

From Chance to Strategy: Advancing Educational Games about Vertebrates for Elementary Students

Nantarat Kruea-In, Kulthida Nugultham, Thanarat Taewattana and Kittiphan Wiboonsin

Kasetsart University Kamphaeng Saen Campus, Nakhon Pathom, Thailand

nantarat.p@ku.th

kulthida.n@ku.th

thanarat.tae@ku.th

kittiphan.wi@ku.th

Abstract: This study presents the development and improvement of an educational game aimed at enhancing elementary students' understanding of vertebrate classification. The original version used a dichotomous key to help classify five groups of vertebrates: fish, amphibians, reptiles, birds, and mammals. Initial implementation showed promising results, with average post-test scores exceeding 80% and high student satisfaction. However, limitations were found, such as excessive reliance on chance through dice-rolling, limited strategic options, and lengthy gameplay that reduced engagement, especially in the later stages. In response to these limitations, the game was redesigned to encourage visual observation, reasoning, and strategic decision-making. Players must now analyze animal traits, justify their choices, and select cards that match the game's objectives. The development process involved collaboration with experts including university lecturers, science teachers, game designers, and students aged 10–13. Data were collected through classroom observation and informal interviews and used to refine the game across multiple iterations. The revised game promoted higher student engagement, critical thinking, and strategy through trial and error. Mistakes made during gameplay helped students remember animal traits more accurately and improve in later rounds. While the game supported advanced thinking skills, some areas still needed improvement. Experts suggested simplifying the scoring system, improving the clarity of animal images, and enhancing the game's replayability. Some experts recommended immediate revision, while others believed students would adapt through repeated play and become more familiar with the game.

Keywords: Vertebrates, Educational games, Game-Based learning, Iterative design, Observation and analysis

1. Introduction

Educational games are learning tools specifically designed to teach certain skills or concepts. They are often linked to curriculum standards to support formal learning objectives. Although educational games have attracted academic interest since the 1970s, there is no clear evidence that they are more effective than traditional teaching methods (Engström, 2020). However, game-based learning offers many advantages. It increases student motivation and engagement through interactive and enjoyable experiences (Qian & Clark, 2016). When students actively participate in gameplay, learning becomes more meaningful and less monotonous. This positive engagement also encourages students to explore complex topics with greater interest and confidence (Dichev & Dicheva, 2017). The combination of fun, challenge, and competition in educational games can stimulate curiosity, improve memory, and support deeper understanding of concepts (Kapp, 2012).

In biology education, there are still many limitations in teaching materials. For example, lessons on vertebrate classification often follow a teacher-centered approach. Students usually learn by listening to the teacher and looking at pictures of common animals. They are then asked to classify animals by comparing external traits using their existing knowledge (Ausubel, 2000). These materials often provide oversimplified generalizations and fail to show the diversity of life. As a result, students may develop misconceptions, especially when they encounter unusual animals such as egg-laying mammals (e.g., platypus, echidna) or mammals with reptile-like traits (e.g., pangolin) (Diamond & Bond, 2004). These cognitive challenges show the need for new teaching strategies that promote analytical thinking and deeper understanding.

Educational games about vertebrates can offer a new and promising way to improve biological knowledge. These games use real biological features of animals and combine them with game mechanics that naturally engage students in learning. Many studies have shown that both digital and board games in biology can increase motivation, support learning outcomes, and promote critical thinking about ecosystems and biodiversity (Gros & Wisson, 2020; Moreno et al., 2020). Chang et al. (2019) also found that immersive gameplay helps students develop analytical thinking and better understand complex ideas. A clear example is the VERT card game by Punyasettro and Yasri (2021), which allows students to explore vertebrate phylogeny through competitive and cooperative play. Their study showed that students gained more self-confidence and

improved their understanding of evolutionary relationships, showing the potential of well-designed classification games.

Although educational games are increasingly used in biology classrooms, there are still few empirical studies on how game mechanics affect students' conceptual understanding. Most existing research focuses on the motivational effects of gameplay (Qian & Clark, 2016; Dichev & Dicheva, 2017). Only a few studies explore which game features help students develop classification skills and increase engagement. To fill this gap, this study aims to examine what characteristics of an educational game can improve learning and student engagement. The focus is on a game developed for teaching vertebrate classification at the elementary level. The study presents findings from redesigning the original game into a new and improved version.

