Journal of Pedagogical Research
Volume 8, Issue 2, 2024
https://doi.org/10.33902/JPR.202425578

Research Article

Beyond play: The interplay of analogy and enjoyment in game-based learning

Sittichai Wichaidit[1] and Patcharee R. Wichaidit[2]

[1]*Faculty of Learning Sciences and Education, Thammasat University, Thailand (ORCID: 0009-0009-4189-0250)*
[2]*Department of Curriculum and Instruction, Faculty of Education, Chulalongkorn University, Thailand (ORCID: 0000-0002-2121-5655)*

Game-based learning has gained significant attention from educational researchers because of its ability to create an engaging and enjoyable learning environment for students. However, there was a research gap regarding the design of game mechanics that specifically helped students understand abstract scientific concepts. Also, the impact of increased motivation, interest, and engagement on conceptual understanding remained uncertain. The objective of this study was, therefore, to analyze the efficacy of using analogy teaching as a learning design principle for creating game mechanics to improve students' conceptions of bioaccumulation and biomagnification. Additionally, the study aimed to investigate whether providing a clear analogy comparison after gameplay could have a significant impact on students' learning outcomes. The research also examined the correlation between students' enjoyment level during gameplay and their learning outcomes. An embedded experimental mixed methods design was utilized to address the research objectives. The participants were 54 undergraduate students from non-science disciplines. They were divided into two groups: the Game-based Learning [GL] group and the Game-based Learning with eXplicit analogy discussion [GLX] group. Both groups used a board game to learn about bioaccumulation and biomagnification. The GL group had reflective discussions about the concepts after playing the game. The GLX group had an additional task where they identified similarities and differences between the gameplay and the scientific concepts, and they explicitly discussed these through a worksheet provided before the discussion. Results showed that after engaging in game-based learning, both groups exhibited a significant improvement in their understanding of bioaccumulation and biomagnification, moving from incomplete or partial understanding to more scientifically accurate concepts. Notably, the GLX group scored higher in post-tests compared to the GL group. Despite high levels of enjoyment during gameplay, there was no correlation between this enjoyment and the post-test scores. An unexpected slight negative correlation was found between immersion during the game and post-test scores. Discussion and implementation of the research results were provided.

Keywords: Game-based learning; Analogy teaching; Conceptual development; Enjoyment

Article History: Submitted 21 December 2023; Revised 2 March 2024; Published online 24 April 2024

1. Introduction

The integration of various forms of games to support learning has attracted the attention of educators and researchers, due to the ability to create an engaging and enjoyable learning environment for students (Klopfer et al., 2009; Li et al., 2022). Research has shown that games can

Address of Corresponding Author

Patcharee R. Wichaidit, Department of Curriculum and Instruction, Faculty of Education, Chulalongkorn University, Pathum Wan, Bangkok, 10330, Thailand.

patchareerompayom.w@chula.ac.th

How to cite: Wichaidit, S. & Wichaidit, P. R. (2024). Beyond play: The interplay of analogy and enjoyment in game-based learning. *Journal of Pedagogical Research*, *8*(2), 276-295. https://doi.org/10.33902/JPR.202425578

be effective in improving knowledge understanding (Hsu et al., 2011; Jasti, et al., 2016; Spiegel et al., 2008), as well as problem-solving (Spires et al., 2011) and scientific argumentation skills (Squire & Jan, 2007), whether through interpersonal interactions in the classroom (Fjællingsdal & Klöckner, 2020) or via digital platforms (Barab & Dede, 2007). However, it is important to note that educational games should be used to achieve specific learning objectives and game mechanics must be part of a well-designed instructional process to ensure that the desired learning outcomes are achieved (Aleven et al., 2010).

Game mechanics are essential elements in game design that affect learners across various domains, including affective, behavioral, cognitive, and sociocultural aspects (Plass et al., 2015). Aleven et al. (2010) defined game mechanics as *"the basic components out of which the game is built: the materials, rules, explicit goals, basic moves, and control options available to the players"*

Scholars have emphasized the significance of designing game mechanics that is consistent with instructional design to promote learning within educational games (Gunter et al., 2008; Plass et al., 2015). In other words, educational game mechanics can be designed effectively by applying appropriate learning design principles. These principles can help create games that engage students to learn (Aleven et al., 2010).

While many studies have explored the benefits of using games to enhance learning, there remains a gap in research regarding the design of game mechanics that can specifically help students understand abstract scientific concepts. One of the learning design principles that can simplify complex and abstract scientific ideas is analogy teaching. By relating unfamiliar ideas to something within the student's existing knowledge, analogies provide a bridge from the known to the unknown, allowing students to grasp intricate concepts that might otherwise prove challenging (Glynn & Takahashi, 1998). Therefore, designing game mechanics based on the concept of analogy teaching could potentially help students grasp abstract and complex scientific concepts. Furthermore, game elements such as competition, point accumulation, and collaborative gameplay might enhance students' enjoyment and social interaction, which are crucial components of learning (Plass et al., 2020)

Bioaccumulation and biomagnification are abstract and complex scientific concepts related to environmental issues. Schlussel et al. (2018) found that distinguishing between bioaccumulation and biomagnification can be challenging for students. While bioaccumulation describes the build-up of external substances in organisms without specifying the entry pathway, biomagnification relates to the increased concentration of residual substances along food chains and is mainly associated with dietary absorption (Arnot & Gobas, 2006; Connell, 1990; Woodwell et al., 1967). Biomagnification is a complex concept that involves other scientific concepts such as food webs, mass transfer in an ecosystem, and trophic levels. However, some students mistakenly believe biomagnification and bioaccumulation are the same, or that biomagnification only occurs with heavy metals (Kim & Kim, 2013). Therefore, it is interesting to consider how the principles of analogy teaching can be employed in designing game mechanics to facilitate the understanding of complex and abstract scientific concepts such as bioaccumulation and biomagnification.

To make the most effective use of analogies, several studies suggest that a phase of discussion should be included which compares the similarities and differences between scientific concepts and the analogy used. This ensures that learners develop a correct understanding and avoid any misconceptions that may arise from the analogy (Harrison & Treagust, 1993; Treagust et al., 1992; Venville, 2008). Therefore, when designing game mechanics, it's important to have an additional activity for analogy comparison after gameplay. However, this step might extend the learning time and cognitive load for the students as they need to compare and contrast the analogy to understand scientific concepts by themselves. Therefore, research is required to determine the necessity of an analogy comparison activity after gameplay when incorporating analogy principles to design game mechanics.

Furthermore, Li and Tsai (2013) reviewed empirical research articles on game-based science learning [GBSL] published from 2000 to 2011 and argued that there was an implicit assumption that playing games leads to learning. It's crucial to validate this assumption by analyzing the correlation between in-game performance, gaming behaviors, and science learning outcomes. Interestingly, the impact of increased motivation, interest, and engagement on cognitive learning outcomes, such as scientific knowledge and problem-solving, remains uncertain.

The objective of this research is to explore the effectiveness of using analogy teaching as a learning design principle to create game mechanics to enhance student's conceptions of bioaccumulation and biomagnification. Importantly, this study aims to investigate whether providing an explicit analogy comparison after gameplay significantly improves students' learning outcomes. Moreover, the correlation between the students' enjoyment level during gameplay and their learning outcomes is examined. This research provides valuable insights into the use of analogy teaching in game mechanics design and will offer evidence to either support or challenge the claims about the relationship between cognitive and affective factors in game-based learning. The research questions are as follows:

RQ 1) What is the effectiveness of using analogy game learning to enhance student's conceptions of bioaccumulation and biomagnification?

RQ 2) What is the impact of explicit analogy comparison activity on students' conception after the gameplay?

RQ 3) What is the relationship between students' enjoyment and students' conception after the gameplay?

RQ 4) What are the students' opinions of gameplay in terms of how it contributes to learning of bioaccumulation and biomagnification?

