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ORIGINAL ARTICLE

# The Effect of Game-based Learning on Student's Conceptual Change in Bioaccumulation and Biomagnification

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## ABSTRACT

The conceptual change approach has been a prevalent theoretical foundation for comprehending students' acquisition of scientific knowledge. Despite its extensive use, only a limited number of studies have employed this framework to examine the effectiveness of game-based learning (GBL). The GBL was utilized to teach 101 middle school students concerning bioaccumulation and biomagnification concepts. Concept cartoons were used for pre- and post-test to assess the extent of conceptual change. Students' reflections were employed to understand the emotional and social aspects analyzed by content analysis. The result indicated that before engaging in the GBL activity, most students had limited concepts of bioaccumulation (50%) and held partially accurate concepts of bioaccumulation without biomagnification (49%). After learning with the game activity, the students changed their concepts range from limited concepts to accurate concepts of bioaccumulation and biomagnification. The Wilcoxon signed-rank test revealed a significant change ($Z = 2850$, $p \leq 0.001$), with an effect size of 1.00 indicating a large effect. This result provided evidence of the cognitive and the intentional aspects of conceptual change in which students extended their conceptions through GBL experiences. Furthermore, the students reported feeling joyful and expressed positive sentiments toward the learning activity and collaborative work.

**KEY WORDS:** Bioaccumulation; biomagnification; conceptual change; game-based learning

## INTRODUCTION

The world has been facing an environmental challenge in that a wide range of hazardous chemicals produced by humans are accumulating in the environment, and those chemicals negatively impact ecosystems and human health (UNEP, 2021). The use of chemical pesticides for crop protection has increased globally by 58% over 30 years, from 1.69 million tons in 1990 to 2.66 million tons in 2020 (Ritchie et al., 2022). The application of pesticides and their dispersion through water, wind, and soil can potentially cause harmful toxicity affecting various organisms' reproductive, respiration, and nervous systems (Dhuldhaj et al., 2023; Gonçalves et al., 2020; Mostafalou and Abdollahi, 2017) and eventually causing health problem in humans (Pimentel et al., 1992; Boudh and Singh, 2019). Therefore, people should understand and be aware of the environmental impacts of chemical usage to implement effective management strategies.

Unfortunately, many reports suggest that environmental education for youth still needs to be improved. UNESCO (2021) reported that in almost half of the 46 member countries, the national education documents analyzed showed minimal or no mention of an environmental theme. The OECD (2022) presented that <1 in five 15-year-olds in OECD countries could explain environmental phenomena in the PISA 2006, and students' scientific knowledge strongly correlated with understanding environmental issues. Moreover, numerous studies indicate that students worldwide with limited environmental knowledge and skills also have misconceptions about environmental issues (Kiryak et al., 2021; Palmer et al.,1996; Spiteri, 2021; Wyner and Blatt, 2019), including bioaccumulation and biomagnification (Kim and Kim, 2013).

Students often confuse bioaccumulation and biomagnification (Schlussel et al., 2018). Bioaccumulation refers to accumulating external substances in organisms without specifying the entry pathway, while biomagnification specifically focuses on increased concentrations of residual substances along food chains and is primarily related to dietary absorption (Alexander, 1999; Arnot and Gobas, 2006; Connell, 1990; Kelly et al., 2007; Marher et al., 2016; Woodwell et al., 1967). Biomagnification is more complicated than bioaccumulation because it relates to other scientific concepts (e.g., food web, mass transfer in an ecosystem, tropic levels). However, many students mistakenly perceive biomagnification and bioaccumulation as the same thing or believe biomagnification only occurs with heavy metals (Kim and Kim, 2013). Students need to have accurate concepts of bioaccumulation and biomagnification to increase their awareness of how human activities impact the environment. If students confuse bioaccumulation and biomagnification, there can be several potential consequences. First, they may not recognize how pollutants and toxins move through food chains and impact ecosystems. Second, bioaccumulation and biomagnification play a crucial role in assessing the potential risks of toxic substances in the environment (Chormare and Kumar, 2022). If students do not differentiate between these concepts, they may have difficulty in accurately assessing the risks associated with certain substances and their potential impacts on human health and the environment. Finally, students may incorrectly apply the concepts to different situations or substances, leading to inaccurate conclusions about the movement and effects of pollutants in ecosystems (Kim and Kim, 2013; OECD, 2022). When students have misconceptions or incorrect understandings of environmental concepts, it can hinder their ability to comprehend and engage with scientific information. By addressing these misunderstandings, students can develop a more accurate understanding of environmental concepts, which is crucial for making informed decisions and taking action to protect the environment.

The conceptual change approach is a learning theory extensively studied since the 1980s, aiming to understand the process of developing students' conceptions that are accurate and consistent with scientific ones. This theory continues to explore three aspects that influence the formation of students' conceptions. First, the epistemological aspect primarily studied the cognitive processes behind students' conceptual change (Carey, 1985; Hewson and Hewson, 1992; Posner et al., 1982; Strike and Posner, 1992; Vosniadou, 1994). Several teaching strategies have been developed, including conceptual change texts (Wang and Andre, 1991), presenting discrepant events (Wright and Govindarajan, 1995), the Predict-Observed-Explain (POE) method (White and Gunstone, 1992; Liew and Treagust, 1995), teaching with analogy (Harrison and Treagust, 1993) and the Thinking Frames Approach (McLure, 2023). The strategies challenge the students' current ideas and help them understand new concepts. Second, the ontology aspect relates to the shift in perspectives toward the nature of reality (Chi et al., 1994; Tsui and Treagust, 2004; Venville, 2004). Third, the intentional aspect regards the significance of social, motivational, and self-regulation (Pintrich, 2003; Sinatra and Taasoobshirazi, 2011). Teaching strategies emphasizing group work, learning motivation, and self-regulation have been employed to enhance students' conceptual change (McLure et al., 2020). Therefore, experiences that promote conceptual change should lead learners to understand scientific ideas, undergo changes in their perspectives on nature, and foster motivation and self-regulation for developing those ideas.

