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A Game-Based Learning Activity to Promote Conceptual Understanding of Chordates' Phylogeny and Self-Efficacy to Learn Evolutionary Biology

Santhanat Punyasettro*
Mahidol University, THAILAND

Pratchayapong Yasri
Mahidol University, THAILAND

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Abstract: Understanding phylogenetic trees representing evolutionary relationships of living organisms is essential in school biology. Traditional instructions based on lectures and textbooks with pictorial presentations have been proven ineffective to promote students' understanding of the concept. This study, therefore, developed a game-based learning activity called the VERT card game to enhance students' learning of the phylogenetic taxonomy of chordates. The VERT card game was designed to lay the foundation for different characteristics of chordate classes, as well as to allow students to construct and interpret their evolutionary relationships based on the phylogenetic tree. The effectiveness of the VERT card game was verified by a pre-test and post-test design with 109 middle school students in Thailand. The statistical result revealed that students' mean scores increased significantly in the post-test, compared to the pre-test, indicating their improved understanding. In addition, after participating in the learning activity, the student participants were found to increase their self-efficacy to learn evolutionary biology statistically. Also, it showed positive views towards the usefulness of the developed card game as a large number of them expressed that they would like to use it for their lesson reviews and wished to have this form of learning activity in other topics in biology.

Keywords: *Chordates, game-based learning, level of use, phylogeny, self-efficacy.*

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Introduction

Nowadays, various forms of active learning have been developed and implemented to improve students' learning which have been reported in a wide range of disciplines such as science, technology, engineering, and mathematics education (Changtong et al., 2020), computer sciences (Threekunprapa & Yasri, 2020), and biology education (Meekaew & Yasri, 2020). These can be seen in a number of instructional approaches such as hands-on activities, game-based learning, problem-based learning, and mobile learning (Chen et al., 2009). These research findings have shown that innovative teaching methods can help improve student learning both from cognitive and emotional perspectives. In addition, among them, card games appear to be the most popular due to their interactive and entertaining nature, which can help students learn challenging concepts with enjoyment (Piyawattanaviroj et al., 2019).

To follow this research trend, this study developed a game-based learning activity as an educational innovation to learn the concept of chordates' phylogeny, which is missing in the literature. It is expected that this learning activity can help secondary school students improve their conceptual understanding of chordates' phylogeny and their ability to construct phylogenetic trees. It is also expected that student participants in this research can enhance their self-efficacy to learn and find the learning activity useful. These two aspects are set to be investigated through the lens of self-efficacy and the level of use which will be discussed later in greater depth.

The study of phylogeny

In evolutionary biology, chief among numerous topics is the concept of phylogenetic trees which are visual representations of taxonomic relationships of different organisms in the form of branching diagrams (Baum & Offner, 2015; Dees & Momsen, 2016; Novick & Catley, 2007). They are considered primary tools that evolutionary biologists use to convey evolutionary patterns and shared characteristics of organisms (Baum et al., 2005). Various terms are used interchangeably to refer to a phylogenetic tree, such as a family tree, a tree of life, a phylogenetic diagram, an evolutionary

* **Corresponding author:**
Santhanat Punyasettro, Institute for Innovative Learning, Mahidol University, Thailand. ✉ the.pual.jay@gmail.com

diagram, a phylogeny, a cladogram, to name a few (Novick & Catley, 2012). The importance of this biology topic lies on the ground that a phylogenetic tree enriches the understanding of how genes, genomes, species, and physical traits have evolved. In addition, it can be used as a general principle for evolutionary biologists to predict how organisms will potentially change in the future (Novick & Catley, 2007).

As a result, learning about phylogenetic trees has become an essential part of the biology curriculum, as well as an area of immense interest in biology education research. However, it remains ambiguous whether students, especially school graders, can fully comprehend how to read, interpret, and construct a phylogenetic tree, not to mention how this concept should be taught among different levels of learners (Baum et al., 2005; Hara, 1998; Omland et al., 2008; Young et al., 2013). Biology educators have suggested that students should begin to understand different characteristics of living organisms as well as their relationships before proceeding to fundamental principles of phylogenetic trees at the primary level (Catley et al., 2005; Novick & Catley, 2007). To be more precise, starting from grades 3 to 6, it is expected that primary school students should be exposed to the learning of common traits of different taxa of organisms. Later on, from grades 7 to 9, middle school students should learn to compare characteristics of different taxa, leading them to understand relationships between organisms (Catley et al., 2005). Furthermore, students in grades 10 to 12 should be able to indicate the distinction between analogous structures and homologous structures and to form basic structures of their phylogenetic relationships (Catley et al., 2005). This linear development of conceptual understanding of evolutionary biology is believed to cultivate students' ability to perceive the evolutionary relationships between different taxa of organisms, as well as to become more ready to develop tree thinking (Young et al., 2013).

In order to meet the aforementioned goal of learning, a number of instructional approaches have been proposed. Traditionally, lecture-based learning has been executed using pictorial representations in textbooks. However, this method is not without criticism. A body of research has critiqued its lack of activeness in learning which potentially discourages students from engaging with the learning materials both in cognitive and emotional aspects (Chen et al., 2009; Threekunprapa & Yasri, 2020). In addition, this passive mode of learning where one-way communication is generally given by the teacher can potentially cause misunderstandings and misconceptions about phylogenetic trees because formative assessment is practically limited (Ballen & Greene, 2017). Unless students can effectively read phylogenetic trees and correctly interpret them in the light of taxonomic relationships by themselves, any instructional methods would be considered inappropriate (Baum & Offner, 2015; Baum et al., 2005; Omland et al., 2008; Young et al., 2013). The rationale for this learning goal is that phylogenetic trees do necessitate not only biological understanding but also systematic, logical, and computational thinking skills, which are essential for 21st-century learners (Dees & Momsen, 2016).