2. Literature Review

2.1. Game-Based Learning

Games and game-like environments offer students a chance to learn through practical and authentic experiences (Liu et al., 2014). If games are successful in creating virtual experiences that focus on problem-solving and stimulate learning and mastery as a source of pleasure, they can be seen as powerful tools for deep learning (Gee, 2008). Klopfer et al. (2009) defined games as structured activities with a defined set of rules, where players aim to tackle challenges to achieve a specific objective. Games have a long history of being effective instructional methods. For example, chess, a game dating back to the seventh century, was used to teach military forces strategic decision-making and logical thinking (Kende & Seres, 2006). Games can engage learners on cognitive, affective, behavioral, and sociocultural levels in unique ways. Game-based learning is a form of gameplay designed with clear educational goals in mind (Plass et al., 2015). The potential of game-based learning as an effective instructional method lies in its ability to provide learners with situated learning experiences by immersing learners in game environments that simulate real-world scenarios. GBL enables students to apply their knowledge in contextually relevant settings. This level of immersion fosters a deeper understanding of the subject matter, promotes collaboration, and enhances problem-solving skills (Barab et al., 2007; Squire & Klopfer, 2007; Yien et al., 2011).

The literature has extensively explored the potential of digital games to enhance students' learning experiences, especially in scientific knowledge, scientific processes, and problem-solving (Anderson & Barnett, 2011; Annetta et al., 2009). Barab and Dede (2007) highlighted that digital games can be used as immersive participatory simulations for science education, providing a practical application of theoretical knowledge. In addition, Carr and Bossomaier (2011) conducted a study on physics learning through a computer game, which demonstrated the pedagogical potential of such platforms. While digital games offer immersive experiences, board games present a unique opportunity for face-to-face dialogue and communication. Fjællingsdal and Klöckner's (2020) explores the potential of board games in fostering environmental awareness. Board games such as "Global Warming" by Bucak (2011) and "The Celsius Game" (Carreira et al., 2017) are designed to simulate real-world challenges related to climate change, offering players a tangible understanding of complex issues. These games not only educate but also facilitate discussions on sustainability, climate change, and the broader implications of human actions on the environment. In conclusion, both digital and board games have the potential to enhance learning and promote critical thinking by connecting theoretical knowledge with real-world applications.

2.2. Teaching with Analogy

Analogies are powerful pedagogical tools that can be used to explain complex scientific concepts by draw relationships between familiar concepts and novel scientific phenomena (Jaeger et al., 2016; Treagust et al., 1992). In classrooms, teachers often use analogies to explain scientific concepts. For instance, they might compare arteries or veins to hoses or tubes, describe the eye's function similar to a camera, and categorize plants, animals, and microorganisms as one would organize different sections in a supermarket, such as fresh produce, canned items, stationery, and cleaning products (Harrison & Coll, 2008). Analogies serve as bridges between the known and the unknown, helping students to grasp intricate or abstract ideas by relating them to something they already understand (Glynn & Takahashi, 1998). When analogies are presented in scientific texts or instructional materials, they can significantly enhance comprehension of difficult concepts by providing a shared terminology and framework, making abstract concepts concrete, and aiding in memory retention (Halpern et al., 1990). Moreover, the use of analogies often involves visualization, which is crucial for understanding certain scientific concepts, especially those that are abstract or hard to imagine. Analogies can enhance students' spatial skills, allowing them to construct mental representations and better understand scientific processes or systems (Jaeger et al., 2016).

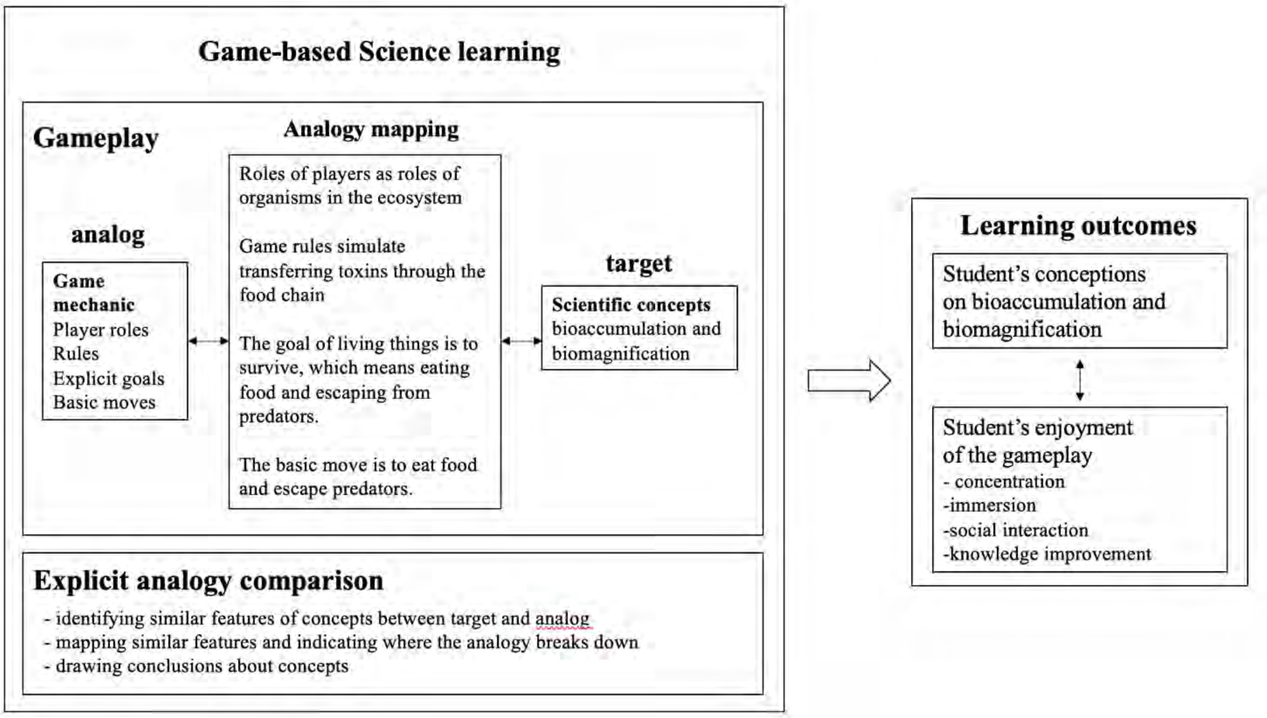
However, students might fail to recognize how analogies represent scientific concepts. Frequently, students may interact with instructional tools such as diagrams or models without realizing how these tools accurately reflect the underlying scientific phenomena they aim to represent (Gobert & Buckley, 2000; Lehrer & Schauble, 2005; Vosniadou & Brewer, 1992). It is important to note that analogies possess certain limitations regarding their ability to precisely represent reality, which may not be fully comprehended by some students (Cvenic et al., 2021). Moreover, analogies can hinder learning by adding to the cognitive load of the task when the analogy is more complex or less understandable than the science concept being taught (Dagher, 1995). Therefore, systematic guidance is needed during analogy teaching (Niebert et al., 2012)

Various systematic approaches have been suggested on how analogy can enhance the understanding of science. One approach involves using bridging analogies, which connect familiar concepts to new scientific ideas. For these analogies to benefit learners, the teacher might need to provide clear guidance and instruction (Brown & Clement, 1989; Clement, 1988). Another framework was Teaching With Analogies Model which offered a clear sequence of steps to maximize the effective use of an analogy, including 1) introducing the target concept, 2) recalling the analog concept, 3) identifying similar features of concepts between the target and analog 4) mapping similar features 5) indicating where the analogy breaks down 6) drawing conclusions about concepts (Harrison & Treagust, 1993). Lastly, the FAR guide divided the analogy process into three stages: Focus (preparation before class), Action (activities during class), and Reflection (review after class). The Focus phase emphasizes pre-class planning to ensure effective analogy use, while the Action phase involves identifying the similarity between the subject and analogy and recognizing where the analogy breaks down, and the Reflection phase considers the clarity and usefulness of the analogy (Harrison & Coll, 2008; Treagust et al., 1992; Venville, 2008). All the mentioned approaches emphasized the importance of explicitly comparing the similarities and differences between scientific concepts and their analogues. Therefore, when designing learning experiences using games that employ analogies, it would be crucial to prioritize such comparisons after the gameplay.