Game-based learning (GBL) is an effective approach proven to enhance cognitive and social/affective learning, as supported by evidence from Plass et al. (2015). A meta-analysis by Vogel et al. (2006) showed that students who used computer games or interactive simulations demonstrated greater cognitive improvements and more positive attitudes toward learning when compared to those who used traditional instruction. Cheng et al. (2020) also stated that GBL integrates real-world situations into a learning context, aligns gameplay goals with learning goals, and provides social support to improve student engagement. Therefore, GBL is an excellent tool to help students connect scientific knowledge with real-life situations, boost motivation, and encourage social interaction, all essential for conceptual change.

Research on educational games has mainly focused on demonstrating their effectiveness or design rather than exploring how students undergo conceptual changes during the learning process (Sengupta et al., 2015). Although some studies have examined how GBL affects students' conceptual change (Gauthier and Jenkinson, 2017; Belova and Zowada, 2020), there have been no studies investigating Thai students' conceptual change in bioaccumulation and biomagnification. This study, therefore, aims to explore the effect of GBL on students' conceptions of bioaccumulation and biomagnification. The study also investigates the changes in students' conceptions and personal reflections on this approach, including its emotional impact and influence on social aspects within the learning environment.

## LITERATURE REVIEW

### Conceptual Change Approach to Learning

During the 1980s, the conceptual change theory emerged in response to the observation that children often held ideas about natural phenomena that conflicted with scientific knowledge, even after learning in science classrooms (Wandersee et al., 1994). Students' ideas were referred to as alternative frameworks (Driver, 1981), naïve principles (Caramazza et al., 1981), or children's science (Gilbert et al., 1982). If these preconceptions disagree with new scientific concepts, they can hinder the learning process. Initially, the conceptual change model emphasized creating cognitive dissatisfaction with an alternative concept and encouraging to adopt a scientific one (Posner et al., 1982). The "conceptual status" was a central idea that referred to the level of intelligibility, plausibility, and fruitfulness of concepts (Hewson and Hewson, 1992). Learners are more likely to abandon their previous concepts when the status of those concepts decreases, such as when they are found to be inadequate in explaining natural phenomena. Conversely, new concepts must be intelligible, plausible, and fruitful (Hewson, 1992). The study of conceptual change in the past thus aimed to explain cognitive processes and the credibility of knowledge, referred to as the epistemology aspect of conceptual change.

Subsequently, there has been a growing interest in the nature of scientific concepts that impact conceptual change. The theory of the ontological aspect of conceptual change argues that scientific concepts are categorized into three distinct ontological groups: matter, processes, and mental states, and the nature of concepts influences students' conceptual change (Chi, 2008). In certain scientific concepts, such as electricity, conceptual change occurs when students shift their ontology from one category to another (Chi et al., 1994). Concepts within the matter category tend to be more concrete compared to those within the process or mental state categories; therefore, the process of conceptual change when acquiring knowledge about mass or density might differ from learning about electricity or weight because the concepts belong to different categories (Tyson et al., 1997). The ontological aspect of conceptual change suggests that understanding the nature of scientific content is crucial to design learning experiences for students' conceptual change.

To effectively facilitate conceptual change among students, it is imperative to take into consideration not only epistemological and ontological aspects but also the impact of self-regulation, motivation, interest, efficacy, and social interaction (Linnenbrink-Garcia et al., 2012; Pintrich et al., 1993). This aspect of conceptual change was called the intentional aspect. Many educators have found evidence of the intentional aspect. Dole and Sinatra (1998) proposed the Cognitive Reconstruction of Knowledge Model which suggests that an individual's pre-existing ideas, motivation, and instructional methods all play a role in determining their level of engagement and the resulting conceptual change. In addition, Cordova et al. (2014) found that various factors related to learners, such as their level of self-efficacy, confidence in prior knowledge, interest, and prior knowledge itself, are significant in conceptual change learning depending on the learning situation. In addition, Huang et al. (2017) explored epistemic belief and metaconceptual thinking as potential facilitators of conceptual change. Therefore, the multidimensional framework (epistemology, ontology, intention) was developed to interpret students' conceptual change (Tyson et al., 1997).

Recently, research on conceptual change has integrated various theories to support students' learning in many aspects. McLure et al. (2020), for example, utilized the conceptual change model or cognitive conflict model, social construction, and scientific ontological model to explore the process of conceptual change and suggest strategies (the thinking frames approach) for promoting conceptual change. Li et al. (2022) explored the potential of scientific argumentation in promoting multidimensional conceptual change. The dimensions consist of cognitive, ontological, and intentional aspects. The cognitive dimension focuses on the change in conceptual contents, emphasizing the need for students to replace or reorganize their existing conceptions to grasp new phenomena. The ontological dimension emphasizes the change in conceptual models within a specific disciplinary context or the change in understanding the nature of science. The intentional dimension involves the change at the level of personal attitudes and beliefs related to science learning, emphasizing the goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge. While these two studies focused on the integration of conceptual change theories, Potvin et al. (2020) suggested that future research in conceptual change should conduct more comparative research efforts. This would involve comparing the effects of different conceptual change models/propositions with each other, as well as with teaching interventions. In conclusion, the trend of conceptual change research is to apply various models of conceptual change to different situations and different groups of students.

