indonesian Teachers. *Infinity Journal*, *13*(1). https://doi.org/10.22460/infinity.v13i1.p139-156

Wong, C. H. S., Tsang, K. C. K., & Chiu, W.-K. (2021). Using Augmented Reality as a Powerful and Innovative Technology to Increase Enthusiasm and Enhance Student Learning in Higher Education Chemistry Courses. *Journal of Chemical Education*, *98*(11), 3476–3485. https://doi.org/10.1021/acs.jchemed.0c01029

***Kusumawati Dwiningsih (Corresponding Author)**
Department of Chemistry,
FMIPA, State University of Surabaya,
Gd. C5-C6 Chemistry, Jl. Unesa Ketintang Campus, Gayungan District, Surabaya, East Java 60231
Email: kusumawatidwiningsih@unesa.ac.id

Achmad Lutfi
Department of Chemistry,
FMIPA, State University of Surabaya,
Gd. C5-C6 Chemistry, Jl. Unesa Ketintang Campus, Gayungan District, Surabaya, East Java 60231
Email: achmadlutfi@unesa.ac.id

Rusly Hidayah
Department of Chemistry,
FMIPA, State University of Surabaya,
Gd. C5-C6 Chemistry, Jl. Unesa Ketintang Campus, Gayungan District, Surabaya, East Java 60231
Email: ruslyhidayah@unesa.ac.id

Sukarmin
Department of Chemistry,
FMIPA, State University of Surabaya,
Gd. C5-C6 Chemistry, Jl. Unesa Ketintang Campus, Gayungan District, Surabaya, East Java 60231
Email: sukarmin@unesa.ac.id

Novia Andriani
MA Darul Ulum Tlasih,
Jl. Tlasih RT. 05 RW. 01, Tulangan District, Sidoarjo, East Java 61273.
Email: noviaandri22@gmail.com

Rizal Fathoni
Sekolah Indonesia Kota Kinabalu-CLC Baturong, Sabah, Malaysia
Email: rizalteacher@gmail.com

827-Kusumawati Dwiningsih.pdf

ORIGINALITY REPORT

16%	15%	8%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	jurnalfkip.unram.ac.id Internet Source	3%
2	www.researchgate.net Internet Source	1%
3	edunesia.org Internet Source	1%
4	ejournal.undiksha.ac.id Internet Source	1%
5	journal.univetbantara.ac.id Internet Source	1%
6	repository.uinsu.ac.id Internet Source	<1%
7	files.eric.ed.gov Internet Source	<1%
8	edupij.com Internet Source	<1%
9	procceding.unram.ac.id Internet Source	<1%
10	e-journal.undikma.ac.id Internet Source	<1%
11	journal.aripi.or.id Internet Source	<1%
12	ecohumanism.co.uk Internet Source	<1%
13	journal.universitaspahlawan.ac.id Internet Source	<1%

14	statik.unesa.ac.id Internet Source	<1 %
15	garuda.kemdikbud.go.id Internet Source	<1 %
16	Submitted to UCL Student Paper	<1 %
17	Submitted to University of Southampton Student Paper	<1 %
18	Endah Retnowati, Anik Ghufron, Marzuki, Kasiyan, Adi Cilik Pierawan, Ashadi. "Character Education for 21st Century Global Citizens", Routledge, 2018 Publication	<1 %
19	cscanada.net Internet Source	<1 %
20	Momo Rosbiono Kartamiharja, Wahyu Sopandi, Dini Anggraeni. "Implementation of Problem-Based Learning (PBL) Approach in Chemistry Instructional with Context of Tofu Liquid Waste Treatment", International Journal of Learning, Teaching and Educational Research, 2020 Publication	<1 %
21	Submitted to Universitas Terbuka Student Paper	<1 %
22	acikbilim.yok.gov.tr Internet Source	<1 %
23	journal.walisongo.ac.id Internet Source	<1 %
24	iiari.org Internet Source	<1 %
25	Khaerunnisa Khaerunnisa, Nanang Rahman, Haifaturrahmah Haifaturrahmah, Emese K.	<1 %

Nagy. "RADEC vs PjBL: Adding make-a-match media to enhance students' creative thinking skills", Journal of Research in Instructional, 2025
Publication

26	ijcat.com Internet Source	<1 %
27	jurnal.stkippersada.ac.id Internet Source	<1 %
28	research.vu.nl Internet Source	<1 %
29	Amanda Chelly da Rocha, João dos Santos Cabral Neto. "Ensino de Ligações Químicas", Educitec - Revista de Estudos e Pesquisas sobre Ensino Tecnológico, 2024 Publication	<1 %
30	Senna Prasemmi, Sri Rahayu, Fauziatul Fajaroh, Saeed Almuntasheri. "Chemical Literacy Skill of High School Students on the Solution Chemistry", JTK (Jurnal Tadris Kimiya), 2021 Publication	<1 %
31	Wulan Patria Saroinsong, Muhamad Nurul Ashar, Irena Y. Maureen, Lina Purwaning Hartanti et al. "Reimagining Innovation in Education and Social Sciences", Routledge, 2023 Publication	<1 %
32	Yerizon Yerizon, Arnellis Arnellis, Suherman Suherman, I Made Arnawa, Cholis Sa'dijah, Lathiful Anwar. "Developing adaptive digital book (ADB) in enhancing students' numeracy literacy ability", Infinity Journal, 2025 Publication	<1 %

eprints.binadarma.ac.id

33	Internet Source	<1 %
34	journal.ia-education.com Internet Source	<1 %
35	journal.trunojoyo.ac.id Internet Source	<1 %
36	journal.uinjkt.ac.id Internet Source	<1 %
37	journal.unilak.ac.id Internet Source	<1 %
38	journalfkipunipa.org Internet Source	<1 %
39	www.ojcmt.net Internet Source	<1 %
40	Dewi Satria Ahmar, Muhammad Fath Azzajjad. "OPTIMIST-G (Optimization of Metacognitive Thinking Skills through STEAM-Based Gamification) in Chemical Bonding Learning", Daengku: Journal of Humanities and Social Sciences Innovation, 2025 Publication	<1 %
41	Jimmi Copriady, Bella Pratiwi, Lenny Anwar. "Development of E-Module based on Phenomenon-based Learning in Thermochemistry to Facilitate Student during Covid-19 Pandemic", 2021 Universitas Riau International Conference on Education Technology (URICET), 2021 Publication	<1 %
42	doaj.org Internet Source	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		