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MicroEvo: An educational game to enhance high school students' learning performance of microevolution

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Microevolution is a biological concept that explains changes in a genotypic level cumulatively leading to allele frequencies of a population, which can then potentially bring about evolution. Due to its conceptual complexity, several students find this topic difficult to study and hold negative perceptions towards it. This study, therefore, adopted the use of game-based learning to develop an educational game, called MicroEvo which aims to enhance students' conceptual understanding of the biological concept. A pre-post research design based on a 10-item two-tier test was adopted to demonstrate the effectiveness of the game among 79 high school students in Thailand. The results revealed that the mean score performed by the participants statistically improved from 12.35 in the pretest to 15.39 in the post-test, at a significance level of 95%. Also, an item analysis showed that the percentage of scientifically accurate answers increased from 45.06% to 63.67% after playing the game, while the percentage of misunderstanding reduced from 21.25% to 9.75%. Therefore, this present study points out that the MicroEvo game can be considered as an alternative teaching tool to help promote students' conceptual understanding of microevolution.

Keywords: *Biology Education; Board game; Evolution; Game-based learning; Microevolution*

Introduction

Due to its contribution to making sense of natural phenomena based biological processes that explains natural events from the past to the present reasonably described, evolution has long been accepted by biologists as a unifying theme in biological sciences (Luttikhuizen, 2018). To explain the theory of evolution, two scales of biological mechanisms have to be taken into consideration namely, microevolution and macroevolution. While macroevolution concerns how life forms have changed over time which sufficiently leads to the process of speciation (the emergence of new species), microevolution focuses on microscopic phenomena of the change in allele frequency over a series of generations by driving factors including natural selection, migration, mutation, and genetic drift (Stearns & Hoekstra, 2000).

To elaborate changes in the genotypic level, characteristics of all individual organisms are controlled by genes that are passed on from their parents in the form of alleles (Reece et al, 2014). Alleles are different forms of a gene that are in the same locus on a chromosome. Different forms of allele would bring about genetic variation (Pasternak, 2005). Take the whole population into consideration, all types of alleles that are present in one population are called a gene pool. The term population in an ecological perspective is defined as a group of interbreeding individuals of the same species, which is isolated from other groups (Stearns & Hoekstra, 2000). Therefore, within a gene pool, each type of allele can be counted as allele frequency. In the scenario where no disturbance occurs in a gene pool, allele frequency remains stable in a population from generation to generation. However, if the frequency changes over time until the equilibrium in the population is disrupted, it will lead to microevolution (Reece et al, 2014).

According to Hardy-Weinberg equilibrium, there are five factors causing changes in allele frequency, which are natural selection, migration, mutation, genetic drift, and non-random mating (Raven et al, 2011; Stearns & Hoekstra, 2000):

- First of all, natural selection is the process whereby organisms that are more fit to their environment tend to survive and produce more offspring, leading to a preference of some particular traits (called adaptive traits), whereas less preferable traits have gone declining over time. As a result, it leads to changes in allele frequency towards selected traits.
- Second, genetic mutation is the alteration in the DNA sequence that makes up a gene. Mutations in genes can either have no effect, alter the product of a gene, or prevent the gene from functioning. However, through a collective process, this also results in changes in allele frequency.
- Third, migration is moving alleles in or out of population and reproduction can cause gene flow. As a consequence, a gene pool can change into a new proportion of allele frequency.
- Furthermore, genetic drift is the change in the frequency of an allele in a population over time due to the random sampling of organisms. Although it occurs in all populations of non-infinite size, its effects are strongest in small populations.
- Finally, non-random mating refers to a phenomenon where organisms prefer to mate with others of a particular genotype (either the same or different). Such preference leads to favor of some traits which can then alter allele frequency in the gene pool.

Despite having a great variety of learning approaches for microevolution such as lectures, simulations, experimentations, and field trips, research has shown that students encounter difficulties in comprehending the concept due to its conceptual complexity (Yasri, 2014a). Besides, evolutionary processes involve historical inferences and microscopic imagination, as a result, it leads to perceived conflicts to common-sense expectations (Yamanoi, Suzuki, Takemura, & Sakura, 2012). Different forms of misconceptions have been reported among learners of this concept, including common sense misconception, content-based misconception, misconceptions about nature of science, non-scientific misconception, or vernacular misconception (Yasri, 2014a). Also, emotional challenges may arise from learning this topic due to boredom of extensive content and conflicts with students' beliefs (Yasri, 2014b; Yasri & Mancy 2014; Yasri, et al., 2013; Praputpittaya, Chalermsean, & Yasri, 2020). Therefore, it all turns out to become a great challenge for teachers to teach students holding misconceptions and struggling to learn emotionally (Yasri, 2014a; Yates & Marek, 2014).