## GBL

Games can be characterized as structured play involving a specific set of rules and a goal to overcome obstacles (Klopfer et al., 2009; Salen and Zimmerman, 2004). GBL is a kind of gameplay that has explicit learning objectives (Plass et al., 2015). The potential of GBL as an effective instructional method is promising due to its ability to captivate learners and positively impact their motivation and learning outcomes (Budasi et al., 2020; Loderer et al., 2019; Steinkuehler and Squire, 2014; Van Gaalen et al., 2022).

Plass et al. (2015) suggested a theoretical basis for incorporating games into the learning process that involved motivational, cognitive, affective, and sociocultural foundations. For *motivational foundation*, games motivate learners to stay engaged over long periods with features including incentive systems, game mechanics, and exciting activities (Plass et al., 2015; Steinkuehler and Squire (2014). For *cognitive foundation*, Mayer (2019) asserted that learners are mentally engaged by selecting important game information, organizing it effectively, and linking it to their prior knowledge. The *affective foundation* is related to positive emotions induced by game mechanics and exciting game situations (Isbister et al., 2011). Finally, from the *sociocultural foundation*, learning involves interactions among game players, leading to the development of shared knowledge. This knowledge is then put into practice within the framework of cultural context (Squire, 2006).

The use of GBL in science had been explored. The learning objectives included scientific knowledge (Hsu et al., 2011; Jasti et al., 2006; Spiegel et al., 2008), scientific method (Spires et al., 2011), problem-solving (Moreno and Mayer, 2000), learning attitude and emotion (Li, 2010), and student's engagement (Lim et al., 2006)

Board games have been used in GBL. According to Woodbury et al. (2001), board games that allow players to interact with physical elements are more effective in teaching environmental issues than text-based representations. Price et al. (2003) also noted that tangible game pieces on a board make the game more engaging, exciting, and accessible than digital interfaces. As suggested by Fjællingsdal and Klöckner (2020), tactility is a crucial aspect to consider when using board games for educational purposes, as it can positively impact learning outcomes. In addition, Fjællingsdal and Klöckner (2020) demonstrated that board games could effectively simplify the intricate and interrelated environmental issues, which were often presented in a complex manner by scientists and were challenging for laypeople to comprehend.

## Conceptual Change through GBL

There were a number of research studies that directly stated the use of the conceptual change theory in designing educational game, or the use of GBL to facilitate conceptual change. For example, the work of Gauthier and Jenkinson (2017) designed game mechanics called productive negativity, which caused students to face challenges that prompted them to reevaluate and change their misconceptions to progress in the game. Therefore, the game was designed to confront students' misconceptions directly, particularly in the context of molecular biology. When students' actions based on misconceptions did not yield the expected results in the game, they were encouraged to reconsider and adjust their understanding. The result showed that the students who were exposed to the game resolved significantly more misconceptions compared to those who did not receive any intervention. This suggested the effectiveness of the game in facilitating conceptual change. Another study by Belova and Zowada (2020) also used GBL to address student's misconceptions in chemistry. The game required students to confront with specific misconceptions. The result indicated that this interactive and engaging method could be more effective in facilitating understanding and retention compared to traditional lecture-based approaches. Both studies demonstrated that the cognitive aspect of conceptual change could be utilized in game design to create a sense of dissatisfaction with learners' misconceptions, prompting them to pursue new scientific ones.

Certain studies focused on student's conceptual understanding in science even they did not directly assert conceptual change theory. For example, Chen et al. (2020) explored the impact of digital GBL in Physics teaching, particularly when enhanced with a conceptual change teaching strategy, the POE method. The study incorporated the POE model into a digital game environment. This model involves making predictions, observing outcomes, and explaining findings. The results showed that the group using the POE model demonstrated significantly better conceptual understanding and game performance compared to the control group. Koops and Hoevenaar (2013) also applied interactive experiences that challenge students' preconceptions and encourage reflection to facilitate conceptual change in Physics. These results suggested that GBL incorporated with conceptual change teaching strategy could effectively facilitate learning.

To summarize, the relationship between GBL and conceptual change was established when educational game design was based on conceptual change theory, or when the goal is to create games that help learners change their conceptions. As a result, conceptual change teaching strategies were often integrated into game mechanics to encourage students to modify their preconceptions to align with scientific ones.

## Conceptual Framework of this Study

This study integrated the theoretical foundations of GBL (Plass et al., 2015) and the multidimensional conceptual change framework (Tyson et al., 1997; McLure et al., 2020). GBL contributed to students' learning in cognitive, motivational, affective, and sociocultural foundations. The cognitive foundation led to the epistemology aspect of conceptual change that focuses on students changing their ideas from a limited conception of bioaccumulation toward an accurate conception of bioaccumulation and biomagnification. The motivational, affective, and sociocultural foundations can be interpreted as the intentional aspect of conceptual change. The evidence of the student's conceptual change in the intentional aspect can be obtained from the student's reflections related to motivation, emotion, and social interaction. The conceptual framework is illustrated in Figure 1.

## Objectives of the study

The objectives of the study are as follows:

1. To explore student's preconceptions related to bioaccumulation and biomagnification
2. To examine the effectiveness of GBL on student's conceptions of bioaccumulation and biomagnification and how those conceptions changed after learning with GBL
3. To explore student's reflections about GBL experiences related to affective, and social aspects.