2. Research Design and Methodology

This study used a design-based research (DBR) approach to develop and improve an educational game about vertebrate classification. DBR is a flexible but systematic method. It supports both practical innovation and theoretical understanding in real classroom settings (Anderson & Shattuck, 2012). The main goal of this study was to improve the original game step by step using evidence from practice. The research was guided by one question:

What features should an educational game have to support students' classification skills and learning engagement?

The study took place in two phases:

Phase 1: Testing the Original Game (Amass Me)

The original game was tested with Grade 4 students, aged 9 to 10. Data were collected through classroom observation, informal interviews, and post-game assessments. The results showed that the game helped students learn the content. Most students scored above 80% in the post-test. However, there were some problems. The game relied too much on luck, especially from rolling dice. It also offered few chances for students to plan or use strategy. In addition, many students found it hard to understand the symbols used in the game. These problems led to the redesign of the game.

Phase 2: Developing and Testing the Revised Game (Vertebrate Auction)

The new version of the game was designed to solve the earlier problems. It kept the same scientific content but changed how students played. The new game encouraged students to observe, analyze, and plan. It helped them identify both common and unusual traits of animals more accurately. The new version was reviewed by experts, including science educators, teachers, gamers, and board game designers. Their suggestions helped improve the game's accuracy and usefulness in real classrooms. The revised game was tested with students aged 10 to 13. These students had already learned some basic ideas about vertebrates and could handle more complex thinking tasks. During testing, the researchers observed classroom interactions and interviewed students informally. They used this information to improve the game further. The results gave insight into how students learned and engaged with the new game design.

3. Original Game Concept: Amass Me

The original game, Amass Me, was developed to support the cognitive and educational needs of Grade 4 students (ages 9–10), aiming to cultivate basic knowledge of vertebrate classification, rule-following, reasoning, and decision-making skills through playful learning. It was designed for both classroom use and informal home learning, with content and visuals tailored to be age-appropriate, colourful, and engaging to maintain student interest and autonomy.

The gameplay combined elements of chance, analytical thinking, and strategy. Players rolled dice to match biological traits on animal cards and used a dichotomous key for classification. Correct classifications were rewarded with coins, while mistakes incurred penalties. The central mechanics required players to manage luck (dice outcomes), knowledge (trait analysis), and decision-making (action choices) to classify ten animals and collect the most coins.

Game components included 55 animal cards, 8 special cards, coins, classification boards, dice, and bases—designed for clarity and visual appeal. Icons on dice represented five key biological traits: body covering,

appendages, respiration, reproduction, and thermoregulation. Game visuals were created using Canva and refined with expert input.

Each of the five dice displayed six faces, each depicting different trait values commonly used in vertebrate classification. These were proportionally repeated to reflect real-world biological variation, providing both realism and gameplay balance. The trait categories and representative values were as follows:

Table 1: Characteristics of vertebrates shown on dices

Dice	No.	Characteristics
1. Body Covering		
	1	Has scales
	2	Moist skin
	3	Has hard scales
	4	Has feathers
	5	Has hair
	6	Nothing shown
2. Animal Appendages		
	1	Appendages are fins, has 5 fins, and tail fin moves side to side
	2	Appendages are fin-like, has 4 fins, tail fin moves up and down
	3	2 pairs of appendages, front pair are wings not connected to hind pair
	4	2 pairs of appendages, front pair are wing-like connected to hind pair
	5	2 pairs of appendages, used for movement or grasping objects, and/or has 1 tail
	6	No appendages
3. Respiration		
	1	Breathes using gills
	2	Larvae use gills but adults use skin and lungs for breathing
	3	Breathes using lungs
4. Reproduction		
	1	Lays eggs with jelly-like covering
	2	Lays eggs with hard shell
	3	Gives birth to live young
5. Body Temperature		
	1	Body temperature does not change with environment (warm-blooded)
	2	Body temperature changes with environment (cold-blooded)

These symbols guided players during gameplay to identify which animals they could attempt to classify based on the dice results, integrating biological concepts directly into the core game mechanics.