3. Conceptual Framework

This research is based on the theory of game-based learning, which emphasizes the use of games to facilitate the learning process towards learning objectives (Plass et al., 2015). The game mechanics are designed using the principle of analogy teaching (Harrison & Coll, 2008). That is, components in the game mechanics such as player roles, rules, explicit goals, and basic moves serve as analogs, which are familiar and tangible to students. The abstract scientific concepts are bioaccumulation and biomagnification, which are the target concepts for learning. Analogy mapping is a crucial part where students connect ideas from the analog to the target. An additional aspect beyond gameplay is the explicit analogy comparison, where students must compare similarities and differences between the analog and the target and conclude the knowledge themselves (Harrison & Treagust, 1993). The learning objectives are the student's conception of bioaccumulation and biomagnification and the student's enjoyment of gameplay. Moreover, this research also examines the relationship between the students' conceptions after playing the game and their enjoyment. Figure 1 shows the conceptual framework of this study.

Figure 1
Conceptual framework of the study



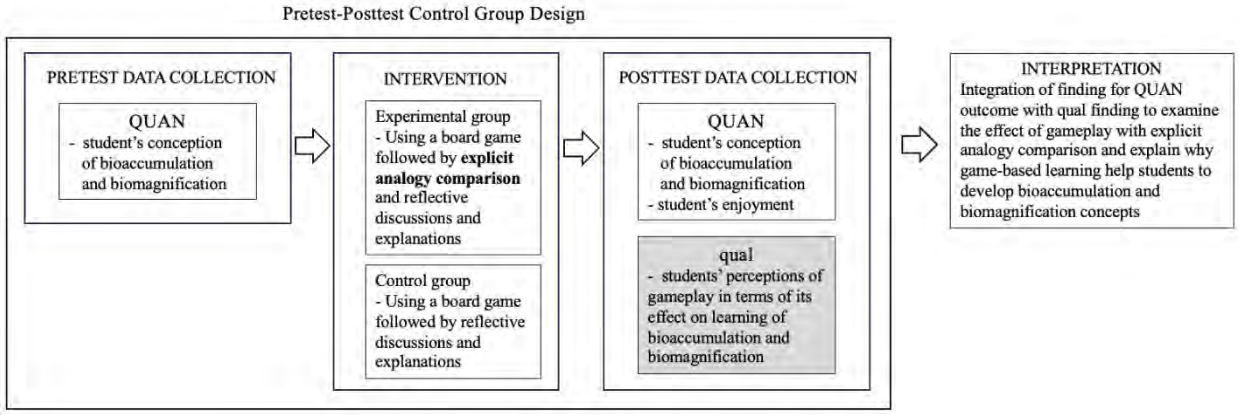
4. Method

4.1. Research Design

This study utilized an embedded mixed methods design where both quantitative and qualitative data were collected and analyzed within a traditional quantitative design. This method has been used to evaluate the effectiveness of pedagogy or instruction in many studies. For instance, Aydın and Çakır (2022) conducted a study using an embedded experimental mixed methods design to examine the impact of game-based learning on language acquisition. Similarly, Ziegler (2014) utilized an embedded experimental mixed methods design and qualitative data to understand the perceptions of students and teachers regarding The European Language Portfolio [ELP]. In this study, the primary research question was whether game-based learning, with explicit analogy comparison, can aid students in developing the concepts of biomagnification and bioaccumulation. The study also explored the level of enjoyment students experienced during the game and whether this was related to their understanding of scientific concepts. Therefore, the primary approach was a quasi-control group experimental design, involving a control group and an experimental group. The control group, Game-based Learning [GL] group, engaged in learning using a board game, followed by reflective discussions of the concepts of bioaccumulation and biomagnification. Meanwhile, the experimental group, Game-based Learning with eXplicit analogy discussion [GLX] group, also used the board game for learning but followed this with a task where students identified similarities and differences between the gameplay and the scientific concepts of bioaccumulation and biomagnification, explicitly articulating these through a worksheet provided before they also involved in the discussion part. The secondary research question was why did game-based learning help students learn abstract concepts such as bioaccumulation and biomagnification? To answer this question, students' reflective writings were collected as qualitative data and analyzed using thematic analysis to describe and explain why game-based learning helps students to learn. The methodology framework is illustrated in Figure 2.

Figure 2

An Embedded Experimental Design Framework



4.2. Participants

The participants in this research were 54 undergraduate students from non-science disciplines. They enrolled in a course with the researcher across two sections, leading to the formation of two research groups based on the sections they registered for. Group 1, serving as the control group, consisted of 30 students, while Group 2, the experimental group, had 24 students. Both groups had similar prior learning experiences, being in the same program and familiar with reflective writing, a tool frequently utilized in several courses within their program. Previous studies have examined the impact of game-based learning in university classrooms. For instance, Hartt et al. (2020) found that the use of games affects university students' learning.

4.3. Intervention

4.3.1. The TOXIC CHAIN board game

According to a study by Wichaidit and Sumida (2023), the board game TOXIC CHAIN was designed with the specific educational goal of improving middle school student's understanding of bioaccumulation and biomagnification. The rules and appearance of the board game can be found in their article. Our study, however, focused on the game mechanics that demonstrated an analogy how pesticides could be transferred from one organism to another through the food chain. Furthermore, the analogy showed how top predators in food chains accumulate more toxic substances than other organisms. Table 1 presents the analogy features of the board game.

Table 1

Analogy of bioaccumulation and biomagnification in the TOXIC CHAIN boardgame

Analogs	*Target concepts*	*Similarity*	*Difference*
Roles of players	Roles of organisms in the food chain	Organisms in a food chain consume and are consumed by others.	Organisms have diverse diets, but only specific living things are designated to be consumed in the game.
Rule of collecting beads	Accumulating toxin by eating	The toxin is transferred from one organism to the other when one organism consumes another organism, much like transferring beads from one container to another.	The transfer of toxins from one living organism to another may not transfer all toxins, as some may remain in inedible parts.
Game objectives are to survive by eating food and avoiding predators	The behavior of living things is to survive by eating food and avoiding predators	The goal of the game is to eat food and avoid predators, which aligns with the behavior of living things.	The behavior of living things is indeed more complex than just the basic needs of food and safety. There are many intricacies involved and a variety of factors that can influence an organism's actions.

4.3.2. Explicit analogy comparison worksheet

The Explicit Analogy Comparison Worksheet was created to help students compare the similarities and differences between features in the board game and the scientific concepts of bioaccumulation and biomagnification. The first part provides content descriptions, while the second part poses questions for students to compare game elements and mechanisms with scientific concepts. The experimental group of students completed this worksheet before engaging in a summary discussion and taking a post-test. In contrast, the control group did not work on this worksheet and only participated in the classroom discussion.

4.4. Instruments

4.4.1. Concept cartoon

The Concept Cartoon, designed by Wichaidit and Sumida (2023), was utilized to assess the students' conception of bioaccumulation and biomagnification. This tool presented the thoughts of cartoon characters, and the students indicated whether they agreed or disagreed and provided the reason (Keogh & Naylor, 1999). This study also implemented the interpretation framework from Wichaidit and Sumida (2023) to analyze student's responses. The student's answers to the concept cartoon would show a range of understanding, from a limited conception of bioaccumulation to an accurate conception of bioaccumulation and biomagnification. Table 2 displays the rating scales used to evaluate students' conceptions.

Table 2
Rating scales for evaluating student's conception

Level of conceptions	*Score*	*Student's response*
Limited conception of bioaccumulation	1	Toxic substances can only be obtained by individuals who consume rice from the field
Partially accurate conception of bioaccumulation without biomagnification	2	Toxic substances can be obtained through contamination of air, water, and soil
Partially accurate conception of bioaccumulation with biomagnification	3	Toxic substances can be obtained through contamination of air, water, and soil
Accurate conception of bioaccumulation with biomagnification	4	Toxic substances can be obtained from eating contaminated animals through food chain and organisms higher up in the food chain are more likely to have higher levels of toxic substances than those lower in the food chain.

If students did not incorporate ideas related to biomagnification in their answers, they would receive a score between 1 and 2. Alternatively, answers that included these concepts would receive a score between 3 and 4. The validity of the assessment was verified by a scientist, a science educator, and a science teacher who reviewed the concept cartoon (Wichaidit & Sumida, 2023). To ensure the assessment's reliability, it was administered to 10 students who were not part of the study group. Two people rated their answers, and the agreement between these raters was analyzed, resulting in a reliability score of 80%, showing its accepted reliability for this study.