## Research Hypotheses

1. Students might hold a limited conception of bioaccumulation before having experience in GBL activity.
2. Based on the literature review, which suggests that GBL can facilitate conceptual change, the following hypotheses are posited:
   Null Hypothesis ($H_0$): There is no difference in conception scores of bioaccumulation and biomagnification between pretest and posttest ($H_0$: $\mu_{posttest} = \mu_{pretest}$).
   Alternative Hypothesis ($H_a$): Students' conceptions score of bioaccumulation and biomagnification after having experience in GBL was more than before the instruction at a.05 level of significance. ($H_0$: $\mu_{posttest} > \mu_{pretest}$).
3. Students' reflections might express positive opinions related to motivation, emotion, and social interaction.

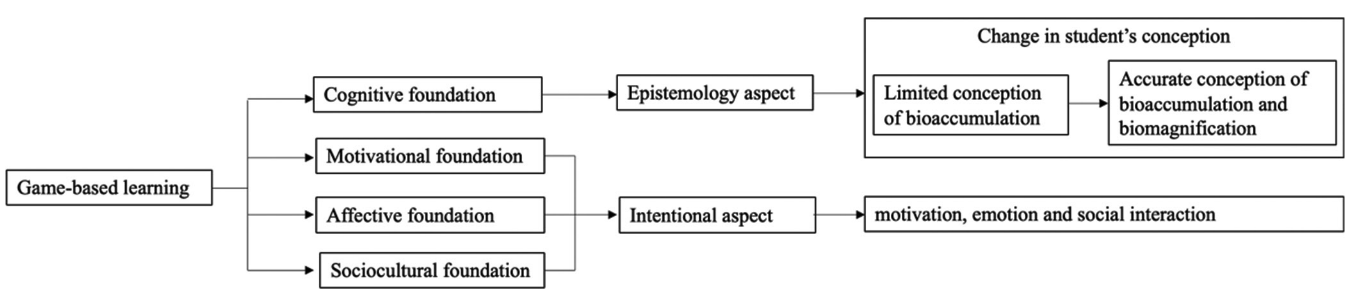


**Figure 1:** Conceptual framework of the study

## METHODOLOGY

This study utilized a quasi-experiment which was a one-group pre-test-post-test design. The students' responses in the pre-test and post-test were assessed and scored to examine how their understanding changed following the instruction. Non-parametric statistics and effect size analysis were used to test the research hypotheses. Participating students were prompted to reflect on their gains and how they feel. Content analysis (Carley, 1990) was used to interpret students' reflections.

### Participants

This study involved 101 middle school students (48 male and 53 female) who were purposefully selected to participate. The group of students consisted of 33 gGade 7 students (aged 13), 34 Grade 8 students (aged 14), and 34 Grade 9 students (aged 15) who were all enrolled in a special science classroom program at a school in the central region of Thailand. Students in this program learned intensively in science and mathematics. Since they are all in the same program, they are assumed to have similar educational backgrounds. The students participated in the study with the consent of their parents.

### Context of the Study

Thailand's basic education curriculum adopts a spiral curriculum structure, which means that the content gradually increases in complexity according to the student's level. At the primary level, the curriculum covers topics related to the relationships of living things and food chains in the ecosystem. Meanwhile, topics related to energy transfer and the accumulation of toxins in the ecosystem are included in Grade 9. Therefore, it could be assumed that all students had learned about food chains, but only Grade 9 students had learned about energy transfer and the accumulation of toxins in the environment. The students took part in a STEM camp activity that emphasized environmental issues in society. In a GBL activity, the TOXIC CHAIN board game was designed for study and utilized as the teaching material. The entire activity, which included an evaluation component, lasted 2 h, and the researcher acted as the activity's facilitator.

### The TOXIC CHAIN Board Game

This board game, initially developed for this study, had a specific educational goal. The goal intended to allow students to experience firsthand how pesticides can be transferred from one organism to another through food chains. In addition, it aimed to demonstrate how top predators in a food chain accumulate toxic substances more than other organisms. The game has three characters: planthoppers, mantises, and a frog. Planthoppers eat rice, mantises eat planthoppers, and a frog eats both mantises and planthoppers. The game takes place on a game board that simulates a rice field, where each square on the board contains a certain amount of rice. Figure 2 illustrates a game board and items used in the game.

### Research Instrument

The student's conception of bioaccumulation and biomagnification was evaluated using the Concept Cartoon by examining whether they agree or disagree with the ideas of characters in cartoons (Black and Harrison, 2004; Naylor and Keogh, 2009; Chin and Teou, 2010). The Concept Cartoon can also be used in a positive and safe environment for students to express their opinions (Keogh and Naylor, 1998; Naylor et al., 2007). In this