Figure 1: Components of the original game “Amass Me,” including animal cards, dice, and classification boards

3.1 Gameplay Summary

- Each player received 5 animal cards and 10 bases.
- On their turn, players could roll dice, draw/discard a card, or use a special card.
- Players rolled five dice and placed cards with at least three matching traits.
- Cards were classified using the dichotomous key for rewards or penalties.
- The game ended when a player successfully classified all ten animals.

3.2 Playtesting and Findings

Initial testing with Grade 4 students showed that they were excited to play. However, many students had trouble understanding the rules and the meaning of the symbols. This confusion caused the game to progress slowly. The researchers adjusted the rules by changing the required number of matching dice faces from three to two. After this change, the game became easier to play. Students showed more cooperation with each other, became more emotionally involved, and used more strategic thinking. Informal interviews confirmed that students enjoyed the game. They also helped each other and became more skilled over time. In a different trial, 29 Grade 4 students played the updated version of Amass Me. After playing, their test scores averaged 83.8 percent. This score was higher than the 80 percent benchmark and the difference was statistically significant with a p-value less than 0.05. These results showed that the game helped students improve their understanding of how to classify vertebrates.



Figure 2: Implementation of Amass Me to Support Vertebrate Classification Learning in Grade 4

3.3 Analysis and Limitations

Amass Me helped students feel more motivated and engaged. It also supported their understanding of core concepts. The use of visual symbols and the need for decision-making encouraged teamwork and reduced stress. However, some students found the game too complex. There were many symbols to learn, and the game relied too much on chance. These factors made it harder for some students to follow. The game also

took a long time to complete. This long duration may have caused some students to lose interest, especially if their skill levels were different from others.

To solve these problems, the game was redesigned. The new version focused more on observation. It reduced the role of luck and gave players more control. The rules were clearer, and the mechanics allowed for better strategic planning.

4. Revised Version of the Game: Vertebrate Auction

To address the limitations identified in *Amass Me*, the game was redesigned and renamed *Vertebrate Auction*. This revised version enhances students' observational and analytical thinking while minimizing randomness. The game incorporates five types of cards:

1. Dichotomous Key Cards These five visual reference cards illustrate essential traits used in vertebrate classification. Designed for clarity and instructional value, they help students distinguish between groups based on observable physical features.

2. Animal Cards Each of the 54 double-sided animal cards features a full-color image on the front and key classification details on the reverse. These traits align with the Dichotomous Key Cards and provide diverse examples for comparative analysis.

3. Main Target Card This card presents the core scoring criteria: players earn 2 points for collecting one animal from each vertebrate group, and 5 points for collecting two from each. This encourages players to diversify their collection strategically.

4. Additional Target Cards These supplementary goal cards feature specific traits that players must identify in the Animal Cards. Bonus points are awarded for matching the required traits, reinforcing detailed observation and trait recognition.

5. Auction Cards Players use numbered bidding cards (1–6) to compete for animals during each round. Higher bids allow earlier selection, fostering strategic planning in card acquisition.

4.1 How to Play: Vertebrate Auction

1. Game Setup Place the Main Target Card and draw three Additional Target Cards to be displayed in the center. Each player receives 5 Dichotomous Key Cards and a full set of Auction Cards (1–6).

2. Gameplay Structure The game consists of 6 rounds. In each round, players compete to collect animals through an auction mechanism. By the end of the game, each player will have 12 Animal Cards to classify.

3. Auction and Selection At the start of each round, reveal Animal Cards equal to twice the number of players. Players then bid using one Auction Card. The highest bidder selects first, followed by others in descending order. Each player repeats this process to obtain two animals per round.

4. Classification and Scoring After six rounds, players classify their 12 Animal Cards using the Dichotomous Key Cards and score according to the Main and Additional Target Cards. The highest scorer wins.