Many educators, therefore, put their attempts to further develop learning tools to make the learning of phylogenetic trees more conceptually and emotionally appropriate. For example, Young et al. (2013) used a set of learning activities consisting of lectures, laboratory activities, and museum visits (i.e., the Harvard Museum of Natural History in Cambridge). The ability to draw a phylogenetic tree of 20 familiar taxa as a result of the learning activities was investigated among 160 introductory-level biology students who exhibited significant improvement in their ability to draw phylogenetic trees properly; nevertheless, there was no improvement in their ability to portray the evolutionary relationships between the group of taxa accurately. In addition, Dees and Momsen (2016) explored the usefulness of textbook-based reading, reading quizzes, multiple-choice questions, and letter cards on phylogenetic trees. The activity served 88 students in an introductory biology course at various stages in their academic program (24% freshmen, 33% sophomores, 18% juniors, and 25% seniors). However, the learning outcomes from this setting were not as pleasant as expected because students' constructed trees are not without detectable errors, especially in respect of the placement of nodes and branches.

More recently, game-based learning has been adopted to foster students' conceptual understanding as well as emotional engagement in school lessons including biology (Kordaki, 2015; Piyawattanaviroj, et al., 2019; Qian & Clark, 2016). This teaching pedagogy can be executed in various forms such as card games, board games, video games, computer games, puzzle games, and role-playing games (Fidan & Tuncel, 2019; Kordaki, 2015; Luchi et al., 2019; Threekunprapa & Yasri, 2021). Various concepts in school biology have been developed to use games including card games as instructional tools (Sadler et al., 2013) including those related to cell biology (Seangdeang & Yasri, 2019), the reproductive system (Butsarakam & Yasri, 2019) and ecology (Miralles et al., 2021). To use game-based learning for promoting students' understanding of phylogenetic trees, Gibson and Cooper (2017) developed a card game sorting activity for high school and undergraduate biology courses, which involves the tree thinking concept in plant taxonomy and evolution. The activity was designed with the aim to construct phylogenetic trees representing the relationship of terrestrial plants and showing essential events that occurred in evolutionary processes. The result demonstrated that those exposed to this learning activity developed a proper understanding of plant evolution and accurate interpretation of phylogenetic trees. However, according to existing literature, little attempt is found to develop learning activities for promoting students' understanding of phylogenetic trees of animals.

The cited literature leaves research gaps for this present study to form its significance and contribution. The aims of this study were three folds. First, a game-based learning activity called the VERT card game was developed to promote students' understanding of the phylogenetic taxonomy of vertebrate classes. Second, it demonstrated empirical support for the effectiveness of this activity based on a pretest-posttest design. Finally, it asserted from a pedagogical point of view that this form of activity could be used among middle school students to introduce the concept of tree thinking and interpretation of phylogenetic classification; thus, early introduction of this principle yields great learning outcomes.

Self-efficacy

Not only conceptual understanding that is focused on learning activities but also psychological aspects associated with learning such as motivation and confidence in students' ability. Self-efficacy appears to be one important aspect on which researchers have long emphasised (Wangwongwiroj & Yasri, 2021). From a general point of view, self-efficacy is used to explain one's confidence in his or her own ability to overcome a challenge (Bandura, 1977). This can be an indicator to predict active participation in a certain task; for example, those with a higher level of self-efficacy are likely to embrace challenges. In contrast, those with a relatively lower level may shy away from difficulties (Bandura & Schunk, 1981). In addition, it is likely that those perceiving that they are inefficacious are prone to give up on difficult tasks more easily and avoid participating in activities that they are not familiar with. On the other hand, for those who experience a sense of completion through achieving a certain task successfully, their self-efficacy is effectively heightened (Schunk, 1989).

In educational contexts, self-efficacy can be viewed as students' belief in their own ability to complete learning tasks (Punyasettro et al., 2021). When students are exposed to any learning environment, this can affect their level of self-efficacy in some way. Research shows a positive correlation between students' self-efficacy and their own growth mindset, suggesting that any learning activity that can help promote students' belief in their own ability is also likely to enhance their growth mindset, which is an essential life skill for every learner (Wangwongwiroj & Yasri, 2021). Bandura (1982) proposes four main sources that play great roles in self-efficacy, consisting of mastery experiences (doing), vicarious experiences (seeing), verbal persuasion (hearing), and psychological states (feeling), which will be reviewed in turn.

To begin with, a *mastery experience* is referred to as direct exposure to a certain phenomenon in which one uses his or her own ability to tackle various tasks in the phenomenon. If this direct experience allows one to progress positively, this will help develop a stronger sense of self-efficacy. In contrast, if this involves failures, it could potentially lower the level of confidence (Bandura, 1982). A positive mastery experience cultivated in a particular context can be sufficiently transferred to another context which requires a similar skill set to manage, meaning that if one can accomplish a task in context A, it is likely that he or she would be confident that a similar task in context B can also be successfully accomplished (Bandura et al., 1975).

Secondly, what people see can influence their level of self-efficacy, regardless of their hands-on experience in that particular task (Rosenthal & Zimmerman, 1978). This is referred to as a *vicarious experience*. When people observe someone, who has a similar level of competency successfully completing a certain task, they may intuitively perceive that they can also accomplish this as well if they have more time and put some effort into practice (Bandura & Barab, 1973). On the other hand, if such an observation leads to a negative perception such as failures, the observers may feel less confident to do likewise (Brown & Inouye, 1978).