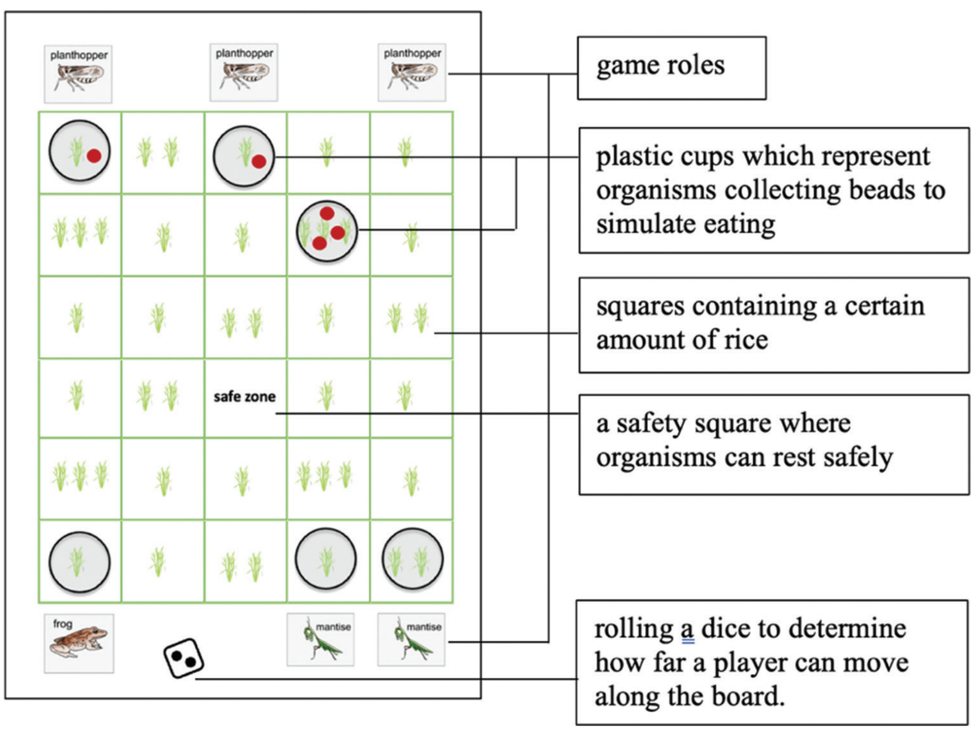


**Figure 2:** TOXIC CHAIN game board and items for playing game

study, we create the Concept Cartoon which depicted three children discussing the effects of a farmer spraying pesticide on his rice field. Students were asked to indicate which child's viewpoint they agreed with and explain their reasoning as illustrated in Figure 3.

Students' responses to the concept cartoon would represent a spectrum of conceptual development, from a limited conception of bioaccumulation to an accurate conception of bioaccumulation and biomagnification. Figure 4 depicts the decision-making scheme that was developed for rating students' conceptions. Magnusson et al. (1997) suggested that the decision-making scheme was helpful for assessing students' conceptions and proposed using "accurate" instead of "complete" scientific conception.

Student responses that did not contain ideas related to biomagnification would be interpreted at scores 1 and 2, and the response that included the ideas of biomagnification would be scored 3–4. To verify the validity of the assessment, the concept cartoon activity underwent content validity review by a scientist, a science educator, and a science teacher. It was subsequently revised and confirmed to ensure consistency of content, questions, and scoring criteria used in the measurement. To ensure the reliability of this assessment, the concept cartoon was administered to 30 students who were not part of the sample group, and two raters evaluated their responses. Inter-rater reliability was analyzed using the percent agreement method and a reliability score of 83.3% was obtained, indicating sufficient confidence level for practical use.

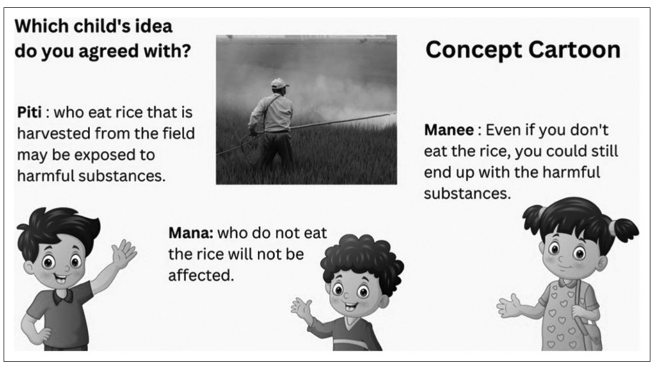


**Figure 3:** The concept cartoon used as an assessment tool

## FINDINGS

Three research objectives included: (1) To explore student's preconceptions related to bioaccumulation and biomagnification, (2) to examine the effectiveness of GBL to student's conceptions of bioaccumulation and biomagnification and how those conceptions changed after learning with GBL, and (3) to explore student's reflections about GBL experiences related to affective, and social aspects. The following session provides a detailed account of this analysis.

### Student's Preconceptions Related to Bioaccumulation and Biomagnification

The research hypothesis stated that students might hold a limited conception of bioaccumulation before having experience in the GBL activity. The result supporting this hypothesis is illustrated in Figure 5.

Figure 5 reveals that 50% of the students had limited concepts of bioaccumulation, while 49% of students held partially accurate conceptions of bioaccumulation without biomagnification. Interestingly, only 1% held partially accurate conceptions of biomagnification, and no students held accurate concepts of those two concepts. An example of the students' responses excepted from the concept cartoon response sheet that shows how concepts are limited is that "*farmers use chemicals, toxic stuff, to kill bugs, which might leave toxic residues in the rice plants. Hence, only people who eat rice from this field might*

