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BioMol DigiGames: An App for the Mastery of Biomolecules

Joshua TUMOLVA[a*], Armando Victor GUIDOTE[ab], John Lorence VILLAMIN[a] & Joselito Christian Paulus VILLANUEVA[a]
[a]*School of Arts & Sciences, National University, Philippines*
[b]*School of Science & Engeineering, Ateneo de Manila University, Philippines*
*jltumolva@nu-moa.edu.ph

Abstract: Despite advances in ICT and chemistry education, students find chemistry to be particularly difficult to grasp due to its abstract nature. To address this, a digital game-based learning approach, herein referred to as BioMol DigiGames, was employed to determine students' confidence towards chemistry, wherein the main aim of the study was to design, develop, and evaluate a game application that can be used as review material for the mastery of biomolecules. The game app consisted of three games namely: (1) PuzzBuild, (2) Shooting Strucher, and (3) Food Pyramidash, with varying levels of complexity. For this, the study utilized a design and development research approach for the game app and a quasi-experimental, non-randomized pretest-posttest design was used on 100 Grade 12 STEM students enrolled in a public school. Students' game ratings for entertainment and educational aspects posited positive results. Statistical analyses showed significant effects on student's academic performance ($p = 0.004^{**}$), retention ($p = <0.001^{***}$), attitude toward chemistry ($p = 0.002^{**}$), and motivation toward chemistry ($p = <0.001^{***}$). Significant correlations were found between post-academic performance and short-term retention ($p = 0.021^{*}$); academic performance and chemistry motivation ($p = 0.027^{*}$); attitude and chemistry motivation ($p = 0.001^{***}$). However, a low correlation was observed between academic performance and attitude toward chemistry ($p = 0.418$) which suggests to include small -scale laboratory game-like activities. Results corroborated the qualitative data obtained from focus group discussions, with students exhibiting higher self-efficacy, improvement in academic performance, being well-motivated, retention of short-term knowledge, and appreciation of the use of the game app remotely without the use of the internet. The game app is a playful alternative instructional tool that will foster engaging and collaborative learning and can be an effective substitute for conventional educational strategies in reviewing content that is related to biomolecules. Overall, the results suggest that DGBL performs better than NGBL in terms of review material and mastery of biomolecules.

Keywords: 12th Grade Senior High School STEM, chemistry education, games/mobile application, digital game-based learning, motivation, biomolecules

1. Introduction

With technology as a learning tool and ally, the standard of education has opened new windows and doors leading to a brighter future. According to the 2018 PISA results, some 22% Filipino students attained Level 2 or higher in science. These students can recognize the correct explanation for familiar scientific phenomena and can use such knowledge to identify, in simple cases, whether a conclusion is valid based on the data provided. Although multilevel thinking plays a role in many STEM disciplines, the triple nature of chemistry, known as Johnstone's triangle is difficult to learn because students struggle to coordinate their thinking across three distinct levels of chemical knowledge: (1) macro, (2) sub-micro, and (3) symbolic (Gilbert & Treagust, 2009). On their way to various STEM fields, students frequently find chemistry to be a particularly difficult rite of passage (Cook, Kennedy, and McGuire, 2013). The same authors also suggested that students encounter difficulties because of rote memorization of facts and formulas rather than comprehending the concepts and developing fundamental problem- solving skills. The abstract nature of chemistry further compounds these challenges (Treagust et al., 2000). Additionally, Gao et al., (2020) noted that conventional STEM classroom hardly attracts students' interest, resulting in difficulties in implementing practical activities that address the educational need for cultivating advanced problem-solving abilities, owing to constraints in time and resources (Klopfer & Thompson, 2020). Consequently, there is an urgent need for innovative instructional methods to enhance STEM education.

In science education, digital innovations provide new educational resources, facilitate new instructional methods, and expand the scope of research opportunities (Linn, 2003). Increasingly potent personal devices have allowed students to study and utilize technology in science classes. As opposed to previous generations who relied on textbooks and classroom instruction, current learners frequently acquire knowledge via the internet and mobile apps. The ubiquitous presence of technology has inspired a shift from classroom lectures to integrated digital learning environments.