Furthermore, *verbal persuasion* is a source of self-efficacy that comes through auditory inputs. This can appear in a positive form such as praises and compliments or a negative one like complaints and destructive criticisms (Bandura, 1982). Since this source of self-efficacy can have negative consequences for those being emotionally sensitive, it is essential not to let vulnerable learners expose the inappropriate form of verbal persuasion. In contrast, those with greater confidence who can reasonably justify the intention of negative comments may learn to reflect on themselves when being exposed to this (Chambliss & Murray, 1979). Additionally, statistical analysis reveals that there is a positive correlation between verbal persuasion and growth mindset (Wangwongwiroj & Yasri, 2021), pointing to the importance of words that one takes in on ones' potential to develop his or her own abilities and skills.

Lastly, another main source of self-efficacy is related to a *physiological state* or *emotional arousal* in a particular moment. In a circumstance where no arousal is present, people tend to be more confident to participate in a certain task. In contrast, in a situation where stress is predominant, self-efficacy is likely to be lowered (Bandura, 1982). Nonetheless, through consistent development and practice of their own skills, learners can become more confident in coping with challenges. It is therefore a matter of time and experience that they have to learn to confront anxiety and fear with their own ability (Wangwongwiroj & Yasri, 2021).

Level of Use (LoU)

LoU focuses on the predicted behaviours of users and indicates how they perceive the usefulness of a particular innovation. The LoU spectrum can be divided into eight continuous stages (Anderson, 1997). First, *non-use* represents the behaviour of those who are involved in the innovation but has no intention to further use it. Second, *orientation* describes the behaviour that begins to explore the implication of the use of the innovation by exploring both advantages and disadvantages of the innovation. Third, *preparation* reveals the behaviour that shows a commitment to fully adopt the innovation in a particular situation and specifically on a particular date without making any further modifications.

Fourth, *mechanical use* depicts the behaviour of users who try to use the innovation in ways that they can manage it more easily.

Fifth, *routine* users are those who commit to using the innovation with no change on a regular basis. This could vary from the user only as a part of an established way of doing things to full adoption. Sixth, called *refinement*, this level of use refers to those who commit to using the innovation regularly with slight modification to make it fit their context. Seventh, *integration* behaviours in this level occur when the innovation is reached by all users individually. In other words, it focuses more on the collective use of innovation. However, the actions in this level occur to improve the ways to gain more profit to users in groups. Finally, *renewal* is the level that users individually realise alternatives or major modifications to the innovation by using. The users consider the profit of innovation and tend to use it to other disciplines for increasing outcomes.

Adopting this framework in educational research, it is suggested to use a questionnaire containing eight statements that represent the eight levels. This questionnaire is supposed to be administered after a group of participants are exposed to any learning innovation. Once they gain experience of using the innovation, they would be able to reflect how useful it is from the perspective of users. This result would allow researchers to know how their users would express their commitment to using their developed innovation, which ranges from *non-use* to *renewal* (Threekunprapa & Yasri, 2020). A wide number of research studies adopt this framework to explore students' perceptions towards learning activities using the aforementioned procedure (Newhouse, 2001; Sultana, 2015).

Methodology

Research framework and questions

Based on the literature reviewed above, this study aimed to develop a card game activity to promote students' learning of the phylogeny of chordate species, called the VERT card game for middle school students. To demonstrate the effectiveness of this learning activity, three learning aspects were emphasised based on adopting quantitative means to convey research findings. First, we statistically compared students' learning achievement based on a conceptual test conducted before and after participating in the activity. Second, we statistically compared students' level of self-efficacy, which is believed to be an important area of learning as it is expected that students develop their own confidence in their ability to learn through the lens of self-efficacy alongside their conceptual development. Like above, this comparison was made before and after students' participation in the activity. We hoped that the VERT card game could help enhance these two aspects after their participation. Therefore, to demonstrate this, statistical comparisons were performed to answer this question: Are there any statistical differences in pre-test and post-test conceptual scores and levels of students' self-efficacy participating in the VERT card game? Finally, we would like to learn how useful student participants found the learning innovation after their participation. This was done after student participants were exposed to the learning innovation and to address the question: What are the levels of use perceived by students participating in the VERT card game? In this respect, we wished that students would express their perception as initial adopters who would like to use our learning innovation in their own study. The following sections describe the development of the VERT card game, data collection and data analysis in greater depth.

The VERT card game activity

Despite having a variety of game choices, such as board games and digital games, this study chose a card game activity owing to the fact that the rule of card games involves grouping and ordering, which represent the key principle of taxonomic classification. To be more precise, there are seven taxonomic classes of vertebrate animals, consisting of Cyclostomata, Chondrichthyes, Osteichthyes, Amphibians, Reptiles, Aves, and Mammals (i.e., grouping). The named taxonomic classes are ordered according to evolutionary events (i.e., ordering), starting from the lowest to the highest ones. Table 1 summarises the characteristics of these taxonomic classes and sample species.

Table 1. Summary of key characteristics of chordate species

Class	Key characteristics (emphasis is on the underlines)	Sample species
Cyclostomata	Jawless fishes with an epidermal structure to function as teeth	Lampreys, hagfishes
Chondrichthyes	Cartilaginous fishes with jaws and paired fins	Sharks, skates, rays
Osteichthyes	Bony fishes made up of either the lobe-finned and the ray-finned structures	Swordfish, sturgeons, coelacanths
Amphibians	Cold-blooded tetrapods (four limbs) with moist skins that live in water in the beginning and then live on land when they become adults	Frogs, toads, salamanders
Reptiles	Cold-blooded tetrapods with scaly skin and lungs that lay shelled eggs on land	Crocodiles, snakes, lizards
Aves	Warm-blooded vertebrates whose forelimbs are modified into wings for flying covered by feathers	Hummingbirds, penguins, ostriches
Mammals	Warm-blooded vertebrates with four limbs and amniotic eggs that possess mammary glands and hair	Gibbons, platypuses, kangaroos

The VERT card game consists of 42 cards in total. There are five selected species that are used to represent each of the taxonomic classes, making up 35 species cards. Seven additional cards are used for challenges, consisting of one start card (to start off the game), two double stop cards (to pause for two turns), two double skip cards (to skip to the next two players on the right), and two double act cards (to discard two cards in one turn). Each of the species cards contains useful information for students to know about the selected species: the picture of the animal, its common name both in English and Thai, and its scientific name. In addition, key characteristics of the animal are highlighted on the left part of the card (see Figure 1), which allow students to make a decision to classify it into a proper taxonomic class. These characteristics are shown as icons representing the presence of jaws, bony skeletons, limbs, an amniotic egg, feathers, and a mammalian gland.