To overcome the said challenges, it is important to develop a learning activity about microevolution that is effective in promoting conceptual understanding and enhancing positive attitudes towards learning. Current research studies point out that teachers generally prefer activities in the classroom that promote active learning (Su, Cheng, & Lin, 2014) and collaborative learning (Praputpittaya & Yasri, 2020). Among many other active learning approaches, game-based learning can enhance learning achievement and learning motivation in science education in general and biology education in particular (Plass, Homer, & Kinzer, 2015). The reason for its effectiveness is attributed to the incorporation of aspects of education and entertainment in learning. It adopts the rule of the game to promote excitement in learning while the rule itself is developed according to scientifically correct concepts. As a result, through a playful environment with a scientific content-led game rule, students can learn with full effectiveness of conceptual development and emotional engagement (Nadolny, Alaswad, Culver, & Wang, 2017).

Several educational games have been developed to use in biology teaching such as female reproduction board game (Butsarakam & Yasri, 2019), plant transportation board game (Sirironnarong & Yasri, 2018), tonicity card game (Seangdeang & Yasri, 2019), and plant taxonomy card game (Suriyabutr & Yasri, 2018). However, no educational game exists for teaching microevolution. Therefore, this study aims to develop an educational game that focuses on teaching the concept of microevolution in respect of gene pool in the population, allele frequency, the relationship between alleles and phenotypic traits, as well as factors contributing to changes in allele frequency. Furthermore, it aims to demonstrate that this developed educational game can help promote a scientifically accurate understanding of microevolution based on a pre-post research design.

Two specific research questions were proposed: *(1) Is there a statistical difference in students' mean scores achieved before and after participating in the developed educational game, called MicroEvol?*, and (2) *What are changes in students' level of conceptual understanding of the concept, comparing between before and after participating in MicroEvo?*

The MicroEvo game

Many games can be adapted to assist the learning of science, ranging from a digital game, a card game, to a board game. As the development of the educational game in this study is expected to be cost-effective so that teachers and students even in less privileged backgrounds can afford or develop by themselves, a form of the digital game is excluded, although it is fully accepted that a great number of studies have shown the effectiveness of digital game-based learning (Srisawasdi & Panjaburee, 2019). Therefore, a board game is chosen as a form of activity since this concept involves biological mechanisms such as allele frequency and factors contributing to microevolution, student interaction with the board that lays out the scenario containing a certain mission to accomplish and action cards that are cognitively challenging for learners while playing, are believed to be crucial for the development of conceptual understanding (Butsarakam & Yasri, 2019).

The game components consist of a board containing a grassland and a forest area (which symbolizes an area where the population lives in), blocks with 2 different shades (dark and pale shades which represent two different alleles), a pin for marking the area on the board, a block for frequency cards to determine block frequency (which signifies allele frequency in a gene pool), event cards for challenging all players (which introduce factors causing changes of allele frequency), and action cards for possible interactions among the players (see Figure 1). The main mission of the MicroEvo game is for each player to maintain his or her allele frequency (the ratio of the dark and pale shades) which means that he or she can protect the gene pool from frequency alteration and that is to prevent microevolution to take place. Besides, to let excitement emerge, the players can develop strategies to win the game through the use of action cards to introduce changes in the allele frequency of others.