Digital game-based learning (DGBL) engages students in a competitive activity with educational goals intended to promote knowledge acquisition. The games may be designed to promote education or the development of cognitive skills, or they may take the form of simulations that allow students to hone their skills in virtual settings (Erhel S. & Jamet E., 2013). The use of educational games in chemistry education presents both numerous opportunities and challenges. In general, pre-, in-, and post-game guidance and instructions from a teacher have a great impact on students' motivation and learning achievement, fostering enthusiasm toward the subject of learning (Ke, 2009). Consequently, there is a great deal of interest in tools and methodologies that enable scientific thinking (Kalogiannakis M. et al., 2021). Teachers may have a high level of responsibility in selecting and evaluating ICT tools to integrate into the teaching and learning processes.

Currently, in the Philippine context, the Google Play Store has at least thirty-three online apps for chemistry topics. So far, only a few game-based learning apps have been created for chemistry in offline mode, and based on the literature, none of these heavily focus on the structure and function of biomolecules. Thus, this study primarily aimed to develop an offline game app on biomolecules using the DGBL approach. Specifically, it sought to answer the following research questions:

1. What are the initial performance and user evaluations of the game app in terms of: Accuracy of Concept, Attractiveness, Functionality, Accessibility and Interactivity?
2. What is the level of acceptance of students toward the use of the game app in terms of: (a) educational aspect; and (b) entertainment aspect?
3. Is there a significant difference between the academic achievement, short-term retention attitude, and motivation of students in the NDGBL and DGBL group before and after intervention?
4. Is there a significant relationship between the students' academic performance and (a) attitude towards learning chemistry, (b) short-term retention, (c) motivation towards learning chemistry, and (d) motivation and attitude towards learning chemistry?

2. Review of Related Literature

2.1 Foundational Theories Underpinning Digital Game-Based Learning within STEM Education

Digital technologies, particularly DGBL, have the potential to significantly enhance the learning experience in science education, especially in areas where students often face conceptual challenges and negative emotions. By integrating play into the learning process, DGBL helps students remain engaged and focused on their studies. Gui, Y. et al. (2023), highlight that digital educational games offer interactive and engaging environments conducive to the development of STEM-related knowledge and skills. This raises an important question: Why do digital educational games effectively enhance STEM learning? The situated learning theory, as proposed by Lave and Wenger (1991), offers a compelling explanation. According to this theory, digital educational games provide a context where learners can construct new knowledge through interaction with the game environment and other players. In the context of STEM education, digital games are crucial for fostering student achievement and cognitive growth. These educational games provide an innovative, stimulating, and interactive learning environment that promotes student activity and enhances problem-solving and critical thinking skills—essential components of STEM education goals (Stehle & Peters-Burton, 2019). Moreover, digital educational games incorporate various pedagogical elements—such as pedagogical agents, self-explanation strategies, and adaptive learning features—that support cognitive development and scaffold learners from novice to expert levels. One study done by Licorish et al. (2018) also suggests that DGBL enhances science education by increasing student motivation, engagement, and learning objectives. To add, a computer or mobile game is one of the most effective modern tools that reinforces essential skills such as problem-solving, collaboration, and communication (Saraiva et al., 2021). The adaptability of educational games allows teachers to address instructional challenges effectively and maintain students' attention through engaging interfaces. It was said that digital games assist students in being active and energetic during lectures, resulting in the formation of a successful learning environment. The pervasiveness of technology in classrooms has resulted in the emergence of classroom experiences in digitally integrated learning environments. These interactive learning environments offer the chance to evolve the teaching process by incorporating game elements that have been shown to capture user attention and motivate them toward goals and attitudes toward learning. Furthermore, feedback mechanisms within these games offer continuous support, which is vital for the learning process. Therefore, digital games provide learners with a graphic system of interaction that enhances scientific concepts within an enjoyable environment. This means that digital games are seen as excellent tools for facilitating and supporting the situated learning of students.

2.2 DGBL and Student’s Motivation towards Chemistry

Learning is a complex cognitive process, with numerous scholars highlighting motivation as a crucial factor for effective education (Fortus & Touitou, 2021). Despite the acknowledged importance of motivation, many educational systems face challenges related to student apathy. This issue is particularly pronounced in subjects such as chemistry, where maintaining student engagement remains a significant hurdle. Daubenfeld and Zenker (2015) addressed this challenge by developing educational modules incorporating game-based learning to enhance motivation for self-directed learning outside of classroom settings. Their findings suggest that game-based learning can significantly boost student motivation and engagement in chemistry.