4.4.2. Student enjoyment of gameplay

In this study, we adapted the learner enjoyment scale from Fu et al. (2009) to evaluate the emotional experience of gameplay and to investigate the correlation between enjoyment levels and students' conceptions after gameplay. The original scale had 56 Likert-type items, where 1 represented the least agreement, and 7 indicated the most agreement with each statement. The adapted scale comprises four dimensions: concentration, immersion, social interaction, and knowledge improvement. We selected a total of 12 statements that align with the gameplay in this research. Examples of the statements are: "Generally speaking, I can remain concentrated in the game," "I forget about time passing while playing the game," "I feel cooperative toward other classmates," and "The game increases my knowledge." To ensure the reliability of the scale, Cronbach's alpha coefficient was calculated, and the result was .76 (N=54).

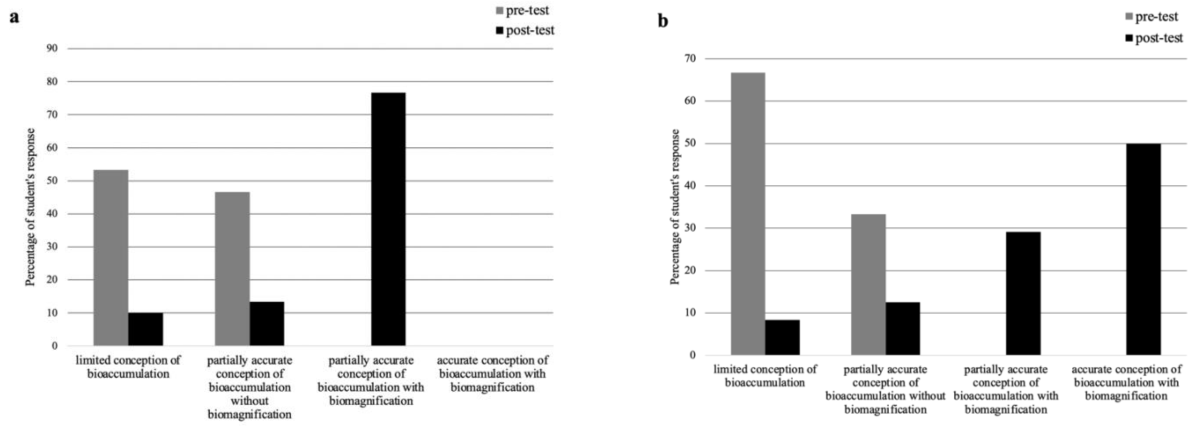
5. Results

This study aimed to achieve four objectives. Firstly, it intended to examine the effectiveness of analogy game-based learning in enhancing students' conceptions of bioaccumulation and biomagnification and how those conceptions changed after learning with game-based learning. Secondly, it sought to investigate the impact of explicit analogy comparison activity on students' conception post-gameplay. Thirdly, it aimed to evaluate the level of enjoyment students experienced during the game and its potential correlation with their understanding of scientific concepts. Lastly, it aimed to analyze students' reflective writings to determine the reasons why game-based learning might aid in understanding abstract concepts. The details of these analyses are as follows.

5.1. The Effectiveness of Analogy Game-based Learning on Students' Conceptions of Bioaccumulation and Biomagnification

In both groups, students who learned through game-based learning expanded their knowledge and enhanced their understanding of bioaccumulation and biomagnification. Following the implementation of game-based learning, the results indicated a significant shift in students' conceptions from limited or partial concepts towards a more scientifically accurate comprehension. Figure 6 displays how students' conceptions changed after game-based learning.

Figure 6
*Percentage of students' conceptions before and after game-based learning: **a** Game-based Learning group, **b** Game-based Learning with eXplicit analogy discussion group*



In the GL group, as illustrated in Figure 6a, there was a decline in students possessing a limited concept of bioaccumulation from 53% to 10%. Similarly, students with a partially accurate concept without biomagnification dropped from 47% to 13%. Notably, there was a substantial rise in students with partially accurate concepts of bioaccumulation and biomagnification, increasing from 0% to 77%. In the GLX group, as shown in Figure 6b, students with a limited conception of bioaccumulation decreased from 67% to 8%. Those with a partially accurate concept without biomagnification reduced from 33% to 13%. Remarkably, students with partially accurate concepts of bioaccumulation and biomagnification increased from 0% to 29%, and those with an accurate concept of both surged from 0% to 50%.

Furthermore, the effectiveness of game-based learning on student understanding was examined. A paired-sample t-test was employed for both groups to analyze the difference between student's scores. Cohen-d was calculated as an effect size measure (see Table 1).

Table 1
Descriptive and Inferential Statistics for Pre-test and Post-test Scores

		N	*Mean*	*Median*	*SD*	*SE*	*t*	*df*	*p*	*Effect size*
GL Group	Pre-test	30	1.47	1.00	0.507	0.0926	8.64**	29	<.001	1.58
	Post-test	30	2.67	3.00	0.661	0.1207				
GLX Group	Pre-test	24	1.33	1.00	0.482	0.0983	9.70**	23	<.001	1.98
	Post-test	24	3.21	3.50	0.977	0.1994				

The study observed a significant increase in the mean score for both the GL and GLX groups from pre-test to post-test. For the GL group, the mean score increased from 1.47 (SD = 0.507) to 2.67 (SD = 0.661), while the median score increased from 1.00 to 3.00. The Student's t-test showed a highly significant difference with a *t*-value of 8.64, df = 29, and $p <.001$, indicating a large effect size of 1.58. Similarly, the GLX group exhibited a significant improvement in student's conception with an increase in the mean score from 1.33 (SD = 0.482) to 3.21 (SD = 0.977), and the median score rose from 1.00 to 3.50. The t-test showed a significant difference between two groups with a *t*-value of 9.70, df = 23, and $p <.001$, and a considerable effect size of 1.98. The results highlight the positive impact of game-based learning, with both groups showing a significant increase in scores from pre-test to post-test. The GLX group had a higher effect size than the GL group.

5.2. The Impact of the Explicit Analogy Discussion on Students' Learning

The students in the GLX group worked on the Explicit Analogy Comparison Worksheet and had a discussion comparing the similarities and the differences between a game mechanic and the process of bioaccumulation and biomagnification after playing the game, while those in the GL group were provided scientific explanations of bioaccumulation and biomagnification after playing the game. To investigate the effectiveness of the explicit analogy discussion on students' scores, the scores of both groups were compared using an independent sample *t*-test. The pre-test scores were compared to ensure that the prior knowledge of both groups was not different. Meanwhile, the post-test scores were compared to test the hypothesis that learners who studied with game-based learning that includes an explicit analogy discussion have higher scores than those who learned through only explaining scientific concepts after playing the game. The results are presented in Table 2.

Table 2
Comparing between GL and GLX group score

		N	*Mean*	*Median*	*SD*	*SE*	*t*	*df*	*p*	*Effect size*
GL Group	Pre-test	30	1.47	1.00	0.507	0.0926	0.981	52	.331	0.269
GLX Group	Pre-test	24	1.33	1.00	0.482	0.0983				
GL Group	Post-test	30	2.67	3.00	0.661	0.1207	2.42*	52	.019	0.664
GLX Group	Post-test	24	3.21	3.50	0.977	0.1994				

The data indicated that the pre-test scores of the GL and GLX groups were not significantly different, suggesting that both groups had similar prior knowledge (t =0.981, p = .331). However, there was a significant difference between the post-test scores of the two groups at a .05 level of significance (t =2.42, p = .019), indicating that students in the GLX group performed better than those in the GL group. Cohen's d value of 0.664 also suggests a medium to large effect size, indicating that the observed differences between the groups are both statistically and practically significant (d = 0.5 for medium and d = 0.8 for large effect size). These findings suggest that the explicit analogy discussion positively impacted students' understanding of bioaccumulation and biomagnification.