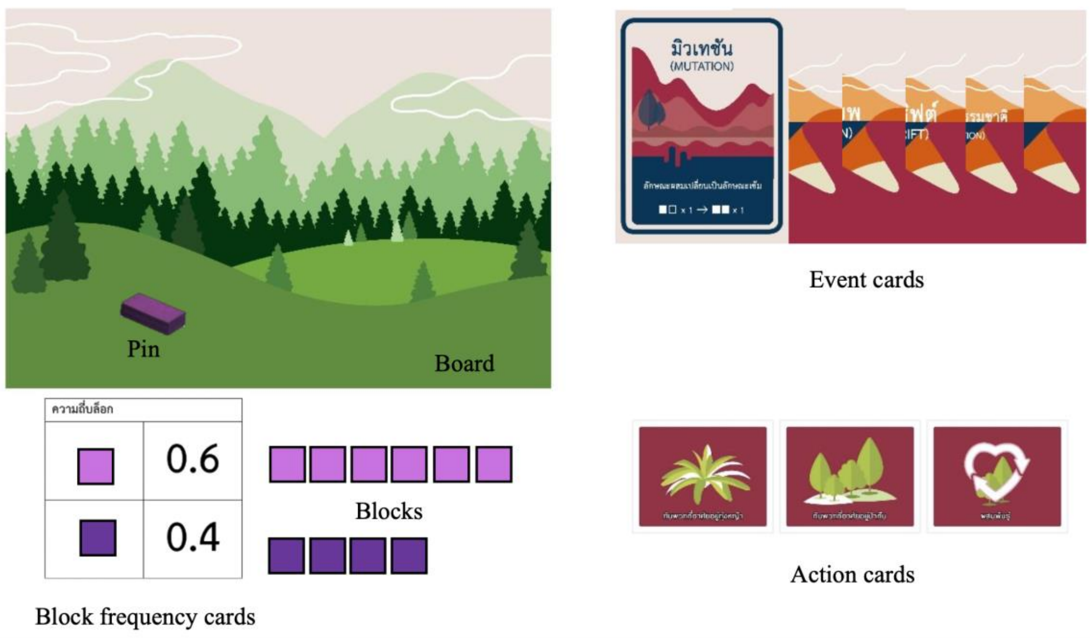

Figure 1: MicroEvo game elements

To make it more visualized, 3-4 players are grouped around the board. First of all, they are provided with a pin, a set of action cards, and a frequency block. Then they have to choose a location where their population resides using a pin provided. After that, each player is allowed to choose a preferred ratio of the dark and pale shaded blocks to start with. This ratio is treated as an initial allele frequency of the population which the players have to maintain in constant to win the game. Then they are ready to start the game rounds. One game round consists of two phases. In the first phase, one player opens an event card and all players have to respond to the command in this event card. There are four main features of the event cards altogether which represent factors causing changes of allele frequency composing of natural selection, genetic mutation, migration, and genetic drift. Since one event card affects all players, each has to decide how to respond to the event with minimal effects on their allele frequency as a whole.

For example, the event card would determine to get rid of two pale shaded blocks. The players have to remove two pale shaded blocks while thinking about how to maintain the rest in a constant ratio. Once all players respond to the event card, now it is time for the players to continue the second phase in which they can use their action cards to attack the others. They can choose anyone to attack, but only one at a time. The one who starts drawing the event card in the first phase is the one who starts the attack phase. Then the turns go clockwise until everyone finishes their attack. This is when they can use strategies to make others lose their initial ratio of allele frequency. When all players use their action cards to attack, the second round of the game can begin, starting from responding to the event card, followed by the attack using an action card as mentioned.

The card continues to run until all event cards are used up. Then each player has to sum up the total score by considering the number of action cards used (1 point each), the allele frequency kept until the end (3 points for completely maintaining ratio), and the number of blocks remaining (1 point each). Therefore, to make a logical sense from this, the players will have put strategies to maintain the frequency ratio which signifies that they can keep allele frequency in the gene pool of their population. Also, the constant ratio, it is important to keep the number of blocks that may point to the number of organisms that survive within the population. Finally, the number of action cards used would represent how they can apply the knowledge that different factors can cause the alteration of allele frequency to help them win the game.

Methodology

Student participants

The participants were 79 students majoring in science and mathematics who enrolled in grade 10 in one school in Northern Thailand. They were all recruited based on their convenience and time availability. The recruitment process was conducted after the ethical guidelines issued by Mahidol University. The participants were made aware of their right to volunteer to participate in the data collection where their identity was anonymous and confidential. They were fully informed that their participation was not compulsory so that they could withdraw their participation at any time without having any negative consequences on their study. Once they all agreed and signed up a consent form, they were teamed up in a group of 3-4 members voluntarily to proceed with the set activities.