The role of motivation in digital educational games is central to their effectiveness. Motivated students are more likely to engage actively with the material, whether in a classroom or online setting. However, further research is needed to fully understand the impact of intrinsic and extrinsic motivations on game-based learning. Recent studies, such as those by Van der Meij et al. (2020), have explored additional design elements, such as collaborative features, to improve peer interaction and the overall effectiveness of educational games. Despite these efforts, significant improvements in motivation levels remain elusive. The authors suggest that considerations regarding the time investment required for gameplay could help maintain student interest.

To wit, modernizing education with engaging teaching methods is crucial as schools grapple with academic achievement and student motivation. Digital game-based learning, particularly in subjects like chemistry, can enhance interest and knowledge retention without needing internet access. The main challenge is creating effective and enjoyable learning experiences to boost chemistry literacy and motivate students towards advanced degrees and careers. Introducing educational games as a review material for the mastery of a certain concept can address these issues by increasing student engagement and motivation.

3. Methodology

This section presents the technical approach and design decisions in the development of the game app. This study consists of three phases: (1) development and validation of the game app; (2) implementation phase; and (3) analysis and evaluation phase.

3.1 Development and Validation of the Game App

For the game app's development methodology, the STEM digital game-based learning strategy developed by Ishak SA et al. (2021) was utilized as guide as it offers a linear input-process-output structure (Figure 1). Any game designer, developer, or even educator can use this method to produce a captivating STEM digital game for students.

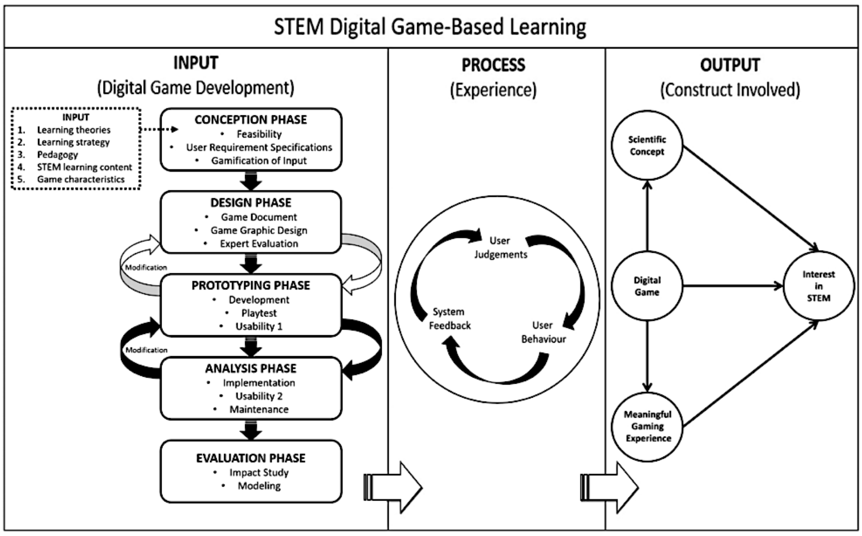

Figure 1. Framework on STEM Digital Game-based Learning (Ishak SA et al.,2021).

This framework was used to guide the researcher and game designers in the creation and evaluation of games, as well as to assist validators in assessing and supporting a game-based session. Three games were developed using Unity software which is a cross-platform game engine developed by Unity Technologies to gradually extend support to a variety of desktop, mobile, console, and virtual reality platforms. This real-time game development platform is free to use to create and build games.