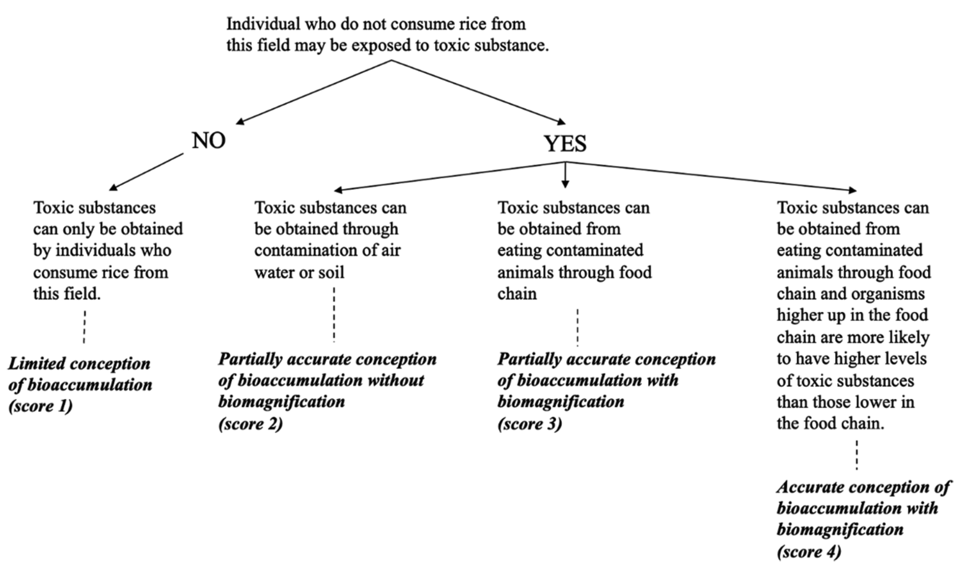


**Figure 4:** The decision-making scheme for rating student's conception

*end up receiving toxins."* Another student, who holds a partially accurate concept of bioaccumulation without biomagnification, stated, *"Rice will get toxins, and the toxic stuff sprayed might float in the air and spread in the water. So, even people who don't eat rice from this field might end up getting toxins, too."* In addition, the only student who partially accurate concept of bioaccumulation without biomagnification, stated, *"Rice will get toxins, and the toxic stuff sprayed might float in the air and spread in the water. So, even people who don't eat rice from this field might end up getting toxins, too."* In addition, the only student who held a partially accurate conception of bioaccumulation with biomagnification stated that "*If you eat rice from this field, you'll end up with some leftover toxins in your rice. And for those who don't eat rice from here, they might still get some toxins from the air or by eating animals that have been exposed to the toxins."*

## The Effectiveness of GBL on Student's Conceptions of Bioaccumulation and Biomagnification

After engaging in GBL, the study found that once students' concepts regard as being either limited or partially concepts changed to be more in line with scientific concepts. In Figure 6, the percentage of students with a limited concept of bioaccumulation decreased from 50% to 14%, and those with a partially accurate concept without biomagnification also decreased from 49% to 18%. Meanwhile, the percentage of students with partially accurate concepts of bioaccumulation and biomagnification dramatically increased from 1% to 61%, and those with an accurate concept of both concepts increased from 0% to 7%.

Related-Samples Wilcoxon Signed-Rank Test, a non-parametric statistic, was employed to analyze the difference between Students' test scores using IBM SPSS version 29. The Glass rank-biserial correlation coefficient ($r_b$) was calculated as an effect size measure (Table 1).

The null hypothesis ($H_0$) stated that there is no difference in conception scores of bioaccumulation and biomagnification between pre-test and post-test and the alternative hypothesis ($H_a$) stated students' conceptions score of bioaccumulation and biomagnification after having experience in GBL was more than before the instruction at a 0.05 level of significance. The test statistic ($Z$) was 2850, and the $p < 0.001$. Using a significant level of 0.05, we found strong evidence to reject the null hypothesis, indicating a significant difference between pre-and post-test scores. López-Martín and Ardura-Martínez (2023) proposed reference values for the rank-biserial correlation coefficient to classify the effect size as very small ($r_b < 0.1$), small ($0.1 \leq r_b < 0.30$), moderate ($0.30 \leq r_b < 0.50$), and large ($r_b \geq 0.50$). The effect size was 1.00, indicating that GBL had a significant and large effect on students' understanding of bioaccumulation and biomagnification.

In addition, an analysis of students' concepts looking deeply to categorize such concepts based on students' grade levels was conducted. The analysis revealed that after GBL, only a limited number of Grade 9 students, specifically seven individuals, demonstrated accurate concepts of bioaccumulation and biomagnification. Furthermore, when considering the cumulative number of students who displayed emerging to full comprehension of biomagnification (score 3–4) and comparing it to the group that solely exhibited ideas about bioaccumulation (score 1–2), it was observed that the highest proportion of students with the concept of biomagnification (82%) belonged to Grade 9 (Figure 7).

Interestingly, compared to Grade 7 and Grade 8 students, only Grade 9 students exhibit a greater tendency to expand their understanding from bioaccumulation to incorporating biomagnification.

## Students' Reflections about GBL Experiences Related to Affective and Social Aspects

Students' reflections after learning with game activities were analyzed using content analysis. After the coding process, categories emerged. The number of students who described these categories is presented in Table 2. The students had a joyful experience and positive emotions towards the learning