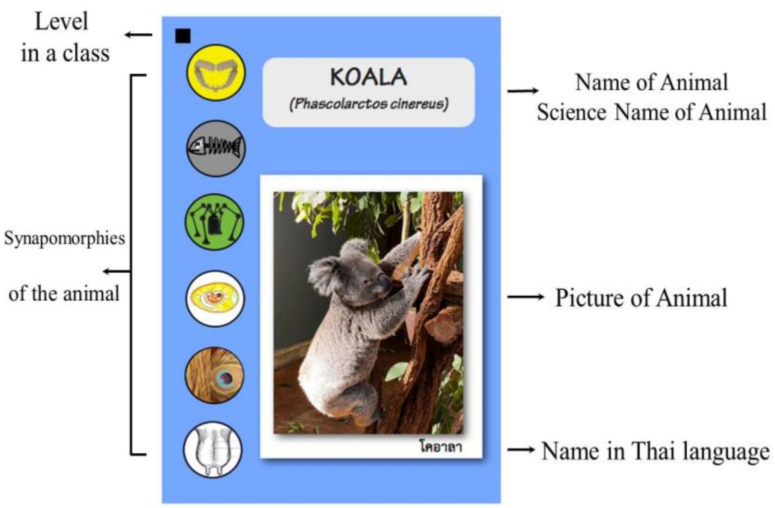

Figure 1. An example of a species card

There are two stages of this game: competitive and collaborative stages. In the competitive stage, the rule of the VERT card game is an extended form of Daifugo (Grand Millionaire) in which players holding 5-7 cards take turns to progressively place higher ranking cards than their opponents. The one who empties all the cards first is the winner. However, after this competitive stage, the student players are then asked to work together in the same group in the collaborative stage to group all discarded cards that belong to the same taxonomic class together so that they can help each other construct a complete phylogenetic tree of the discarded cards. On the one hand, when there are a large number of cards discarded in the competitive stage, it means they have more cards to classify, which take a greater deal of effort from them. On the other hand, they can have more exposure to sample species and their key characteristics, which help them construct a phylogenetic tree more completely. So, it is actually a strategy for the student players to think in the competitive stage whether they would like to end it up as quickly as they can to have a lower number of species cards to work on, which may not yield a complete phylogenetic tree, or to progressively play the game in the competitive stage with a collaborative manner so that in the end they can have a sufficient number of species card to build a complete tree.

In order to play the VERT card game in the competitive stage, up to six students are grouped and seated in a circle. It is expected that the 42 cards are given away all at once with an equal number for each player. The one who has the start card is the first player who places one species card to start off the game. Then the next player is the one who sits on the right-hand side of the first start player. This player has to choose one card that he/she has, which either belongs to the same taxonomic category with the one that is already placed or the one that is in a higher taxonomic category. It is important to note that student players do not need to have prior knowledge to recall this as they can simply look at the six characteristics provided on the left side of the card. The higher the number of characteristics, the higher the taxonomic classes. Through the game rounds, it is believed that students can familiarise themselves with these key characteristics. The same is repeated for the next players until they finish the round. If any member does not have a card to place down, he/she can say "pass". The winner of this game is the first person who empties all his cards during the gameplay. However, the remaining members of the group continue their game until there is only one player left, which marks the termination of the competitive stage.

To continue the game with the collaborative stage where all group members help each other construct a phylogenetic tree of the discarded cards. Firstly, the students are asked to familiarise themselves with the cards they have in their group. After that, they are asked to group the species cards according to their taxonomic class. Next, a rope and scissors are provided for them to arrange the card and connect each taxonomic class with the rope. To do so, the students are asked to put the species cards of the seven classes in order (see Figure 2). Then, the teacher asks scaffolding questions to let students observe the differences between each class carefully.

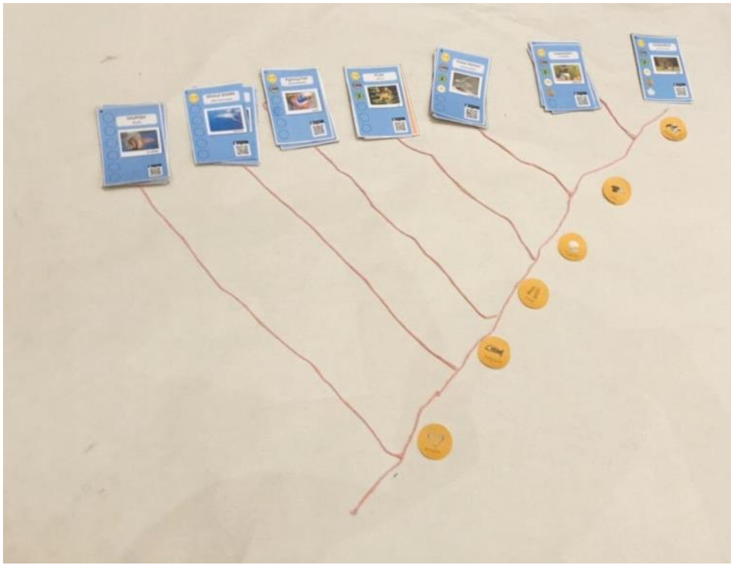

Figure 2. The task on phylogenetic tree construction

Once this is done, the students are asked to choose one species card from each of the seven taxonomic classes. The seven representative cards are used to complete Table 2, where they record acquired characteristics. They can write 1 if the particular species has that particular characteristic and 0 if this is missing.