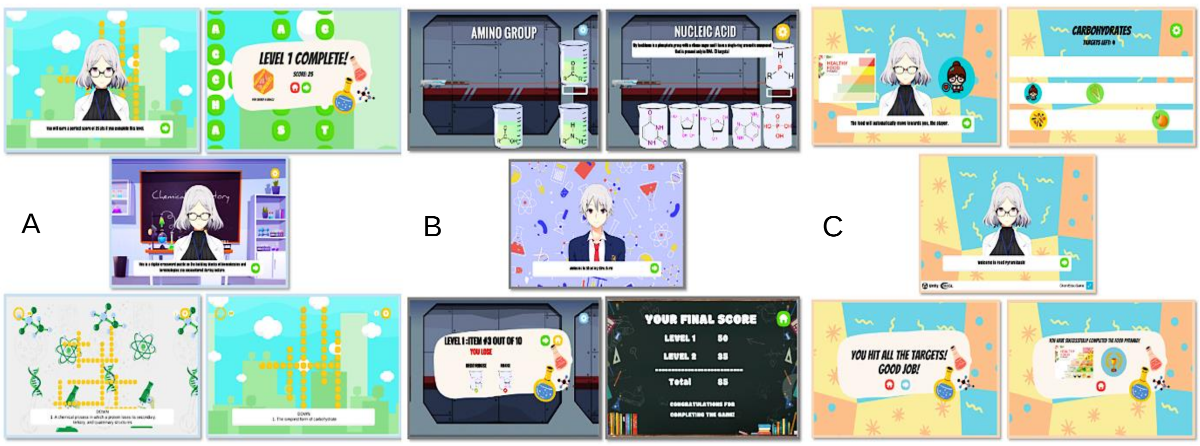

Figure 2. Screenshot of BioMol DigiGames application design (A – Puzzbuild, B – Shooting Strucher, C – Food Pyramidash).

These games tackle the four biological molecules with varying complexity as shown in Figure 2. – carbohydrates, proteins, nucleic acids, and lipids. Game 1: PuzzBuild is a crossword puzzle on the building blocks of biomolecules; Game 2: Shooting StruCher is a 3-dimensional shooting game that has a chemical structure and descriptions of the biomolecules; and Game 3: Food PyramiDash is a selector and dash game based on examples of food sources that contain biomolecules that are beneficial to humans. All three games have varying point systems. The games were designed to be played within thirty minutes, excluding the delivery of instructions before the actual gameplay and the debriefing process after the actual gameplay. The students were able to play each game for at least four meetings, including a session for debriefing.

3.2 Implementation Phase

A quasi-experimental, non-randomized pretest-posttest group design was employed. There were two heterogeneous general chemistry 1 classes: the NGBL (control) with 51 students, which underwent the conventional way of learning and mastering biomolecules such as answering worksheets, and the DGBL (experimental) with 49 students, which experienced playing the BioMol DigiGames as an intervention (Figure 3).

The students in both groups were handled by the same subject teacher to avoid duress. The NGBL group was given 4 sessions to answer the worksheets in which the content is congruent with the DGBL group to have equal opportunities when it comes to knowledge content.

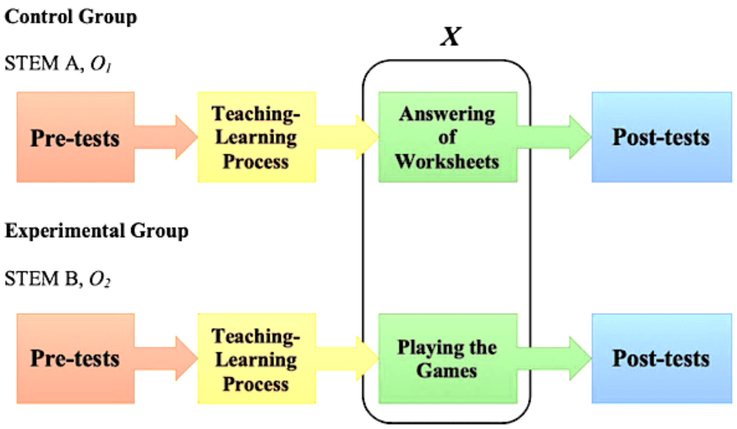

Figure 3. Quasi-experimental nonrandomized pretest posttest group design.

3.3 Analysis and Evaluation Phase

Microsoft Excel 2016 and IBM Statistical Package for Social Science (SPSS) Statistics version 26 were used in the presentation and quantitative analysis of data. On the other hand, qualitative methodologies were employed to have a richer and more comprehensive understanding of outcomes. The entertainment, educational aspects, attitudinal, motivational, and evaluation of the game app were elicited using adopted questionnaires developed by Da Silva Júnior, J. N. et al. (2022), Chemistry Lessons Scale by Cheung (2011), and Chemistry Motivation Questionnaire II adopted from Salta and Koulougliotis (2015) which were used by evaluators, validators, and student participants. Then, the game app was further evaluated using an evaluation rubric made by Bactong, G. et al. (2021). An open-ended questionnaire was administered, followed by a focus group discussion, and interviews were held on the school premises depending on students' on-site schedules.

4. Results and Discussion

4.1 Evaluation of the Game App

Expert panels and student users evaluated the developed BioMol DigiGames application based on five criteria established by Walag et al. (2021). Table 1 summarizes the findings.