Research instrument and data analysis

Both the pre-test and post-test were assessed by a two-tier protocol. While the first tier, containing 10 true-or-false questions, was set to assess their understanding of the concept of microevolution, the second tier was used to explore their reasoning skills based on the appropriate application of the concept to justify the correctness of the first tier which contained another 10 follow-up questions with 4 possible choices. The overall scores were counted based on the summation of both tiers, making a total score of 20 points. The comparison of the pre-test and post-test mean scores was carried out using both descriptive statistics and a Wilcoxon signed-rank test. It is noted here that this conceptual test was tested for both reliability using Cronbach's alpha and validity through the index of Item-Objective Congruence assessed by three biology educators. The analysis showed that the reliability coefficient was 0.628, which is considered acceptable. Unclear test items were revised according to suggestions from the three experts and none was found to get the IOC index lower than 0.5, which shows a satisfactory level of validity.

Furthermore, the levels of understanding of the student participants concerning microevolution were classified into three categories: *scientifically accurate understanding, misconception*, and *misunderstanding*. To classify, the scores from both tiers were taken into consideration. Those classified in the category of *scientifically accurate understanding* were those who answered correctly in both tiers. Those identified as holding *misconceptions* answered one of the tiers incorrectly, whose answers signify that their answer and reasoning for the answer were no incongruence. They could either answer the question correctly with flawed reasoning, or they held a proper reason but made use of it incorrectly so that they came up with a wrong answer. Finally, those classified in *misunderstanding* answered both tiers incorrectly.

Data collection

The whole period of data collection took 140 minutes. To elaborate on this, the participants (N = 79) began with taking the two-tier pre-test for 30 minutes. This was followed by the series of learning activities which took 80 minutes in total (15 minutes for introduction, 60 minutes for participating in the MicroEvo game-based activity, and 5 minutes for debriefing and discussion). Finally, the participants did the post-two-tier test and the level of use questionnaire for another 30 minutes.

Results

The comparison of students' pretest and post-test mean scores

According to the comparison between pre-test and post-test mean scores of the participants (n = 79) using a Wilcoxon signed-rank test, the results revealed that the mean score performed by the participants statistically improved from 12.35 in the pretest to 15.39 in the post-test (Z = -6.456, p = 0.000).

Table 1 Pre-test and post-test mean scores

Test	Mean (20 points)	SD
Pre-test	12.35	3.18
Post-test	15.39	2.75

The comparison of students' level of understanding

An in-depth analysis showed that the percentage of scientifically accurate answers increased from 45.06% to 63.67% after playing the game, while the percentage of misunderstanding reduced from 21.25% to 9.75%. The ratio of those responses with misconceptions also exhibited a decline from one third (33.42%) prior to their participation in the board game activity to around one quarter (26.58%) after participation.

Table 2 Students' level of understanding

Test	Scientifically accurate understanding	Misconception	Misunderstanding
Pre-test	45.06%	33.42 %	21.52 %
Post-test	63.67%	26.58 %	9.75 %

Discussion

The results based on the comparison between students' pretest and post-test means and the levels of students' understanding suggest that the developed MicroEvo game-based activity can enhance students' conceptual understanding of microevolution. Therefore, this study provides another set of evidence supporting that game-based learning is a useful instructional approach that can be considered as an alternative method to traditional teaching like passive lectures (Selvi & Öztürk Çoşan, 2018; Sirironnarong & Yasri, 2018; Suriyabutr & Yasri, 2018; Butsarakam & Yasri, 2019; Seangdeang & Yasri, 2019). However, it appears to be a pioneering work that attempts to apply game-based learning to deal with the learning of microevolution. Also, this study points out that even though the concept of microevolution is rather cognitively challenging to understand, through the aid of game-based learning, this challenge can be lessened (Butsarakam & Yasri, 2019).

A possible mechanism in MicroEvo that is believed to be a major reason for such positive development is the rule of the game that the students interacted with (Nadolny, Alaswad, Culver, & Wang, 2017). This is because when the students played the game, to compete in it, they had to understand the rule of the game and how it works. Since the rule of MicroEvo is content-led, every action in the game can be linked to the scientific concept. Important keywords such as genetic drift, mutation, migration, and natural selection, repeatedly appear in the event cards so that they could become familiarized. Indeed, through repetition, students become more familiar with the rule and the terms, which could potentially lead to connections between the terms and how they contribute to the changes in allele frequency. After that, the debrief and discussion session in this study helped them link the logical sense behind the game that can relate to the concept of microevolution (Nicholson, 2012).