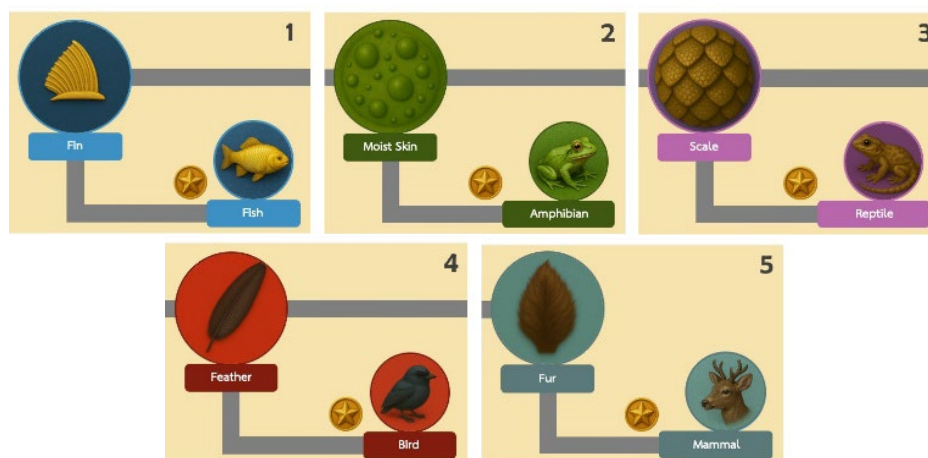


Figure 3: Dichotomous Key cards

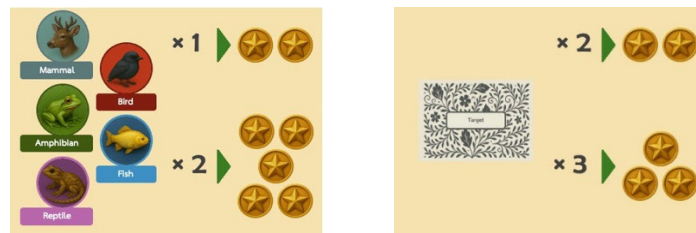


Figure 4: Main Target cards



Figure 5: Animal cards

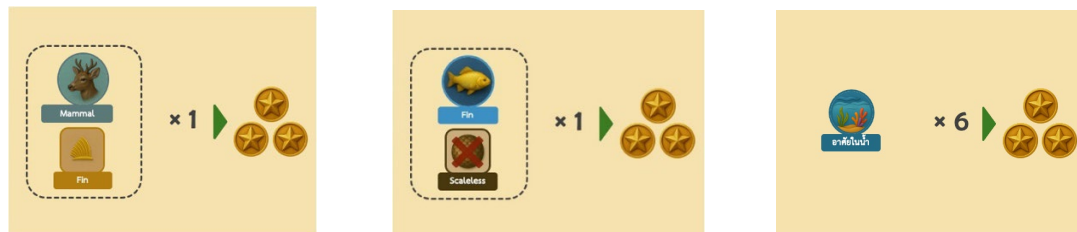


Figure 6: Additional Target cards



Figure 7: Auction cards

5. Research Findings

During the prototype development phase of the Vertebrate Auction game, the researchers conducted a playtest with experts in relevant fields. The purpose was to gather diverse feedback for improving the game and identifying design flaws. The expert responses were thematically analyzed and grouped into three main themes as follows.

Theme 1: Complexity of the Scoring System

One major change from the original version was the scoring system. The revised version allowed players to earn points through multiple methods. This design aimed to promote strategic thinking and encourage players to carefully observe and analyze animal characteristics to score as many points as possible. The scoring rules were as follows:

- 1) Players received 1 point for each animal card they correctly classified using the dichotomous key. This rule encouraged accurate classification through observation and reasoning.
- 2) Players received 2 points when collecting one complete set of animals from all vertebrate groups, and 5 points when completing two full sets. This aimed to motivate players to collect cards from all categories.

3) Players received 2 or 3 additional points, as indicated on the bonus target cards, for collecting animals with specific traits. These traits often represented animals that are commonly misunderstood, such as pangolins, whales, bats, or stingrays.

Examples of expert comments in this theme include:

- “The game might be too difficult for students because there are many things to pay attention to.”
- “The scoring system is quite complicated, but if students play a few times and become familiar with it, it should not be a problem.”