Table 1. *Results of the Game App Evaluation as adopted from Bactong, G. et al. (2021).*

Criteria	Mean ± SD	Description
Accuracy of Concept	4.00 ± 0.00	Contents are scientifically accurate concepts. Graphics promote understanding of science concepts. (Very Good)
Attractiveness	3.60 ± 0.55	The game app is readable, has illustrations that complement the text, and has appropriate media type. (Very Good)
Functionality	3.40 ± 0.55	Student can launch and operate the application with minimal supervision. (Good)
Accessibility	4.00 ± 0.00	The game app exceptionally is downloadable and does not require an internet connection. (Very Good)
Interactivity	4.00 ± 0.00	The game app allows user to interact effectively with the application's features, content, and functions. (Very Good)
Total	**3.80**	**Very good**

As shown in Table 1, the game app has been rated "very good" in most of the criteria. It is notable that the accuracy of concept, accessibility, and interactivity have all received perfect scores. These criteria focus more on the app's ability to operate well, execute its functions, and be user-friendly. Attractiveness and functionality got a slight low mean rating of 3.60 and 3.40, respectively, which calls for further improvement on their graphics and design, fault tolerance, and other system-related operation errors. Nonetheless, the final mean rating of 3.80 reveals that the evaluators are highly satisfied with its overall performance.

This is significant because effective integration of technology into instruction requires not only the provision of instructions and information, but also the encouragement of student engagement in the learning process through interactive features. It has been established that conventional classrooms can benefit from the incorporation of accessible interactive technologies into the teaching-learning process (Walag et al., 2021). Listed below are a number of verbatim comments from experts who used the app to support the evaluation of the students.

Comments:

1. The developed game application is well-made. The illustrations and features of the app are very commendable, as they indeed capture the attention of the user.
2. The game app is interactive and develops critical thinking skills. Moreover, the concepts are contextualized, which allows the learners to understand the importance of the topics given.
3. Overall, it is a great complementary tool for helping the students effectively learn concepts in chemistry while maintaining enjoyment and interactivity.

Based from the study of da Silva Júnior JN et al., (2021), this section summarized these aspects into ten categories based from the recommendations: goal, rules, interaction, catch-up feature, inertia, surprise, strategy, flavor, hook, and fun. To prove this, the students evaluated if the BioMol DigiGames had entertainment and educational aspects by responding to two surveys containing 10 statements, adopting a Likert-type scale. Additionally, the students also rated the game (by attributing a score from 0 to 10), evaluating it as an educational tool for reviewing the topics related to biomolecules. The mean game rating was 4.44 ± 0.632, showing that the students approved the game app as an educational tool for reviewing and mastery of the topics related to the structure and function of biomolecules. The student's high level of agreement (strongly agree and agree) was shown in Figures 4 and 5, and the high scores or percentages demonstrate that the game app contain all the necessary entertainment and educational elements to attract players. This merely indicates that the game is an engaging learning tool that allows students to review and master biomolecules-related content.

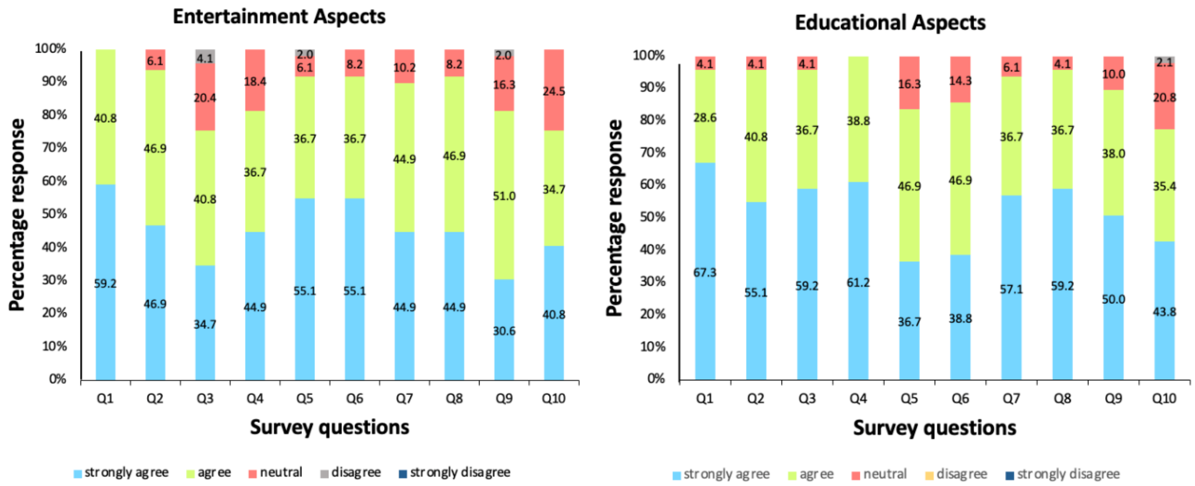

Figure 4 and 5. Entertainment and Educational aspects – distribution of students' responses to survey statements after playing BioMol DigiGames.