However, in the actual process of data collection, the debrief and discussion session did not take long (only 5 minutes to be precise). To set such a short time like this was intentional as it was expected for the students to learn more from the game and discuss with peers, rather than the debrief session itself which can be easily fallen to the form traditional teaching where the teacher or the facilitator explains the whole concept verbally. It is important to emphasize the dynamic that they interacted with the concept while playing, which is why a greater deal of time was given to the game session. Therefore, the debrief session pretty much serves as a conclusion. Based on the data collection, what is most useful is the introduction of the concept and the introduction to the game. If this is clear, students can play the game with enjoyment and see the rationale behind the rule on their own. However, it is important to be reminded that this is not to teach what the concept is really about, but guidance for the students to play the game more successfully. The same principle of the design of this educational game can be applied to other science topics. Other teachers and researchers may find some interest in extending this current finding to other areas of study and other topics in biology.

Furthermore, this study offers an alternative approach for classifying levels of student understanding ranging from scientifically accurate understanding, misconception, and misunderstanding. While scientifically accurate understanding is straightforward, which is any correct answer that is supported by logical reasons which are scientifically defensible, the other two levels need to be considered in greater depth (Reiss, 2008). Although the misconception and misunderstanding of the term are used interchangeably in the literature, it is believed here that both have subtle differences. From a psychological point of view, the misconception is referred to as pieces of information that are stored in a cognitive reservoir of a learner (Van Den Broek & Kendeou, 2008). However, these knowledge fragments are established with scientifically incorrect concepts. Whenever the learner encounters a learning scenario, he or she is likely to retrieve such information to make sense of it, but with an incorrect conception being held in the first place, the scenario is understood from the scientifically incorrect perspective. Therefore, the process to help change this form of understanding is involved with accommodation according to Piaget's cognitive development theory where new information or experiences cause the learner to modify his/her existing schemas to accommodate the new information (Block, 1982). From a social perspective, a misconception is associated with the worldview of the individual which is potentially influenced by non-scientific beliefs which often reinterpret the scientific information in the light of socially constructed disposition. This form of understanding may lead to rejecting some parts of the scientifically acceptable information that is perceived to be inconsistent with the worldview (Yasri, 2014a). On the other hand, misunderstanding can be simply referred to as a lack of knowledge to make any justification for scientific explanations. From a psychological point of view, the new information can be easily assimilated to the cognitive reservoir which seems to lack the information in the first place (Block, 1982). Additionally, this is believed to have no relationship with social influences (Yasri, 2014a). The two-tier approach used in this study can potentially uncover the three levels of understanding as shown in the result section.

Finally, it is worth pointing out what can be done further in terms of research progress. First and foremost, since this is a pioneering study that develops an educational game to teach the concept of microevolution (MicroEvo), there is a need to validate its effectiveness concerning conceptual development. This study includes only one group of participants (79 tenth graders); therefore, it is required to extend its application to other settings to help justify the claims made in this study. One would also consider recruiting a larger number of participants to maximize the robustness of the statistical analysis. Also, others may like to implement this learning activity among other graders to see the appropriateness of the game across educational levels. Second, those interested in digital game-based learning may wish to digitize this board game to make it accessible in mobile and/or computer devices. It would be interesting to see whether the same content and game rules could bring about different learning achievements or not when being implemented in two different learning environments. Last but not least, this study does not incorporate the measurement of students' attitudes towards the developed game. Therefore, assessments that belong to the affective domain of learning are considered useful for supporting the usefulness and effectiveness of game-based learning, in addition to the cognitive focus in this study.

Conclusion

This study developed an educational board game called MicroEvo to teach microevolution for high school students. The result demonstrated that after playing the game coupled with some introduction in the beginning and discussion, in the end, the student participants (79 tenth graders) improved their conceptual understanding statistically. Also, the percentage of scientifically accurate answers increased after playing the game, while the percentage of misunderstanding reduced substantially. Therefore, the findings indicated that MicroEvo has proven effective in promoting conceptual understanding of microevolution. It is recommended for other teachers to use game-based learning as a way to solve pedagogically difficulties in their profession.

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