Table 2. Students' record of chordates' acquired characteristics

	Hagfish	Ray	Salmon	Toad	Turtle	Duck	Human
Jaws	0	1	1	1	1	1	1
Bony Skeleton	0	0	1	1	1	1	1
Limbs	0	0	0	1	1	1	1
Amniotic Egg	0	0	0	0	1	1	1
Hair/Feature	0	0	0	0	0	1	1
Mammary Grand	0	0	0	0	0	0	1

To construct the phylogenetic tree, the teacher guides the students through the process of constructing the phylogenetic tree, which follows the maximum parsimony method (Tamura et al., 2011). First, the direction is given for them to choose one that they think is in the lowest taxonomic class from the table. It is expected that all would choose the card in Cyclostomata (either hagfish or lamprey). This is because it lacks the common traits specified in the card. The remaining cards they have that are in the same class are also grouped here. Then the students are asked to choose what comes; next, it is expected that they would choose a ray card as one characteristic distinctively appears, which is jaws. By doing so, the students can link the first class (Cyclostomata) with the second class (Chondrichthyes or ray) using the rope provided and place an icon of jaws to represent that this characteristic distinguishes the most primitive class and the second one. This process continues until they reach the most advanced class of mammals, as shown in Figure 1. As a result, they would get a complete phylogenetic tree of chordates where they can discuss the nodes and the branches of the tree among their peers as well as the teacher facilitator.

Ethical Consideration

The researcher obtained permission for the research and took safety measures to avoid any psychological or physical injury to the participants. The Institutional Review Board appointed by the Institute for Population and Social Research at Mahidol University, Thailand, approved all of the tools delivered. The participants were informed using a formal invitation letter which includes the objectives of the research and the process of data collection. They were also informed that their participation is fully voluntary. Their response was to keep confidential and anonymous. Moreover, they were also informed that the test score would not be used in their grading. In addition, they were ensured that they could withdraw their participation at any stage. To agree upon this, the student participants were asked to sign the assent and consent forms.

Data Collection and Data Analysis

The study adopted a quantitative research approach to examine the effectiveness of the developed card game and the learning activity of phylogenetic tree construction with 109 secondary school students (33% 7th grade, 32% 8th grade and 35% 9th grade). The period of data collection took around 3 hours in total, starting from a pre-test for 20 minutes, the VERT cad game for 45 minutes, the process of phylogenetic tree construction for 60 minutes, to a post-test for 30 minutes.

Three measuring tools were developed to reveal students' understanding of phylogenetic tree construction, their self-efficacy in this learning context, and perceived levels of use of the developed activity. First, an individual pre-test and post-test examination were developed for measuring students' understanding of phylogenetic trees. In the first part of the test, there were fifteen questions, with four choices for each question. These 15 questions can be grouped into 5 parts according to their relevant concepts: the classification concept, the meaning of the branch and node, reading across the tips, the relative placement of taxa, and the phylogenetic tree concept. The second part was an open-ended question that required students to construct the phylogenetic tree of plants in any form of the phylogenetic tree that students found suitable. The question was applied by Dees and Momsen (2016) based on the plants' diversity, while the instructional activity was designed on chordate animal diversity. Moreover, a rubric for the question was designed and developed to depict the accuracy of the phylogenetic tree produced in terms of classification, branch, and nodes (Dees & Momsen, 2016; Young et al., 2013).

This conceptual test was tested using Cronbach's alpha to determine the level of reliability. The analysis showed that Cronbach's alpha value was 0.83, indicating that the test has a good internal consistency (Taber, 2018). In addition, the content validity was analysed based on the index of item objective congruence (IOC) by three biology education experts (Ghazi et al., 2021). The finalised questions, correct answers, and distractions were those assessed as appropriate to elicit students' conceptual understanding of chordates' phylogeny, and the language used was appropriate for middle school students (the IOC index of 0.75 and above). In fact, no major comments were given by the invited experts, only some minor revisions to enhance the readability of the questions and choices. In addition, the difficulty index was carried out (Hingorjo & Jaleel, 2012). The result showed that the value of each of the 15 questions was in the range of 0.5 and 0.6, which indicates that the test can be used to tackle differences in the conceptual understanding of students.

Second, to seek the difference in self-efficacy, the researchers designed and developed the questionnaire. There were 12 questions with 5-Likert scales ranging from strongly agree (5), agree (4), undecided (3), disagree (2), to disagree (1) strongly. Included in it were the four sources of self-efficacy, composing of mastery experiences, vicarious experiences, verbal persuasion, and emotional arousal (Punyasettro et al., 2021), to ascertain the students' belief in their ability and their academic performance and level of engagement in learning. The reliability test of the questionnaire showed Cronbach's alpha scores of 0.86, indicating that the test has a good internal consistency (Taber, 2018). The validity of the questionnaire was tested based on the IOC index by three educational researchers also showed that the statements represent what the theoretical framework of self-efficacy focuses on, and the level of language used is appropriate for middle school students (the IOC index of 0.75 and above). The detailed report of the reliability and the validity of this self-efficacy questionnaire can be found elsewhere (Punyasettro et al., 2021).

Third, the researchers also designed and developed the questionnaire with eight questions based on the eight continuous levels of perceived usefulness initially developed by Threekunprapa and Yasri (2020), starting from Nonuse, Orientation, Preparation, Mechanical Use, Routine, Refinement, Integration, to Renewal. The student participants were asked to choose which level in particular that they would like to use the VERT card game. The reliability test revealed that Cronbach's alpha value was 0.76, indicating that the test has a good internal consistency (Taber, 2018). The IOC index from the evaluation of three educational researchers also showed that the statements represent the framework of the level of use and the level of language used is appropriate for middle school students (the IOC index of 0.75 and above).