5.3. The Level of Student's Enjoyment and Its Correlation with Student's Conceptions

After the game-based learning activity, students responded to the learner enjoyment scale. This scale consists of four dimensions, namely concentration, immersion, social interaction, and knowledge improvement. The results are presented in Table 3.

Table 3
The level of student's enjoyment

Game factors	*GL group Mean(SD)*	*GLX group Mean(SD)*
Concentration	6.23(0.77)	6.22(0.58)
Immersion	6.37(0.71)	6.31(0.74)
Social interaction	6.43(0.55)	6.18(0.99)
Knowledge improvement	5.48(0.95)	5.78(0.88)
Overall enjoyment	6.13(0.58)	6.12(0.50)

Both groups had positive experiences with game-based learning. The GL group achieved an impressive mean score of 6.13 (SD = 0.58), while the GLX group reported a mean score of 6.12 (SD = 0.50), indicating exceptionally high levels of enjoyment for both groups. Furthermore, both groups showed nearly identical mean scores across all game factors and maintained remarkable levels of concentration, immersion, and social interaction. Despite a slight decrease in knowledge improvement, all game factors consistently indicated a high level of enjoyment throughout the game.

Table 4 presents the correlation between student enjoyment scores in each dimension and the post-test scores of both student groups.

Table 4
Correlation of student's enjoyment and student's conception

		1	2	3	4	5	6
Post-test	r	-					
	p	-					
Concentration	r	−0.083	-				
	p	0.553	-				
Immersion	r	−0.326*	0.329*	-			
	p	0.016	0.015	-			
Social interaction	r	−0.153	0.392*	0.278*	-		
	p	0.269	0.003	0.042	-		
Knowledge improvement	r	0.001	0.286*	0.339*	0.235	-	
	p	0.995	0.036	0.012	0.088	-	
Enjoyment	r	−0.191	0.691	0.685	0.679	0.717	-
	p	0.167	< .001	< .001	< .001	< .001	-

Note. 1: Post-test; 2: Concentration; 3: Immersion; 4: Social interaction; 5: Knowledge improvement; 6: Enjoyment; r: Pearson's r; **p* <.05.

There was no statistically significant relationship between students' enjoyment of game-playing and post-test scores ($p > .05$). Surprisingly, a slight negative correlation was observed between the immersion component and post-test scores ($r = -.326$, $p = .016$). Additionally, there were slight positive correlations between the immersion component and concentration ($r = .392$, $p = .015$), immersion and social interaction ($r = .278$, $p = .042$), immersion and knowledge improvement ($r = .286$, $p = .036$), concentration and social interaction ($r = .392$, $p = .003$), and concentration and knowledge improvement ($r = .286$, $p = .036$). These findings suggested that the level of immersion in the game tended to correlate with attention to the game, interactions with the group, and the learning perception among students. Nonetheless, the observed negative relationship between immersion and post-test scores and the lack of a relationship between overall enjoyment and post-test scores made it inconclusive whether immersion and enjoyment in playing the game contributed to students' learning of bioaccumulation and biomagnification.

5.4. The Students' Perceptions of Gameplay in terms of Its Effect on Learning Bioaccumulation and Biomagnification

Student reflective writings after game-based learning were coded and collated into potential themes using ATLAS .ti Software. Coding of students' responses yielded several emergent themes. The percentage that these themes were mentioned was presented in Table 4. As Braun and Clarke (2006) suggested, "*the keyness of theme is not necessarily dependent on quantifiable measure but rather on whether it captures something important in relation to the overall research question.*", four themes were defined in which they captured the reasons why game-based learning helped students understand scientific concepts. These themes included the visualization of abstract concepts, the discussion and explanation after the gameplay, role-playing of the process of toxin transmission in the ecosystem, and tangible and touchable properties of the game.

Table 5
Summary of key themes identified and the percentage of students who reported each theme

Key themes	*f*
1. The visualization of abstract concepts	23%
2. The discussion and explanation after the gameplay	19%
3. Role-playing of the process of toxin transmission in the ecosystem	10%
4. Tangible and touchable properties of the game	10%

5.4.1. The visualization of abstract concepts

Many students responded that the game helped them understand the concepts of biomagnification and bioaccumulation because it allowed them to "visualize," "imagine," or "see in a tangible form" what the process of toxin transmission in the ecosystem is like. One student mentioned the transfer of beads as a means of visualizing the transfer of toxins from one organism to another.

> It helps to understand because it showed a food chain sequence. This allows me to visually see how the direct intake or accumulation of toxins occurs, or how it happens through ongoing intake.
>
> This game has beads to help see how much toxins are received from another living thing.

This boardgame demonstrates how toxins accumulate in a food chain. In the game, planthoppers eat rice, mantises eat planthoppers, and a frog eat both planthoppers and mantises. Each time an organism eats another, plastic beads representing toxins are transferred. As the beads accumulate in the mantises and the frog, students can "see" this accumulation in the plastic containers that represent these organisms. Therefore, it can be said that the game and its mechanics make abstract scientific concepts more concrete to the students.

5.4.2. The discussion and explanation after the gameplay

The responses from several students indicated an enhanced understanding following discussions and explanations. This comprehension is attributed to mentioned activities, including the "explanation of the game", "post-game discussions", and "reading a worksheet".

> If we talk about the game alone, it might not be very understandable. But when accompanied by discussion and explanations, it becomes more understandable according to scientific theory.

Following the gameplay, there was a discussion and explanation activity. The researcher in the GL group acted as a teacher who explained the concepts of bioaccumulation and biomagnification, comparing with the game's findings. Students exchanged ideas and asked questions both within the group and with the teacher. Alternatively, in the GLX group, the students independently read worksheets and explicitly compared the similarities and differences between the game and scientific concepts of bioaccumulation and biomagnification. Then, they shared their comparisons to other peers in the discussion part. This result suggested that explanations and discussions following gameplay contribute to the student's learning of scientific concepts.

5.4.3. Role-playing of the process of toxin transmission in the ecosystem

The participating students mentioned that the "role-playing" facilitated a better understanding of the mechanism of toxin accumulation in the food chain. The “player's role”, which aligns with organisms in the food chain, allows for a grasp of the sequence of consumption. As one student remarked,

> It becomes clearer because the player's role aligns with the sequence of consumption and the transfer of toxins in the food chain.

When playing a game, students aim to eat as much food as possible while avoiding predators. This behaviour can lead to the accumulation of toxins in their bodies over time. From the result above, the students can better understand how organisms interact with each other by assuming the role of an organism in an ecosystem. This is especially clear when it comes to the transfer of toxins through the food chain as different organisms consume each other**.**

5.4.4. Tangible and touchable properties of the game

The students described the board game as “tactile” and “tangible” and appreciated the ability to “physically interact” with the objects in the game. These features helped them gain a deeper understanding of how toxins are transmitted in an ecosystem, according to a student statement;

> During the game playing, we get to see mechanisms that are tangible from scientific principles. Once it is tangible, we can play and use strategies, which makes us want to know more.

The students used small plastic containers that could be held in their hands to represent individual organisms. They moved these pieces around a board and collected beads as score points whenever the organisms consumed food. The result showed that this hands-on approach helped the students understand abstract scientific concepts better, and they enjoyed playing with the tangible tools.