For the educational aspect, it can be highlighted that eight out of the ten statements got a high percentage of strongly agree. Both Q5 and Q6 got 46.9% for agree which suggests that the game must improve on the content that is presented in macroscopic, submicroscopic, and symbolic levels of understanding chemistry. More so with Q6, it can be drawn that the clues (power-ups) presented at each level help the students answer the items in the game. This must be incorporated more to other games since it was only evident in Game 1: *PuzzBuild*. The students also commented on their remote gaming experiences, which were generally very beneficial to their education. There are three of these comments listed below:

1. "The graphics and easy-to-understand gameplay are appealing. You don't even need a guide. Since I enjoy watching anime, I also enjoy the anime characters that have been incorporated into the game."
2. "I liked that it could be easily downloaded and played on my android phone, so I didn't have to do a great deal of preparation before playing. I could begin playing at any time and in any location."
3. "What I like most about is that it is more than just a game. It is a learning tool. It provides a concise summary of the previous days' discussions on the topic.

This is significant because effective integration of technology into instruction requires not only the provision of instructions and information, but also the encouragement of student engagement in the learning process through interactive features. It has been established that conventional classrooms can benefit from the incorporation of accessible interactive technologies into the teaching-learning process (Bactong, G. et al., 2021).

4.2 Educational-related Results

Statistical analyses showed significant effects on students' academic performance, short-term retention, attitude toward chemistry, and motivation toward chemistry. Significant correlations were found between post- academic performance and short-term retention ($p = 0.021^{*}$); academic performance and chemistry motivation ($p = 0.027^{*}$); and attitude and chemistry motivation ($p = 0.001^{***}$). However, a low correlation was observed between academic performance and attitude toward chemistry (p = 0.418) as shown in Table 2.

Table 2. *F-test for the significance of correlation between posttest academic performance scores, short-term retention scores, posttest attitude scores, and posttest motivation scores. Results are expressed as Mean ± SD and significant differences at *p<0.05.*

Correlated variables	*r*	*F*-value	df	*p*-value
Academic performance → short-term retention	0.328	5.666	48	**0.021***
Academic performance → attitude in chemistry	0.118	0.668	48	0.418
Academic performance → motivation	0.316	5.227	48	**0.027***
Attitude → motivation	0.701	5.477	48	**<0.001***

This means that after playing, the change in short-term retention and motivation would result in a significant change in students' academic performance and implies a strong positive correlation. On the other hand, there is no significant correlation between academic performance and post-test attitude scores, F (1,48) = 0.668, p = 0.418. It was found that the lack of experimental work embedded in the game is one of the reasons why a change in attitude would not result in a significant change in academic performance. Hence, students may still perform better in academics even if their attitudes did not correlate.

Additionally, it is highlighted that the DGBL group does not have students with a negative motivation towards chemistry after playing, unlike the NGBL group, where a student is demotivated in learning biomolecules. The posttest motivation scores of the students from both groups were compared using the t-test for independent samples as showed in Table 3.

Table 3. *t-test for independent sample analysis of posttest motivation and subscale scores. Results are expressed as Mean ± SD and significant differences at *p<0.05.*

	NGBL *(n=51)*		**DGBL** *(n=49)*					
	Mean	SD	Mean	SD	$\overline{x}_d$	*t*-value	df	*p*-value
Posttest	**3.51**	**0.507**	**3.84**	**0.439**	-0.33	**-3.426**	98	**<0.001***
Subscales								
Grade motivation								
	3.73	0.643	3.91	0.583	-0.18	-1.447	98	0.151
Self-efficacy								
	3.32	0.535	3.69	0.549	-0.37	-3.393	98	**<0.001***
Self-determination								
	3.46	0.634	3.76	0.545	-0.30	-2.503	98	**0.014***
Career motivation								
	3.35	0.698	3.78	0.668	-0.43	-3.178	98	**0.002****
Intrinsic motivation								
	3.70	0.620	4.05	0.537	-0.35	-3.022	98	**0.003****

The observed significant difference in posttest motivation scores between the two groups is consistent with the findings of multiple studies on game-based learning. For instance, according to the player experience of the need satisfaction model, features of DGBL environments such as HoloLAB Champions can support fundamental psychological needs for autonomy, competence (e.g., leveling up by optimal challenge), and relatedness resulting in intrinsic motivation Consequently, game design and instructional design seek to increase motivation to learn (Plass et al., 2020), such as through the use of a reward system and motivating music in HoloLAB Champions.