The data analysis was conducted using SPSS. To compare the mean scores gained from the conceptual test and the self-efficacy test, a paired t-test was adopted, in addition to descriptive statistics (means, S.D. and S.E.). This statistical analysis was adopted because the independent data (numeric scores and rating scales) were independent and normally distributed, taken from matched pairs. The interpretation of the results considered a significance level of 95%. In addition, the level of use score was calculated using frequency and percentage.

Results

Overall, the results from the conceptual test of the phylogenetic tree as shown in Table 3 revealed a significant increase of the mean score after the student participants were exposed to the VERT card game activity, both in the levels of understanding of phylogenetic trees based on 15 multiple-choice questions and of construction of phylogenetic trees based on a 5-point written task. To be more precise, a significant improvement at the significance level of 95% was shown in the multiple-choice question from the mean score of 5.99 in the pre-test to 7.39 in the post-test, with the Cohen's d effect size of 0.63, implying that the students showed a medium size of improvement from pre-score to post-score. The results, therefore, revealed that the student participants improved their conceptual understanding of phylogenetic tree construction, including the meaning of branches, nodes, and tips of the tree, as well as the interpretation of taxonomic classes.

In addition, based on the 5-point task on phylogenetic tree construction, the statistical analysis showed that there was a statistical increase in the mean score at the significance level of 95% from 2.56 in the pre-test to 4.21 in the post-test with the Cohen's d effect size of 1.47, implying that the students showed a large size of improvement from pre-score to post-score. The results suggested that the student participants could apply their understanding to construct a phylogenetic tree of given species by themselves as a result of their participation in the card game activity and the phylogenetic tree construction.

Table 3. The comparison of test scores of the student participants before and after participating in the VERT card game

Conceptual test		Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)	Cohen's d
Understanding of phylogenetic tree	Pre	5.99	2.115	.203	.000	0.63
(total of 15)	Post	7.39	2.317	.222		
Construction of phylogenetic tree	Pre	2.56	1.294	.124	.000	1.47
(total of 5)	Post	4.21	.903	.087		

To examine how the VERT card game activity can support students in improving their self-efficacy in learning animal taxonomy, a comparison of the student participants' self-efficacy between pre-test and post-test was carried out based on a 5-Likert scale survey, ranging from strongly agree (5), agree (4), undecided (3), disagree (2), to strongly disagree (1). Overall, Table 4 shows a statistically significant increase in self-efficacy scores from 3.68 in the pre-test to 3.93 in the post-test, with the Cohen's d effect size of 0.44, implying that the students showed a medium size of improvement from pre-score to post-score. Likewise, all of the individual parts significantly improved between the two periods of data collection at the significance level of 95%. The mean score of *mastery experience* increased from 3.78 to 4.14 with the Cohen's d effect size of 0.50, implying that the students showed a large size of improvement from pre-score to post-score. The mean score of *vicarious experience* improved significantly from 3.79 to 4.07 with the Cohen's d effect size of 0.38, implying that the students showed a small size of improvement from pre-score to post-score. The mean score of *verbal persuasion* also improved significantly from 3.90 to 4.08, with the Cohen's d effect size of 0.26, implying that the students showed a small size of improvement from pre-score to post-score. Finally, the mean score of *emotional arousal* improved significantly from 3.29 to 3.93 with the Cohen's d effect size of 0.23, implying that the students showed a small size of improvement from pre-score to post-score (see Table 4).

Table 4. The comparison of self-efficacy of the student participants between before and after participating in the VERT card game activity

Self-efficacy aspect		**Mean**	**Std. Deviation**	**Std. Error Mean**	**Sig. (2-tailed)**	**Cohen's *d***
Mastery Experience	Pre	3.78	.787	.075	.000	0.50
	Post	4.14	.626	.060		
Vicarious Experience	Pre	3.79	.793	.076	.000	0.38
	Post	4.07	.648	.062		
Verbal Persuasion	Pre	3.90	.718	.069	.000	0.26
	Post	4.08	.643	.062		
Emotional Arousal	Pre	3.29	.704	.067	.025	0.23
	Post	3.46	.741	.071		
Overall	Pre	3.68	.592	.567	.000	0.44
	Post	3.93	.522	.050		

To investigate students' perceptions toward the usefulness of the VERT card game activity adopting the framework of the level of use, a survey was given to the student participants after their participation in the activity. According to Table 5, the highest proportion of the student participants was clustered around *mechanical* (20.2%), *preparation* (17.5%), and *orientation* (16.5%), which are considered early adopters. It is also interesting to see that a large proportion was distributed either in routine (12%) or refinement (18.3%); both are considered more committed users. Around 15% chose one of the marginalised levels, non-use (5.5%), integration (3.6%), or renewal (6.4%).

Table 5. Summary of students' perceived level of use after participating in the VERT card game

	Frequency	**Percentage**
Non-use	6	5.5
Orientation	18	16.5
Preparation	19	17.5
Mechanical	22	20.2
Routine	13	12.0
Refinement	20	18.3
Integration	4	3.6
Renewal	7	6.4

Discussion

Like many others (Qian & Clark, 2016; Sadler et al., 2013; Sousa & Rocha, 2019), this study offers another support to the effectiveness of using card games as an instructional tool to improve students' learning, both conceptually and affectively. As the results showed, after participating in the VERT card game activities, the student participants improved their understanding significantly, implying from their increased mean score in the post-test. To be more explicit, the student participants exhibited their greater understanding of the conceptual understanding of phylogenetic trees, including classification concept, the meaning of the branch and node, reading across the tips, and the relative placement of taxa as well as phylogenetic tree construction.