Theme 2: Fairness of the Scoring System

A consequence of adding more ways to earn points in the revised game was the imbalance between the points awarded and the level of difficulty described on the target cards. Some targets were hard to achieve but gave only a small number of points, while others were easy but gave more points. As a result, some players lost motivation, especially when they received difficult target cards or cards with low rewards. This imbalance may have created unequal chances of winning among players. Examples of expert comments in this theme include:

- “The card asks for 7 warm-blooded animals but gives only 1 point. That’s not interesting.”
- “Collecting animals with shells is too hard. There is only one card out of fifty, and it’s not even guaranteed to come up.”

Theme 3: Overall Game Presentation

The overall presentation refers to how game components are arranged to help communicate ideas or support reflection after gameplay. Experts agreed that the game effectively conveyed biological knowledge about vertebrate animals, including shared and unique traits. Examples of expert comments in this theme include:

- “The overview after playing is clear. When the answers are revealed, the teacher can use them to ask questions and help students summarize the lesson.”
- “The symbols are a bit visually crowded, but the shapes and layout help make them easier to observe.”

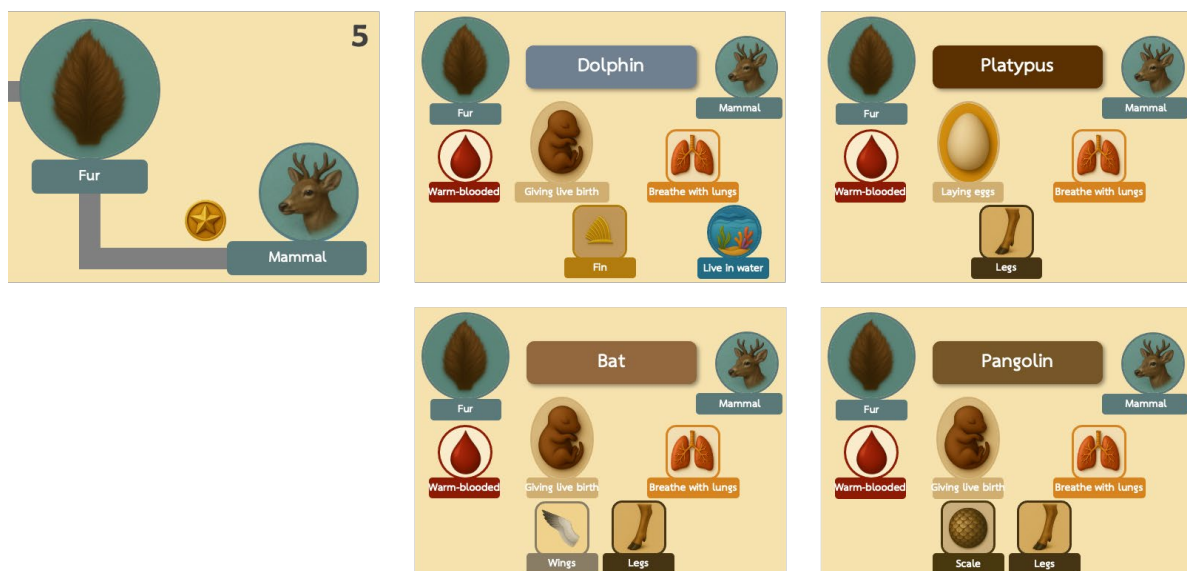


Figure 8: Final Set of Mammal Cards Collected by a Player During Vertebrate Auction Gameplay

Theme 4: Player Interaction

One issue that the early version of the revised game could not fully address was the lack of interaction among players. Initially, each player was given three individual target cards. This rule made players focus only on their personal goals. To solve this problem, the target cards were placed in the center so that all players worked toward the same goals. This change required players to plan their bidding order carefully in order to compete for animal cards that matched the shared targets. Examples of expert comments in this theme include:

- "It feels like everyone is playing on their own."
- "The auction doesn't feel meaningful because, in the end, I still get the card I want."

5.1 Student Playtesting and Feedback

After the game prototype was refined to ensure its accuracy and classroom suitability, it was tested with a small group of students aged 10 to 13. The goal was to evaluate students' perspectives on the game. The testing was conducted by classroom teachers to reduce bias during implementation and data collection. Informal interviews were guided by the following questions:

- Did you find the game enjoyable? Which parts did you like or dislike?
- Would you be interested in playing this game again? Please explain why or why not.
- Are there any parts of the game you would like to see improved or changed? If so, please describe.