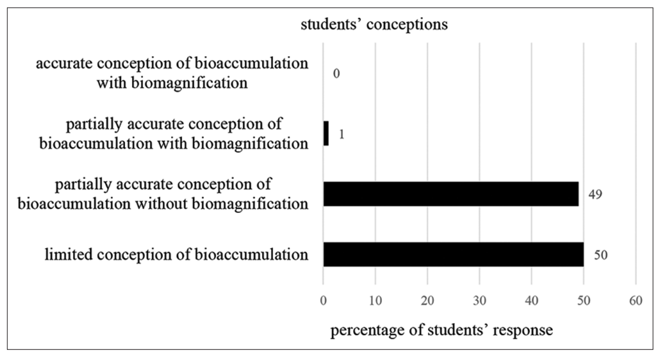


**Figure 5:** Percentage of students' preconceptions on bioaccumulation and biomagnification

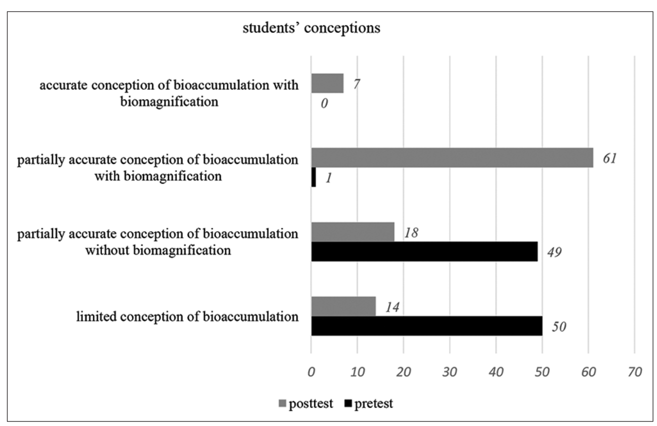


**Figure 6:** Change in percentage of student's conceptions

**Table 1: The result of related-samples Wilcoxon signed-rank test and glass rank-Biserial correlation coefficient**

| Test | Test statistic | p | Effect size (Rank-biserial $r_b$) |
|---|---|---|---|
| Wilcoxon W | 2850.00 | <0.001 | 1.00 |

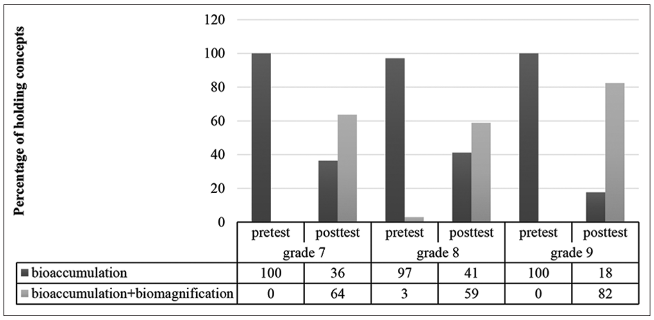


**Figure 7:** The cumulative percentage of students who hold concepts of bioaccumulation and biomagnification

**Table 2: Categories of students' reflections (n=101)**

| Categories of students' reflections | Frequency |
|---|---|
| 1. Feeling good, happiness | 31 |
| 2. Having fun, relaxation | 30 |
| 3. Engaging in enjoyable activities | 27 |
| 4. Practicing skills | 22 |
| 5. Acquiring new knowledge | 81 |
| 6. Emphasizing learning about the food chain | 31 |
| 7. Collaborating/interacting with friends | 42 |

activity as they express the words as feeling good, happiness (31 students)/having fun, relaxation (30 students)/engaging in enjoyable activities (27 students) in their reflections. They gained new knowledge (81 students), especially about the food chain (31 students), and various skills (22 students) from this activity. In addition, they felt content engaging in conversations and building connections with both senior and junior peers, as well as with the teacher (42 students).

This result supported the research hypothesis that students' reflections express positive opinions related to feeling, emotion, or group work. This is evidence of the benefits of GBL on the affective and social dimensions of student learning.

## DISCUSSION AND CONCLUSION

The first research objective was to investigate the preconceptions held by the students concerning bioaccumulation and biomagnification. The analysis revealed that half of the students (50%) demonstrated limited concepts of bioaccumulation, whereas 49% of the students exhibited partially accurate conception only of bioaccumulation without integration with biomagnification. Notably, merely one percent possessed a partially accurate understanding of biomagnification. No student held accurate conceptions of these two concepts. In this manner, the underlying cause could be that most students interpret natural phenomena through their common sense. As perceived by most responses, the notion that living things are exposed to toxins when directly consumed regardless of the channel (e.g., ingestion or respiration), toxins are presumed to only infiltrate upon direct contact. Students' preconceptions in science are shaped by their prior experiences, textbooks, teachers' explanations, or everyday language and are often not in alignment with accepted scientific beliefs (Canlas, 2021; Morrison and Lederman, 2003; Sommeillier, 2021). Research studies had used concept cartoons to elicit students' preconceptions in both physical science (Minárechová, 2016). and biological science (Chin and Teou, 2010; Ekici et al.,2007; Yong and Kee, 2017). The results supporting this study were that students often held conceptions that differed from scientific concepts. Concept cartoons, which combine dialogue in cartoon form with visual stimuli, represent both the scientifically acceptable viewpoint and several alternative conceptions in everyday contexts, and provide a basis for students to realize their own conceptions (Chin, 2001).