This is believed to be the result of the design of the game. As Butsarakam and Yasri (2019) explain when the game rule can be effectively mapped with scientific concepts, and a debrief session is added to make the mapping more explicitly, this can greatly enhance students' conceptual understanding. To elaborate this, in the competitive stage, the student participants play the card game using the rule of grouping and ordering according to the icons provided in the given cards. In this study, students are likely to begin to familiarise themselves with the key traits important for the classification of chordates. Although this stage may not yet fully build conceptual understanding in a proper level, it lays a foundation for the students to get to know various organisms and their respective characteristics. In addition, it could potentially make the classroom environment more engaging and challenging for students. Piyawattanaviroj et al. (2019) explain that to help students engage more in the lesson cognitively, the first door to open is their affective engagement. When students feel at ease in learning and enjoy the task they are doing; it is likely that they could perform well conceptually. In other words, positive feelings towards learning could potentially serve as an important cause to promote conceptual understanding.

The collaboration stage is believed to be the main session for students' conceptual development, both the understanding of the phylogenetic tree of chordates and the construction of phylogenetic trees in general. When they take all discarded cards from the competitive stage to group into the different classes of chordates, they are assumed to observe key characteristics of the organisms within the same class. This would become more evident when they choose one representative species and fill in the characteristic table as described in Table 2. Furthermore, while students construct the phylogenetic tree, they use the rope to tie into a node to make it a common point of evolution before the evolutionary separation (see Figure 3). This allows them to understand the meaning of branch and node, to exercise how to read across the tips, and to observe the relative placement of taxa, as shown by the increased mean score after participating in the VERT card game activity.

Figure 3. Student construction of chordates' phylogenetic tree in small groups

This understanding can moreover be extended to another context which shows that students can apply what they learn from the activity itself to another relevant setting. This statement is made based on the matter of fact that in the post-test, the student participants were asked to construct a phylogenetic tree of plants, not chordates. This is to avoid that they would just use their remembered knowledge to complete the task. In contrast, the written task of constructing the tree was designed to revolve around plant species. To complete this task, students are required to possess a good background knowledge of phylogenetic trees in general. The results from this study demonstrated that the student participants could do so effectively. This is in agreement with previous studies whose results showed that learning activities using card games in particular and game-based learning, in general, can help leverage students' understanding as well as their ability to apply their knowledge to a new learning context (Qian & Clark, 2016; Sadler et al., 2013; Sousa & Rocha, 2019). Furthermore, this form of activity engagement can also promote collaborative learning, which is a learning mode preferred by school students where they can discuss with peers to exchange their knowledge and understanding (Praputpittaya & Yasri, 2020).

According to these findings, a major concern of the findings in this study is the "low" mean score of the conceptual understanding test achieved in the post-test. Although it is statistically greater compared to the pre-test, the mean score is only around half of the total score (7.39 out of 15). However, explanations for this can be given. First, the conceptual understanding includes questions both in the understanding and application levels according to Bloom's taxonomy of learning; it is apparent that the student participants satisfactorily answered questions at the understanding level. However, they encountered some challenges with application questions which is not uncommon among learners across age groups (Lazarowitz & Lieb, 2006). Therefore, the effectiveness of the VERT card game discussed above primarily focuses on students' ability to construct and understand phylogenetic trees (based on the 5-open ended questions). However, it limits its usefulness to help students apply their knowledge to answer application questions in the multiple-choice test. To solve this problem, before moving on to the competitive stage, it is essential for teachers to summarise the lesson and get students to learn from the cards they have, which could be done through reflection and/or debriefing (Maneejak & Yasri, 2019). Another explanation would be the nature of the use of games for learning purposes. As mentioned, the understanding of the concept is primarily based on the information in the cards used in the competitive stage. It might not be surprising to expect that younger students would enjoy the competition in the game and become fully involved in it. This active competition may slightly put them off from the learning process as this is also evident in other work (Butsarakam & Yasri, 2019). On the one hand, it may be a good aspect of game-based learning as it can engage students emotionally. On the other hand, without an appropriate strategy to take them back to the core of the game, which is learning, this may lead students astray. Therefore, the same suggestion is given, which is to have another debrief session to recap what students should learn from the competitive stage.

Not only the increase in the score of the phylogenetic tree concept among the student participants, but this study also revealed the increase in self-efficacy in the context of learning animal taxonomy. Of course, it is believed that this is not by chance. The game was designed to support self-efficacy through group work collaboratively completing a series of missions. For mastery experience, the increase in its mean score was a great sign that the student participants could accomplish the tasks successfully by themselves. It is suggested in the literature that this is the most effective method for the development of self-efficacy because it is direct experience, which allows students to exercise multiple modes of learning, including visual, auditory, and kinaesthetic strategies (Hawk & Shah, 2007). In addition, it helps promote deep learning in which the learned concepts and skills can stay with students for a long period of time (Bandura, 1977; Hope, 2009).

For vicarious experience, it is believed to be nurtured while students construct the phylogenetic tree in their group. Based on the observation during data collection, while students were constructing the phylogenetic tree, we walked around the class to observe. If a group is completed, they would raise their hands and call us to see the results. That made other groups see and hear that their peers could make it and succeed in doing it. This then transferred to be their model (Bandura, 1977), making them intuitively reason that once others (who have similar skills) could make it, they could also make it. This form of learning has been proven effective in various settings of learning ranging from formal education to informal education across a wide range of disciplines (Jiménez & de la Fuente, 2016).

Regarding verbal persuasion, this aspect of self-efficacy can be automatically leveraged when students discuss with their teammates while completing their group mission. It is suggested that this may well correlate with vicarious experience (Bandura, 1977; Wangwongwiroj & Yasri, 2021). This study also suggests this trend. However, the statistical result in this study showed a small level of improvement, although significantly at the level of 95%. It is considered that this is due to the fact that the current form of activity allows students to discuss naturally in a certain direction. The discussion may often go to possible strategies to complete the mission rather than encouraging one another. Thus, this may contribute to such a relatively small increase. However, including a proper session for student discussion in the learning activity can help strengthen this aspect of self-efficacy as they can reflect and discuss more meaningfully.