6. Discussion and Conclusion

From the results of this study, after participating in game-based learning, students' conception scores for bioaccumulation and biomagnification are significantly higher than before in both GL and GLX groups. The students changed their conceptions from limited or partial concepts to more scientifically accurate conceptions. However, the students participating in an explicit analogy comparison activity, GLX group, had higher post-test scores than those in the GL group. The enjoyment students experience during the game was at a high level, but it had no correlation with student’s post-test scores. Interestingly, a slight negative correlation was observed between the immersion component and post-test scores. Finally, the reasons why game-based learning helped students develop scientific concepts included the visualization of abstract concepts, the discussion and explanation after the gameplay, role-playing of the process of toxin transmission in the ecosystem, and tangible and touchable properties of the game. The results of this study provide valuable insights into the impact of game-based approaches on science education and the importance of designing game mechanics and learning processes for educational games, as follows:

The design of game mechanics that facilitate role-playing, visualization and tangibility contributes to the promotion of abstract scientific concept learning

The positive feedback on role-playing and visualization highlights its potential as an effective pedagogical tool. By "stepping into the shoes" of organisms in the food chain, students could intuitively grasp the sequence of consumption and the transfer of toxins. This experiential form of learning, where students actively participate in the process, can lead to deeper understanding. Certain research found the benefits of role-playing in understanding complex concepts such as economics and ethics (Alden, 1999; Kraus, 2008). Van Ments (1999) argued that role-playing allows students to experience and understand concepts from a first-person perspective, leading to better retention and understanding. Shaffer (2006) asserted that computer games using role-playing as a central mechanic have great educational potential. It allows students to "think in action" and leads to deeper understanding. Crookall (2010) suggested that reflecting on the role-play experience is crucial for enhancing learning and bridging the gap between the simulated experience and real-world concepts. Moreover, many researchers agree with the advantages of visualization and tangibility features of the game mechanics in supporting science learning (Fjællingsdal & Klöckner, 2020; Kim & Jin, 2022; Price et al., 2003; Woodbury et al., 2001). Geelan et al. (2014) also suggested that to obtain effectiveness in promoting conceptual development, it is necessary to thoughtfully design visualization and consider associated educational methods.

The design of post-game learning processes is a crucial procedure that significantly enhances the learning experiences of learners, particularly when games incorporate explicit analogy comparisons.

The research findings suggested the importance of discussions and explanations following gameplay. Students reported a clearer understanding of bioaccumulation and biomagnification when gameplay was accompanied by structured discussions. This aligns with educational theories that emphasize the role of reflection and discussion in learning. John Dewey highlighted the importance of reflection in the learning process. He argued that reflection transforms experiences into genuine learning (Dewey, 1933). Kolb (1984) also suggested that reflection on experiences is crucial for deep learning and understanding. In the context of game-based learning, post-gameplay discussions can help in bridging the gap between the virtual game environment and real-world scientific concepts (Gee, 2003; Hmelo-Silver, 2004; Squire, 2006; Steinkuehler & Duncan, 2008). This study supports the importance of reflection and discussion in the learning process, especially in experiential and game-based learning environments. In case of science learning, the research conducted by Munkebye and Staberg (2023) suggested that it was crucial to have reflective discussion on a practical activity and science content right after the activity, rather than as a separate final phase. Discussions can help learners make sense of their experiences, connect them to prior knowledge, and apply them to real-world contexts.

The explicit analogy discussion in the GLX group emphasized the importance of drawing parallels between game mechanics and scientific concepts. When used effectively, analogies can simplify complex ideas and make them more understandable. However, it is important to ensure that students recognize where the analogy holds and where it breaks down to avoid misconceptions. This result supports the theory about teaching with analogy that structure-mapping is crucial and providing explicit support, such as highlighting similarities and differences, can enhance students' understanding. (Duit, 1991; Gentner & Markan, 1997; Harrison & Coll, 2008; Richland et al., 2007; Thagard & Shelley, 1997; Treagust et al. 1992; Venville, 2008). This study supported the value of analogies in making complex ideas more accessible and relatable. Similar to the recent research results in science education (Martin et al., 2019; Shana & Shareef, 2022), it also highlights the importance of guiding students to recognize the similarities and differences between analogy and scientific concepts.

Immersion does not directly impact learning; moreover, excessive immersion may hinder students' learning experiences.

The interesting finding in this study was the inverse correlation between game immersion and post-test scores. Although immersion was associated with higher attention and group engagement levels, it did not necessarily lead to improved learning outcomes. This surprising result related to the study by Kuhail et al. (2022), which indicated that immersion could foster participation but also introduce cognitive overload. Adam et al. (2012) found that while narrative games can be engaging, they can sometimes distract from the core educational content. Kaplan and Kaplan (1989) discuss how immersion in nature can be both restorative and distracting. The balance between immersion and distraction can be influenced by the individual's prior experiences and the context. Several research found that immersive interfaces can significantly enhance engagement but can also lead to cognitive overload, which may hinder learning (Dede, 2009; Mayer & Moreno, 2003). Moreover, VanLehn et al. (2003) suggested that the nature of the task and the guidance provided played a crucial role. Too much immersion can introduce distractions, especially if not directly related to the learning objectives. Future studies might explore the balance between immersion and distraction, potentially identifying optimal levels of immersion for educational games.

Games have the potential to generate positive emotional experiences for learners, although this does not directly correlate with learning outcomes.

The results of this study found that student's level of enjoyment in playing the game was high. However, there was no correlation between the level of enjoyment and the post-test scores. Therefore, this study could not provide evidence that positive emotional experience in gameplay was related to better learning outcomes. Studies on this topic have produced inconsistent results. Several educational research suggested that positive emotions, such as enjoyment, could increase motivation and improve learning outcomes (Csikszentmihalyi, 1990; Linnenbrink & Pintrich, 2004; Pekrun et al., 2002; Shernoff et al., 2003; Zhao & Wang, 2023). Furthermore, game-based learning research indicated that games promoting flow and enjoyment could lead to enhanced engagement and educational outcomes (Hamari et al., 2016; Kiili, 2005; Rachmatullah, 2021; Ryan et al., 2006). Numerous studies have suggested that the presence of positive emotions can have a beneficial impact on the process of learning. Nevertheless, there are opposing arguments that must be considered. Boekaerts (2007) discussed the intricate relationship between emotions and learning in the classroom. While positive emotions, such as enjoyment, can be beneficial, it is important to note that other emotions, like curiosity or even frustration, can also influence the learning process. D'Mello and Graesser (2012) also suggested that confusion, which is not typically associated with enjoyment, can sometimes be beneficial for learning, especially when followed by moments of insight. Plass et al. (2014) emphasized that certain game elements could induce positive emotions. However, not all positive emotions necessarily lead to better learning outcomes. The result of this study suggested that enjoyment and positive emotional experiences did not always lead to better learning outcomes. It is important to consider the broader context, instructional methods, and the interplay of various emotions in the learning process.

7. Recommendation

Analogy Game-based learning offers a promising approach for teaching complex and abstract scientific concepts. However, as our study suggested, the design of the game mechanic and learning process, the level of immersion, and post-gameplay activities played a crucial role in determining its effectiveness. Future research might focus on optimizing these factors to harness the full potential of Analogy game-based learning.

Author contributions: All authors have made significant contributions to the study and have reached a consensus on the results and conclusions.

Declaration of interest: The authors declare that no competing interests exist.

Ethical statement: The researchers acknowledged that their study involved human participants, but they concluded that it did not require ethical committee approval as it posed no risks and was considered harmless. They did not reveal the identity of the data provider in their results, and no sensitive information was disclosed. Informed consent was obtained from all students who participated in the study.

Funding: No funding source is reported for this study.

References

Adams, D. M., Mayer, R. E., MacNamara, A., Koenig, A., & Wainess, R. (2012). Narrative games for learning: Testing the discovery and narrative hypotheses. *Journal of Educational Psychology*, *104*(1), 235. https://doi.org/10.1037/a0025595

Alden, D. (1999). Experience with scripted role play in environmental economics. *The Journal of Economic Education*, *30*(2), 127-132. https://doi.org/10.1080/00220489909595949

Aleven, V., Myers, E., Easterday, M., & Ogan, A. (2010). Toward a framework for the analysis and design of educational games. In E. Board (Eds.), *2010 third IEEE international conference on digital game and intelligent toy enhanced learning* (pp. 69-76). IEEE. https://doi.org/10.1109/DIGITEL.2010.55

Anderson, J., & Barnett, M. (2011). Using video games to support pre-service elementary teachers learning of basic physics principles. *Journal of Science Education and Technology*, *20*, 347-362. https://doi.org/10.1007/s10956-010-9257-0

Annetta, L. A., Minogue, J., Holmes, S. Y., & Cheng, M. T. (2009). Investigating the impact of video games on high school students' engagement and learning about genetics. *Computers & Education*, *53*(1), 74-85. https://doi.org/10.1016/j.compedu.2008.12.020

Arnot, J. A., & Gobas, F. A. (2006). A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Reviews*, *14*(4), 257-297. https://doi.org/10.1139/a06-005

Aydın, S. M., & Çakır, N. A. (2022). The effects of a game-enhanced learning intervention on foreign language learning. *Educational technology research and development*, *70*(5), 1809-1841. https://doi.org/10.1007/s11423-022-10141-9

Barab, S., & Dede, C. (2007). Games and immersive participatory simulations for science education: An emerging type of curricula. *Journal of Science Education and technology*, *16*(1), 1-3. https://doi.org/10.1007/s10956-007-9043-9

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., & Herring, S. C. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education*, *91*(5), 750-782. https://doi.org/10.1002/sce.20217

Boekaerts, M. (2007). Understanding students' affective processes in the classroom. In P. Schutz, R. Pekrun, & G. Phye (Eds.), *Emotion in education* (pp. 37-56). Academic Press. https://doi.org/10.1016/B978-012372545-5/50004-6

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, *18*, 237-261. https://doi.org/10.1007/BF00118013

Bucak, S. D. (2011). *Global Warming* [Board game]. Mücke Spiele.