Students' responses were analyzed thematically and grouped into three main categories. These themes reflected the game's strengths, challenges, areas for improvement, and learning-supporting features. A summary of each theme with sample student quotes is presented below.

Theme 1: Challenges and Limitations During Gameplay

A common theme in student feedback was the complexity of the scoring system. Many students noted that tracking points—especially when trying to complete both main and additional targets—was difficult and sometimes confusing. This complexity occasionally distracted players from the core learning goal, which was vertebrate classification. Sample student comments include:

- "The scoring system should be improved because keeping track of points is quite complicated, especially with so many targets to monitor."
- "It's fun, but the scoring is a bit too complicated."
- "During the game, players might forget to complete the main target."
- "Counting the score is really confusing."

These responses suggest a desire for a simpler scoring system to promote smoother gameplay and sustained engagement. Interestingly, the feedback also implies that players placed more importance on classification tasks than on scoring, which aligns with the design goal of encouraging repeated play to improve classification fluency and accuracy.

Theme 2: Difficulty in Identifying Animal Types

Another key challenge was the difficulty of identifying animals based on the pictures on the cards. Students said that without prior knowledge of animal characteristics, it was often hard to classify animals correctly. Examples of student feedback include:

- "Identifying the animals just from the pictures is quite hard if you don't already have background knowledge."
- "Some pictures are difficult. For someone like me who doesn't know much, they are really hard to understand."

This theme highlights the gap between visual interpretation and conceptual understanding. It also shows the importance of background knowledge for gameplay success. The designers intentionally included this challenge to encourage players to observe, interpret, and build knowledge gradually through the revealing of biological traits on the reverse side of each card in subsequent rounds.

Theme 3: Positive Learning Experience and Educational Value

Despite the challenges, most students provided positive feedback about the educational value of the game. They found it both enjoyable and helpful for understanding vertebrate classification. Examples of student comments include:

- "It's fun and educational."
- "This game is really good for teaching animal classification. After scoring, the game explains the animal's features, which helps players learn more."

These responses confirm the game's objective of making science learning engaging and meaningful. The game's iterative structure encourages analysis of classification features, supports the application of prior knowledge, and helps students refine their strategies through repeated play and interaction with others.

6. Conclusion

This study demonstrates the potential of educational board games to enhance elementary students' conceptual understanding of vertebrate classification. Through a design-based research (DBR) approach, the game Amass Me was iteratively improved into Vertebrate Auction, incorporating feedback from both experts and students. The findings highlight key design features that support scientific thinking, such as the use of visual cues, shared goals, and strategic decision-making. The revised game reduced reliance on chance, increased player agency, and fostered meaningful interaction—addressing the limitations observed in the original version. Both expert evaluations and student feedback emphasized the game's educational value, especially in promoting observation, analytical thinking, and collaborative learning. Challenges such as scoring complexity and animal identification were acknowledged, suggesting areas for further refinement. Nevertheless, the game successfully transformed traditional instruction into an engaging, student-centered experience.

This research contributes to the growing body of literature on game-based learning by offering empirical insights into how specific mechanics influence learning and engagement. It also underscores the importance of iterative design grounded in real classroom contexts. Future research could explore long-term learning outcomes, scalability across diverse educational settings, and the integration of such games into broader science curricula.

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AI Declaration: The authors declare that AI tools were used to assist in language refinement and grammatical accuracy checking of this manuscript. Specifically, AI was employed to improve clarity, coherence, and formal academic tone without generating or altering the substantive content, data interpretation, or conclusions of the study. All revisions suggested by the AI tool were reviewed, verified, and approved by the author(s) to ensure accuracy and alignment with the intended meaning.

Ethics Declaration: This study was conducted in accordance with ethical standards for research involving human participants and was approved by the Institutional Review Board (IRB) of Kasetsart University prior to data collection (Approval No.: COE67/060). All participants, including students under the age of 18, were informed of the purpose and procedures of the study, their right to decline or withdraw at any time without penalty, and the measures taken to protect their personal data. Written informed consent was obtained from all participants and, where applicable, from their legal guardians before participation. The researchers affirm that all data were anonymized and treated confidentially, and that the information collected will be used solely for academic and research purposes.

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