Furthermore, the increase in emotional arousal results is believed to be the result of design of the learning activit that did not put pressure or stress on students; instead, the activity was fun, making students interested in and cooperate effectively. The competitive stage of the VERT card game could excite students as they were trying to complete the mission. Likewise, the collaborative stage of the game would allow students to build their sense of teamwork to accomplish a common goal. Both forms of interaction would engage students in difficult concepts more effectively, which can promote students' self-efficacy to learn in particular and conceptual engagement in general. According to Ninaus et al. (2019), positive emotional engagement can be significantly enhanced in a game-based learning environment, while negative feelings can be observably minimised.

Finally, regarding the results of perceived levels of use, it is evident that a large proportion of the student participants fall in one of the levels of early adoption: *orientation, preparation,* or *mechanical use*. This reinforces the usefulness of the VERT card game activity as the participants appreciated it and may use it somehow in the future, although it might not be terribly clear for them how to use it by themselves. However, this is not a disappointing finding because, in this form of educational innovation, students are perceived as users rather than developers. Therefore, when a large number of them choose one of these early adoption levels, this is a positive sign. In addition, a more promising result would be the percentage that falls either in *routine* or *refinement*. This shows that there exist serious users who can see that this innovation can help improve their learning, some of who may even see the possibility to further develop this innovation to be more fit with their own learning (Threekunprapa & Yasri, 2021).

Conclusion

The VERT card game is a learning innovation developed in this present study. It adopts the pedagogical practice of game-based learning to enhance students' understanding of the phylogenetic tree of chordate species, as well as their self-efficacy to learn evolutionary biology. The learning innovation was implemented among 109 lower secondary students who voluntarily participated in a pre-post research design that took place for two consecutive days. The results showed that the student participants statistically increased their conceptual understanding of the phylogenetic tree of chordates as well as their ability to construct a phylogenetic tree by themselves, at the significance level of 95%. In addition, there was a statistical increase in the level of self-efficacy after participating in the VERT card game, meaning that the student participants, in general, became more confident in completing their task in the learning of evolutionary biology. Finally, the majority of the participants held a positive view towards the usefulness of the VERT card game as they expressed willingness, if not, determined to use it in their own study in the future. This study, therefore, suggests other researchers, educators and teachers adopt game-based learning as an alternative pedagogical approach to deliver science content to their students in a playful environment.

Recommendations

First, it would be interesting to see how this learning activity can be verified by other researchers who may wish to use it in a new setting where parallel data collection is performed. This would allow the comparison of research findings across regions to emerge. Others may also wish to have a more rigorous experimental design by including a control group where traditional teaching is delivered. This can ascertain the effectiveness of game-based learning activities. Second, it would also be interesting to apply this pedagogy (i.e., game-based learning using card games) to other topics in science and potentially in other disciplines. Card games are suitable for delivering content related to matching, grouping and order in a playful environment, such as the taxonomy of living things in biology and the periodic table in chemistry. In addition, it is important to examine the effectiveness of game-based learning at various educational levels. This present study limits its implication to lower secondary school students. Therefore, there is a need to extend this to other age groups so that pedagogical recommendations to use the learning innovation can be more concise. Last but not least, others may be interested in digitalising this to make an online game so that students can play it on their mobile devices without having to contact each other physically, taking the issue of social distancing in the classroom during the global pandemic of the coronavirus in this present time. However, to do so, the central interest may have to shift from collaborative learning (like the construction of phylogenetic trees in small groups) to self-directed learning. Although challenging, this is considered the direction of future education.

Limitation

In terms of research design, due to practical concerns in the participating school, it was not possible to conduct an experimental design where a control group could be arranged to compare the effectiveness of the VERT card game activity with traditional teaching. Therefore, drawing a solid causal relationship in this study is somehow limited. Other researchers may face similar difficulties. When presenting to the school about the innovation to request permission to do data collection, they are likely to hope that all students would be able to learn from this innovation in the same way. To ask the school to split half of them to learn from the innovation and the other half from traditional teaching, might be perceived as unfair from the side of those in the control group. That is why the pre-post design was adopted in this research. In addition, the data analysis in this study is based exclusively on the test administered before and after participating in the activity. However, discussion, while the students accomplished the task in their small groups, is missing. This qualitative perspective may enrich our current understanding about the process of conceptual development, struggles that students may face, and also some misconceptions that might not be revealed in the test.

In addition, administering the post-test right after the students completed the activity may cause an issue whether the positive outcome of conceptual understanding came directly from the learning activity itself, or it might be caused by students' ability to remember what they did in the activity. To ensure that the improved understanding arose from the designed activity itself, it is worth extending the period of data collection for a delayed post-test done after a specific amount of time to measure retention (Kwon et al., 2005). The comparison of the pretest, the posttest, and the delayed posttest would allow researchers to validate the effectiveness of the learning activity on students' conceptual understanding more appropriately.

Another limitation that may arise in the study is the novelty effect of the learning activity, which is the tendency for students to have potential stress when participating in a new learning environment. This normally takes place when students participate in novel activities involving classical games, computer games or applications, or anything that immediately catch students' attention. Although game-based learning activities have been implemented with this group of participants from time to time, it is still important to ensure that the novelty effect is minimised by extending the period of data collection to make the participants more familiar with the learning activity. As a result, their response would not be much different from what they are used to in a regular setting.

Authorship Contribution Statement

Punyasettro: Game development, data collection and analysis, writing. Yasri: Conceptualisation, research design, editing/reviewing, supervision.

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