Carr, D., & Bossomaier, T. (2011). Relativity in a rock field: A study of physics learning with a computer game. *Australasian Journal of Educational Technology*, *27*(6). https://doi.org/10.14742/ajet.928

Carreira, F., Aguiar, A. C., Onça, F., & Monzoni, M. (2017). The Celsius Game: An experiential activity on management education simulating the complex challenges for the two-degree climate change target. *The International Journal of Management Education*, *15*(2), 350-361. https://doi.org/10.1016/j.ijme.2017.03.012

Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. *Cognitive Science*, *12*(4), 563-586. https://doi.org/10.1207/s15516709cog1204_3

Connell, D. W. (1990). *Bioaccumulation of xenobiotic compounds*. CRC Press.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research.* Sage

Crookall, D. (2010). Serious games, debriefing, and simulation/gaming as a discipline. *Simulation & Gaming*, *41*(6), 898-920. https://doi.org/10.1177/1046878110390784

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. Harper Perennial Modern Classics.

Cvenic, K. M., Ivanjek, L., Planinic, M., Jelicic, K., Susac, A., & Hopf, M. (2021). Analyzing high school students' reasoning about polarization of light. *Physical Review Physics Education Research*, *17*(1), 010136. https://doi.org/10.1103/PhysRevPhysEducRes.17.010136

D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*(2), 145-157. https://doi.org/10.1016/j.learninstruc.2011.10.001

Dagher, Z. R. (1995). Review of studies on the effectiveness of instructional analogies in science education. *Science Education*, *79*(3), 295-312. https://doi.org/10.1002/sce.3730790305

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, *323*(5910), 66-69. https://doi.org/10.1126/science.1167311

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process*. DC Heath.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education*, *75*(6), 649-672. https://doi.org/10.1002/sce.3730750606

Fjællingsdal, K. S., & Klöckner, C. A. (2020). Green across the board: Board games as tools for dialogue and simplified environmental communication. *Simulation & Gaming*, *51*(5), 632-652. https://doi.org/10.1177/1046878120925133

Fu, F. L., Su, R. C., & Yu, S. C. (2009). EGameFlow: A scale to measure learners' enjoyment of e-learning games. *Computers & Education*, *52*(1), 101-112. https://doi.org/10.1016/j.compedu.2008.07.004

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE)*, *1*(1), 20-20. https://doi.org/10.1145/950566.950595

Gee, J. P. (2008). Learning and games. In K. Salen (Ed.), *The ecology of games: Connecting youth, games, and learning* (pp. 21–40). MIT Press.

Geelan, D., Mahaffy, P., & Mukherjee, M. (2014). Scientific visualisations: For developing students' understanding of concepts in chemistry: Some findings and some lessons learned. *Teaching Science*, *60*(1), 30-38.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist*, *52*(1), 45. https://doi.org/10.1037/0003-066X.52.1.45

Glynn, S. M., & Takahashi, T. (1998). Learning from analogy-enhanced science text. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *35*(10), 1129-1149. https://doi.org/10.1002/(SICI)1098-2736(199812)35:10%3C1129::AID-TEA5%3E3.0.CO;2-2

Gobert, J., & Buckley, B. (2000). Special issue editorial: Introduction to model-based teaching and learning. *International Journal of Science Education*, *22*(9), 891-894. https://doi.org/10.1080/095006900416839

Gunter, G. A., Kenny, R. F., & Vick, E. H. (2008). Taking educational games seriously: using the RETAIN model to design endogenous fantasy into standalone educational games. *Educational Technology Research and Development*, *56*, 511-537. https://doi.org/10.1007/s11423-007-9073-2

Halpern, D. F., Hansen, C., & Riefer, D. (1990). Analogies as an aid to understanding and memory. *Journal of Educational Psychology*, *82*(2), 298. https://doi.org/10.1037/0022-0663.82.2.298

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior*, *54*, 170-179. https://doi.org/10.1016/j.chb.2015.07.045

Harrison, A. G., & Coll, R. K. (2008). *Using analogies in middle and secondary science classrooms: The FAR guide–An interesting way to teach with analogies*. Corwin Press.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: A case study in grade-10 optics. *Journal of Research in Science Teaching*, *30*(10), 1291-1307. https://doi.org/10.1002/tea.3660301010

Hartt, M., Hosseini, H., & Mostafapour, M. (2020). Game on: Exploring the effectiveness of game-based learning. *Planning Practice & Research*, *35*(5), 589-604. https://doi.org/10.1080/02697459.2020.1778859

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn?. *Educational Psychology Review*, *16*, 235-266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hsu, C. Y., Tsai, C. C., & Liang, J. C. (2011). Facilitating preschoolers' scientific knowledge construction via computer games regarding light and shadow: The effect of the prediction-observation-explanation (POE) strategy. *Journal of Science Education and Technology*, *20*, 482-493. https://doi.org/10.1007/s10956-011-9298-z

Jaeger, A. J., Taylor, A. R., & Wiley, J. (2016). When, and for whom, analogies help: The role of spatial skills and interleaved presentation. *Journal of Educational Psychology*, *108*(8), 1121. https://doi.org/10.1037/edu0000121

Jasti, C., Lauren, H., Wallon, R. C., & Hug, B. (2016). The Bio Bay Game: three-dimensional learning of biomagnification. *The American Biology Teacher*, *78*(9), 748-754. https://doi.org/10.1525/abt.2016.78.9.748

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press.

Kende, G., & Seres, G. (2006, November 7-8). *Use of chess in military education* [Paper presentation]. New Challenges in the Field of Military Sciences, 4th International Conference, ZMNDU, Budapest, Hungary.