Additional design measures, such as collaboration, have been implemented in this study to improve peer communication and enhance the effectiveness of educational games. Thus, engagement, motivation and learning represent a unity directed towards learning based on digital educational games (Breien & Wasson, 2021). The impact of interventions used per learning group was further determined by gain score analysis. This ration indicates the relative improvement of academic performance from pretest to posttest as shown in Table 4.

Table 4. *t-test for independent sample analysis of academic performance gain scores. Results are expressed as Mean ± SD and significant differences at *p<0.05.*

	NGBL *(n=51)*		**DGBL** *(n=49)*					
	Mean	SD	Mean	SD	$\overline{x}_d$	*t*-value	d*f*	*p*-value
Gain Score	8.02	4.067	10.18	3.127	-2.16	-2.974	98	**0.004****

The results suggest that the use of BioMol DigiGames in teaching, learning, and mastery of biomolecules is more advantageous in enhancing the student's academic performance since after playing, students received immediate feedback during the debriefing process, which may help the students understand, clarify, and retain the knowledge over non-game-based approaches. More so, playing the games collaboratively encourages the students to exchange ideas and learn from one another.

Comparing this with other games on chemistry such as Organic Fanatic, which is a quiz-based mobile app that has an arcade-style game (Shoesmith, J. et al., 2020), and STR120, a web- based board game that can be played remotely (da Silva Júnior JN et al., 2022), BioMol DigiGames provides 3 games in 1 app with varying levels that can be played free-of-charge and remotely. This feature may add up to one of the differences between the developed game app and the other, as it entices students to have three games to play conveniently with.

5. Conclusion

BioMol DigiGames as an application of DGBL had a significant effect on the students' academic performance, short-term retention, attitude, and motivation towards chemistry. These are supported by the students' qualitative responses, indicating that they have learned the lesson from the activities, experienced enjoyment while playing, and developed a preference for chemistry. At the same time, it also had a significant positive effect on the students' liking for chemistry theory lessons and their behavioral tendencies to learn chemistry. DGBL has also made students more motivated, both career-wise and intrinsically. Overall, the use of DGBL approach in designing and developing an offline game app such as the BioMol DigiGames should be strengthen and incorporated in the teaching-learning process in the mastery of the structure and function of biomolecules. This developed app is downloaded and can be played on Android devices. It is recommended to have it available on iOS and include small-scale laboratory activities to increase students' attitude and motivation. Lastly, examine how these games affect students with varying logic abilities and optimize the use of the TOLT (Test of Logical Thinking) to assess students' formal reasoning skills.

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References

Anderson, J., & Rainie, L. (2012). Gamification and the internet: Experts expect game layers to expand in the future, with positive and negative results. *Games Health J, 1*(4), 299-302. https://doi.org/10.1089/g4h.2012.0027

Arztmann, M., Hornstra, L., Jeuring, J., & Kester, L. (2023). Effects of games in STEM education: A meta-analysis on the moderating role of student background characteristics. Studies in Science Education, 59(1), 109–145. https://doi.org/10.1080/03057267.2022.2057732

Bactong, G., Sabas, A., Salva, K., Lituañas, A., & Walag, A. M. (2021). Design, development, and evaluation of CHEMBOND: An educational mobile application for the mastery of binary ionic bonding topic in chemistry. *Journal of Information Technology and Learning, 1*(1), 4-9. https://doi.org/10.12691/jitl-1-1-2

Bonafe, C. F. S., Bispo, J. A. C., & De Jesus, M. B. (2017). The polygonal model: A simple representation of biomolecules as a tool for teaching metabolism. *Biochemistry and Molecular Biology Education, 46*(1), 66–75. https://doi.org/10.1002/bmb.21093