Second, the study found that the prevalence of students possessing a limited understanding of bioaccumulation was reduced from 50% to 14%, while those holding partially accurate bioaccumulation without biomagnification revealed a decline from 49% to 18%. In addition, the cohort demonstrating partially accurate bioaccumulation with biomagnification increased from 1% to 61%. Likewise, individuals attained accuracy in both concepts rose from 0% to 7%. Moreover, the Wilcoxon signed-rank test indicated a significant difference between pre-and post-test scores, and the effect size indicates a large effect of GBL on students' understanding of bioaccumulation and biomagnification. The analysis found that the highest proportion of students possessing a concept of biomagnification (82%) was observed within the grade 9 students. The results of this study indicated that conceptual change occurred through the process of GBL. The percentages of students who "captured" or "extended" the concept of biomagnification increased dramatically, and there was a significant difference between the pre-test and post-test scores. This result demonstrated students' understanding of the transfer of toxins in the environment through biomagnification in the food chain. From the epistemology aspect of conceptual change, Hewson (1992) proposed that the status of one's current conceptions and the conceptual ecology significantly influence the interaction between new and existing ideas. In the case of grade 9 students learning about mass and energy transfer in ecosystems, their existing knowledge might form part of their conceptual ecology. Therefore, when the new concept of biomagnification is introduced, it could be relatively easier for them to grasp and incorporate it within their existing conceptual framework (conceptual capture). Mayer (2019) stated that students actively participate in mental processes that involve creating new ideas during the learning process. This includes tasks such as identifying pertinent information from the game, organizing it logically in their minds, and connecting it to their existing knowledge. Grade 9 students already hold existing knowledge related to the transfer of mass and energy in an ecosystem. Therefore, GBL helped them to connect this knowledge to game situations in a meaningful way. Ambrose and Lovett (2014) also suggest that prior knowledge that is accurate can significantly impact a student's ability to learn new related information. In addition, they provided research evidence that students who had high prior knowledge retained twice as much new information compared to those who had low prior knowledge. Moreover, studies have indicated that students can fully utilize the advantages of their accurate prior knowledge by being prompted to "activate" it.

The research finding of this study was consistent with other GBL in environmental issues. For instance, Arboleya-Garcia and Miralles (2022) designed a board game using an interdisciplinary approach to enhance individual's concepts of oceanic ecosystem. The results showed that there was a significant improvement, with correct answers rising from 39.6% to 60.4% from pre-test to post-test in adults and from <30% to over 70% in children. Cheng et al. (2020) developed an issue-based board game focusing on four design concepts to center real-world issues. The result indicated that GBL improved participants' understanding of water resource adaptation. The correct answer increased from 66% in the pre-test to 75% in the post-test. Both studies argued that GBL provided a learning environment supporting active engagement and collaborative learning.

From the viewpoint of the cognitive foundation of GBL (Plass et al., 2015), the use of game mechanics, where students assume the role of different animals in the food chain, could help students better comprehend the process of biomagnification and increased their cognitive engagement. The game's mechanism simulated the process of biomagnification, where toxins are transferred through the food chain, which is not observable. Moreover, counting the number of beads as a way of toxin accumulation and then creating graphs to show the pattern of phenomena is the learning process called concreteness fading. Goldstone and Son (2005) proposed that using a combination of both concrete and idealized representation was beneficial. The most effective sequence was to start with concrete representations and gradually move toward more idealized ones.

Finally, the third research objective was to investigate the affective and social dimensions exhibited by the students after experiencing the TOXIC CHAIN board game. The result found that the students had joyful experiences and positive sentiments towards the learning activity and collaborative work. The students gained new knowledge and various skills from this activity. Additionally, they felt content engaging in conversations and building connections with both senior and junior peers, as well as with the teacher. This result was consistent with the study by Belova and Zowada (2020) in that more than 70% of participants perceived GBL as motivating. The competitive setting of the game was mentioned as a motivating factor by the students themselves, indicating that it engaged them actively in the learning process. Plass et al. (2013) also found that playing the game with others as competitors or collaborators made it more engaging, but the most effective version for learning was the competitive one. Moreover, the result regarding social interaction was consistent with the study by Cheng et al. (2020) in that GBL provided an interactive environment similar to the real world, where participants could share their opinions with others about public issues. Considering the intentional aspect of conceptual change, the game activity in this research impacted students' interest and offered a setting for the social construction of conceptual understanding through dialogue between teachers and students, as well as among students (Pintrich et al., 1993; McLure et al., 2020). In addition, the TOXIC CHAIN offered a familiar context such as living things in the rice field. Lin (2018) also found that a highly contextualized environment, where students could relate new information to their prior experiences and knowledge, led to meaningful learning and conceptual understanding.

In conclusion, the result indicated that after learning with the TOXIC CHAIN board game activity, most students changed their concepts range from limited concepts to accurate concepts of bioaccumulation and biomagnification. There was a significant difference between pre-test and post-test scores with a large effect size. Moreover, the students reflected their positive feelings toward the TOXIC CHAIN board game activity as well as enjoying playing games with their friends in groups, and their feedback showed a desire for more of these activities. These results contributed to the cognitive, affective, and sociocultural foundations of GBL and the multidimensional frameworks of conceptual change.

### Limitations and Recommendations for Future Research

This study was conducted as an extracurricular activity, and the results were not compared directly with the traditional teaching method. Therefore, it was a limitation of this study. However, according to Thailand's basic curriculum, it was assumed that the participating students had learned about food chains and Grade 9 students had been taught about energy transfer and the accumulation of toxins in the environment, but the research results suggested that they still had limited conceptions of bioaccumulation and biomagnification. In the traditional teaching method that teachers might rely mainly on textbooks, Kim and Kim (2013) found that the limited explanations in textbooks might cause misconceptions about bioaccumulation and biomagnification. In future studies, science GBL should be applied in teaching and learning in regular classrooms, and the results should be compared with the control group, which applied the traditional teaching method or with diverse settings. In addition, future research should investigate more about the correlation between the affective aspects, like student enjoyment, and the cognitive aspect, such as conceptual understanding or concept application.

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## ETHICAL STATEMENT

The authors acknowledged that the study involved human participants but determined that it did not require ethical committee approval because it posed no risks and was considered harmless. The reporting of results did not disclose the identity of the data provider, and there was no sensitive information. Informed consent was obtained from all participating students and their parents. The authors also confirmed that they received permission from the school director to conduct the quasi-experimental study with the selected students.

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