Keogh, B., & Naylor, S. (1999). Concept cartoons, teaching and learning in science: an evaluation. *International Journal of Science Education*, *21*(4), 431-446. https://doi.org/10.1080/095006999290642
Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education*, *8*(1), 13-24. https://doi.org/10.1016/j.iheduc.2004.12.001
Kim, H. T., & Kim, J. G. (2013). How Do High School Science Textbooks in Korea, Japan, and the US Explain Bioaccumulation-Related Concepts?. *Science Education International*, *24*(4), 416-436.
Kim, M., & Jin, Q. (2022). Studies on visualisation in science classrooms: a systematic literature review. *International Journal of Science Education*, *44*(17), 2613-2631. https://doi.org/10.1080/09500693.2022.2140020
Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving learning games forward*. The Education Arcade.
Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* Prentice-Hall.
Kraus, R. (2008). You must participate: Violating research ethical principles through role-play. *College Teaching*, *56*(3), 131-136. https://doi.org/10.3200/CTCH.56.3.131-136
Kuhail, M. A., ElSayary, A., Farooq, S., & Alghamdi, A. (2022). Exploring immersive learning experiences: A survey. *Informatics*, *9*(4), 75. https://doi.org/10.3390/informatics9040075
Lehrer, R., & Schauble, L. (2005). Developing modeling and argument in the elementary grades. In T. A. Romberg, T. P. Carpenter, & F. Dremock (Eds.), *Understanding mathematics and science matters* (pp. 29-53). Routledge.
Li, M. C., & Tsai, C. C. (2013). Game-based learning in science education: A review of relevant research. *Journal of Science Education and Technology*, *22*, 877-898. https://doi.org/10.1007/s10956-013-9436-x
Li, X., Wang, W., & Li, Y. (2022). Systematically reviewing the potential of scientific argumentation to promote multidimensional conceptual change in science education. *International Journal of Science Education*, *44*(7), 1165-1185. https://doi.org/10.1080/09500693.2022.2070787
Linnenbrink, E. A., & Pintrich, P. R. (2004). Role of affect in cognitive processing in academic contexts. In D. Yun Dai, & R. J. Sternberg (Eds.), *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development* (pp. 57-87). Routledge.
Liu, M., Rosenblum, J. A., Horton, L., & Kang, J. (2014). Designing science learning with game-based approaches. *Computers in the Schools*, *31*(1-2), 84-102. https://doi.org/10.1080/07380569.2014.879776
Martin, W., Silander, M., & Rutter, S. (2019). Digital games as sources for science analogies: Learning about energy through play. *Computers & Education*, *130*, 1-12. https://doi.org/10.1016/j.compedu.2018.11.002
Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational psychologist*, *38*(1), 43-52. https://doi.org/10.1207/S15326985EP3801_6
Munkebye, E., & Staberg, R. L. (2023). Qualifying the science experiences of young students through dialogue-A Norwegian lesson study. *Cogent Education*, *10*(1), 2164006. https://doi.org/10.1080/2331186X.2022.2164006
Niebert, K., Marsch, S., & Treagust, D. F. (2012). Understanding needs embodiment: A theory-guided reanalysis of the role of metaphors and analogies in understanding science. *Science Education*, *96*(5), 849-877. https://doi.org/10.1002/sce.21026
Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist*, *37*(2), 91-105. https://doi.org/10.1207/S15326985EP3702_4
Plass, J. L., Heidig, S., Hayward, E. O., Homer, B. D., & Um, E. (2014). Emotional design in multimedia learning: Effects of shape and color on affect and learning. *Learning and Instruction*, *29*, 128-140. https://doi.org/10.1016/j.learninstruc.2013.02.006
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
Plass, J. L., Mayer, R. E., & Homer, B. D. (2020). *Handbook of game-based learning*. Mit Press.
Price, S., Rogers, Y., Scaife, M., Stanton, D., & Neale, H. (2003). Using 'tangibles' to promote novel forms of playful learning. *Interacting with Computers, 15*(2), 169-185. https://doi.org/10.1016/S0953-5438(03)00006-7
Rachmatullah, A., Reichsman, F., Lord, T., Dorsey, C., Mott, B., Lester, J., & Wiebe, E. (2021). Modeling secondary students' genetics learning in a game-based environment: Integrating the expectancy-value theory of achievement motivation and flow theory. *Journal of Science Education and Technology*, *30*, 511-528. https://doi.org/10.1007/s10956-020-09896-8

Richland, L. E., Zur, O., & Holyoak, K. J. (2007). Cognitive supports for analogies in the mathematics classroom. *Science*, *316*(5828), 1128-1129. https://doi.org/10.1126/science.1142103

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, *30*, 344-360. https://doi.org/10.1007/s11031-006-9051-8

Schlussel, A., Rhoades, A., Neiles, K. Y., & Elliott, S. L. (2018). Simulating biomagnification to illustrate trophic pyramids in the middle school classroom. *The American Biology Teacher*, *80*(5), 385–389. https://doi.org/10.1525/abt.2018.80.5.385

Shaffer, D. W., & Gee, J. P. (2006). *How computer games help children learn*. Palgrave Macmillan. https://doi.org/10.1057/9780230601994

Shana, Z. A., & Shareef, M. A. E. (2022). Science teachers' use of analogies: findings from classroom practices. *European Journal of Educational Research, 11*(2), 1023-1036. https://doi.org/10.12973/eu-jer.11.2.1023

Shernoff, D. J., Csikszentmihalyi, M., Shneider, B., & Shernoff, E. S. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School psychology quarterly*, *18*(2), 158. https://doi.org/10.1521/scpq.18.2.158.21860

Spiegel, C. N., Alves, G. G., Cardona, T. D. S., Melim, L. M., Luz, M. R., Araújo-Jorge, T. C., & Henriques-Pons, A. (2008). Discovering the cell: an educational game about cell and molecular biology. *Journal of Biological Education*, *43*(1), 27-36. https://doi.org/10.1080/00219266.2008.9656146

Spires, H. A., Rowe, J. P., Mott, B. W., & Lester, J. C. (2011). Problem solving and game-based learning: Effects of middle grade students' hypothesis testing strategies on learning outcomes. *Journal of Educational Computing Research*, *44*(4), 453-472. https://doi.org/10.2190/EC.44.4.e

Squire, K. (2006). From content to context: Videogames as designed experience. *Educational Researcher, 35*(8), 19–29. https://doi.org/10.3102/0013189X035008019

Squire, K., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, *16*, 5-29. https://doi.org/10.1007/s10956-006-9037-z

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *The journal of the learning sciences*, *16*(3), 371-413. https://doi.org/10.1080/10508400701413435

Steinkuehler, C., & Duncan, S. (2008). Scientific habits of mind in virtual worlds. *Journal of Science Education and Technology*, *17*, 530-543. https://doi.org/10.1007/s10956-008-9120-8

Thagard, P., & Shelley, C. (1997). Abductive reasoning: Logic, visual thinking, and coherence. In M. L. D. Chiara, K. Doets, D. Mundici & J. van Benthem (Eds.), *Logic and scientific methods: volume one of the tenth international congress of logic, methodology and philosophy of science, Florence, August 1995* (pp. 413-427). Springer. https://doi.org/10.1007/978-94-017-0487-8_22

Treagust, D. F., Duit, R., Joslin, P., & Lindauer, I. (1992). Science teachers' use of analogies: observations from classroom practice. *International Journal of science education*, *14*(4), 413-422. https://doi.org/10.1080/0950069920140404

Van Ments, M. (1999). *The effective use of role-play: Practical techniques for improving learning*. Kogan Page Publishers. https://doi.org/10.1108/cdi.1999.4.7.400.4

VanLehn, K., Siler, S., Murray, C., Yamauchi, T., & Baggett, W. B. (2003). Why do only some events cause learning during human tutoring?. *Cognition and Instruction*, *21*(3), 209-249. https://doi.org/10.1207/S1532690XCI2103_01

Venville, G. (2008). The focus-action-reflection (FAR) guide-Science teaching analogies. In A. G. Harrison, & R. K. Coll (Eds.), *Using analogies in middle and secondary science classrooms* (pp. 22-31). Corwin Press.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535-585. https://doi.org/10.1016/0010-0285(92)90018-W

Wichaidit, S. & Sumida, M. (2023). The effect of game-based learning on student's conceptual change in bioaccumulation and biomagnification. *Science Education International, 34*(4), 262-273. https://doi.org/10.33828/sei.v34.i4.2

Woodbury, R. F., Shannon, S. J., & Radford, A. D. (2001). Games in early design education: Playing with metaphor. In B. Vries, J. Leeuwen, & H. Achten (Eds.), *Computer Aided Architectural Design Futures 2001: Proceedings of the Ninth International Conference held at the Eindhoven University of Technology, Eindhoven, The Netherlands, on July 8–11, 2001* (pp. 201-214). Kluwer Academic. https://doi.org/10.1007/978-94-010-0868-6_16

Woodwell, G. M. (1967). Toxic substances and ecological cycles. *Scientific American*, *216*(3), 24-31. https://doi.org/10.1038/scientificamerican0367-24

Yien, J. M., Hung, C. M., Hwang, G. J., & Lin, Y. C. (2011). A game-based learning approach to improving students' learning achievements in a Nutrition course. *Turkish Online Journal of Educational Technology-TOJET*, *10*(2), 1-10.

Zhao, X., & Wang, D. (2023). Grit, emotions, and their effects on ethnic minority students' English language learning achievements: A structural equation modelling analysis. *System*, *113*, 102979. https://doi.org/10.1016/j.system.2023.102979

Ziegler, N. A. (2014). Fostering self-regulated learning through the European language portfolio: An embedded mixed methods study. *The Modern Language Journal*, *98*(4), 921-936. https://doi.org/10.1111/modl.12147