Cheung, D. (2011). Evaluating student attitudes toward chemistry lessons to enhance teaching in the secondary school. *Educación Química, 22*(2), 117–122. https://doi.org/10.1016/s0187-893x(18)30123-x

Cook, E., Kennedy, E., & McGuire, S. Y. (2013). Effect of teaching metacognitive learning strategies on performance in general chemistry courses. *Journal of Chemical Education, 90*(8), 961–967. https://doi.org/10.1021/ed300686h

Da Silva Júnior, J. N., Winum, J., Basso, A., Gelati, L., Moni, L., Leite, A. J. M., Junior, Mafezoli, J., Zampieri, D., Alexandre, F. S. O., Veja, K. B., & Monteiro, A. J. (2022). STR120: A web-based board game for aiding students in review of the structural theory of organic compounds. *Journal of Chemical Education, 99*(9), 3315–3322. https://doi.org/10.1021/acs.jchemed.2c00389

Daubenfeld T, Zenker D. 2015. A game-based approach to an entire physical chemistry course. J Chem Educ. 92(2): 269−277. doi: 10.1021/ed5001697

Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computers & Education, 67*, 156–167. https://doi.org/10.1016/j.compedu.2013.02.019

Fortus, D., & Touitou, I. (2021). Changes to students' motivation to learn science. Disciplinary and Interdisciplinary Science Education Research, 3(1), Article 1. https://doi.org/10.1186/s43031-020-00029-0

Gao, F., Li, L., & Sun, Y.-Y. (2020). A systematic review of mobile game-based learning in STEM education. Educational Technology Research and Development, 68(4), 1791–1827. https://doi.org/10.1007/s11423-020-09787-0

Ishak, S. A., Din, R., & Hasran, U. A. (2021). Defining digital game-based learning for science, technology, engineering, and mathematics: A new perspective on design and developmental research. *Journal of Medical Internet Research, 23*(2), e20537. https://doi.org/10.2196/20537

John Gilbert, Kakonge, & Treagust, D. (2009). Multiple representations in chemical education. https://doi.org/10.1007/978-1

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in science education: A systematic review of the literature. *Education Sciences, 11*(1), 22. https://doi.org/10.3390/educsci11010022

Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In R. E. Ferdig (Ed.), *Handbook of research on effective electronic gaming in education* (pp. 1-32).

Klopfer, E., & Thompson, M. (2020). Game-based learning in science, technology, engineering, and mathematics. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), *Handbook of game-based learning* (pp. 387–408). MIT Press.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Press.

Licorish, S. A., Owen, H. E., Daniel, B., & George, J. L. (2018). Students' perception of Kahoot!'s influence on teaching and learning. *Research and Practice in Technology Enhanced Learning, 13*(1). https://doi.org/10.1186/s41039-018-0078-8

Linn, M. (2003). Technology and science education: Starting points, research programs, and trends. *International Journal of Science Education, 25*(6), 727–758. https://doi.org/10.1080/09500690305017

Perrotta, C. (2013). Game-based learning: Latest evidence and future directions.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist, 50*(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Salta, K., & Koulougliotis, D. (2015). Assessing motivation to learn chemistry: Adaptation and validation of Science Motivation Questionnaire II with Greek secondary school students. *Chemistry Education Research and Practice, 16*(2), 237–250. https://doi.org/10.1039/c4rp00196f

Saraiva, F., Lima, L. V. O., Araújo, C., Magalhães, L. G., & Henriques, P. R. (2021). SHREWS: A game with augmented reality for training computational thinking (short paper). *Schloss Dagstuhl*, 10. https://doi.org/10.4230/oasics.icpec.2021.14

Tham L, Tham R. 2012. Is game-based learning an effective instructional strategy to engage students in higher education in Singapore? A pilot study. Journal of the Research Center for Educational Technology. 8(1): 2-10.

Treagust, D., Duit, R., & Nieswandt, M. (2000). Sources of students difficulties in learning chemistry.*Educación Química, 11*, 228-235. https://doi.org/10.22201/fq.18708404e.2000.2.66458

Tuomisto, M., & Aksela, M. (2015). Design and evaluation framework for relevant chemistry-related educational card and board games. *LUMAT International Journal on Math Science and Technology Education, 3*(4), 429–438. https://doi.org/10.31129/lumat.v3i4.1014

Wang, LH., Chen, B., Hwang, GJ. et al. Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. IJ STEM Ed 9, 26 (2022). https://doi.org/10.1186/s40594-022-00344-0