



An Educational Game to Promote Conceptual Understanding of Microevolution and Perceived Usefulness of Learning Among High School Students in Northern Thailand

Karnrawee Meekaew* and Pratchayapong Yasri

Institute for Innovative Learning, Mahidol University, Nakhon Pathom, Thailand

*Corresponding author, E-mail: karnrawee.mk@gmail.com

Abstract

This study aimed to develop an educational game called MicroEvo to promote students' conceptual understanding of microevolution. It also sought to explore students' perceptions of the level of usefulness of this educational game. The MicroEvo game was implemented with 79 students in grade 10 enrolled in the science-math program. A 10-item two-tier conceptual test was used to investigate the effectiveness of this developed game in promoting conceptual understanding by comparing the mean scores gained before and after playing the game. Also, a level of use questionnaire was used to explore student perceptions after using the educational game to learn about microevolution. The results showed that students improved their conceptual understanding significantly as the post-test mean score (15.39) was statistically higher than that of the pre-test (12.35) at a significance level of 0.05. It indicates that the MicroEvo game can help promote students' conceptual understanding. Besides, the majority of student participants perceived that this educational game was useful for their study. However, this is in the level of end-users, rather than potential developers.

Keywords: *Microevolution, Biology, Educational game, Allele frequency, Science education, Level of use*

1. Introduction

Evolution is a fundamental principle and a unifying theme in biological sciences due to the fact that it contributes to explain various natural phenomena based biological processes and mechanisms, making biological events from the past to the present reasonably described (Luttikhuisen, 2018).

Two main scales of evolution are taken into consideration, consisting of macroevolution and microevolution. While macroevolution concerns how life forms have changed over time which in turn leads to the process of speciation, 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. Characteristics of all individual organisms are controlled by genes, which are passed on from their parents in the form of alleles. Alleles are different forms of a gene which are in the same locus on a chromosome. Different forms of allele would bring about genetic variation. 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. Therefore, within a gene pool, each type of allele can be counted as allele frequency. Normally, allele frequency is always fixed 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. 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

[1092]



of an allele in a population over time due to 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 (Raven et al., 2011).

Despite having a great variety of learning approaches for microevolution such as lectures, simulations, experimentations, and field trips, research has shown that students encounter with a conceptual understanding of the concept due to its complexity. 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 commonsense misconception, content-based misconception, misconceptions about the nature of science, non-scientific misconception, or vernacular misconception (Yasri, 2014). Also, emotional challenges may arise from learning this topic due to the boredom of extensive content and conflicts to students' belief (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 (Yates & Marek, 2014).

To overcome said challenges, it is important to develop a learning activity about the 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). Among many other active learning approaches, game-based learning is able to 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. Basically, 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 boardgame (Butsarakam & Yasri, 2019), plant transportation boardgame (Sirironnarong & Yasri, 2018), tonicity card game (Seangdeang & Yasri, 2019), and plant taxonomy card game (Suriyabutr & Yasri, 2018). However, no educational game exists for teaching the microevolution. Therefore, this study aims to develop an educational game that focuses on teaching the concept of microevolution in respects of the 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 and positive attitudes toward the usefulness of this game according to the framework of the level of use after the Concern-Based Adoption Model (Gundy & Berger, 2016).

In order to determine how students feel about the usefulness of any developed educational games, it is important to have a particular framework to help lay this out. In this study, the framework of the level of use is chosen. It is a dimension of Concern-Based Adoption Model (CBAM) which can determine how users perceive the usefulness of a certain product and how they plan to use it in the future (Tunks and Weller, 2009). The model is constituted by eight levels ranging from one where users do not expect to use the product in their future (Nonuse) to the highest level of engagement in which users would like to develop their own product similar to this one in the future (Renewal). Locating in between these two levels is a spectrum of six levels, composing of Preparation (may use it), Orientation (will use it from time to time), Mechanical Use (will use it frequently), Routine (will use it regularly), Refinement (will use it and make it more effective), and Integration (will suggest others to use it and make it even more effective).



Conceptual framework

The proposed educational game, called MicroEvo, is designed to incorporate the scientific concepts of allele frequency and factors causing changes in the allele frequency. This game design is expected to help students develop conceptual understanding as they proceed with the game dynamic. Besides, the nature of the game, which can be competitive and exciting, is believed to help promote students' attitudes towards learning. In order to reasonably argue that this developed game can promote conceptual understanding, a pre-post intervention using a 10-item conceptual test is adopted to compare how students improve their understanding after interacting with the game. In terms of the emotional aspect, a survey on the level of use is adopted to let students directly express how they view the developed game as a tool for learning about microevolution. However, this could be only logically done after students participate in the developed game.

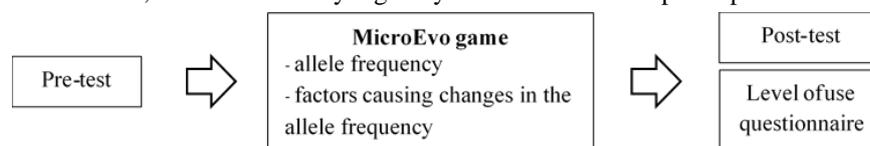


Figure 1 Conceptual framework

2. Objectives

The research objectives of this research are as follows:

1. To develop an educational game using MicroEvo game-based activity in microevolution learning.
2. To compare the conceptual understanding of microevolution before and after using MicroEvo game-based activity among high school students.
3. To explore students' perception regarding the usefulness of the developed educational game using MicroEvo game-based activity.

The research questions are as follows:

1. What would be the difference in students' conceptual understanding of microevolution before and after using the MicroEvo game-based activity?
2. How would student participants perceive the usefulness of the developed educational game using MicroEvo game-based activity?

3. Materials and Methods

3.1 Game components

Teaching materials used in the study included slides for the introduction of the concept of microevolution, the developed MicroEvo game-based activity, a 10-item conceptual test, and a questionnaire on perceived levels of use. Firstly, student participants were asked to complete the 10-item conceptual pretest, followed by a package of learning activities composing of the introduction of the concept, the implementation of the MicroEvo game-based activity, and the debrief and class discussion. Then, they were asked to do the final conceptual test, coupled with the survey of perceived levels of use containing eight statements describing different levels of commitment to use this developed activity in their study.

Figure 1 shows the MicroEvo game. The game consists of a board containing a grassland and a forest area that symbolizes an area where the population live in, blocks with two different shades; dark and pale to represent two different alleles, a pin for marking the area on the board, a block for frequency cards to determine block frequency that signifies allele frequency in the gene pool, event cards for challenging all players introducing factors that cause changes in allele frequency, and action cards for possible interactions among the players. 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 not to allow the 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 of allele frequency of others.



To make it more visualized, 3-4 players are grouped together 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 reside 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 it 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 player, each player 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 2 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 card 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, and this is when they can use strategies to make others lose their initial ratio of allele frequency. When all players use their action card 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, in addition to the constant ratio, it is important to keep the number of blocks which 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.

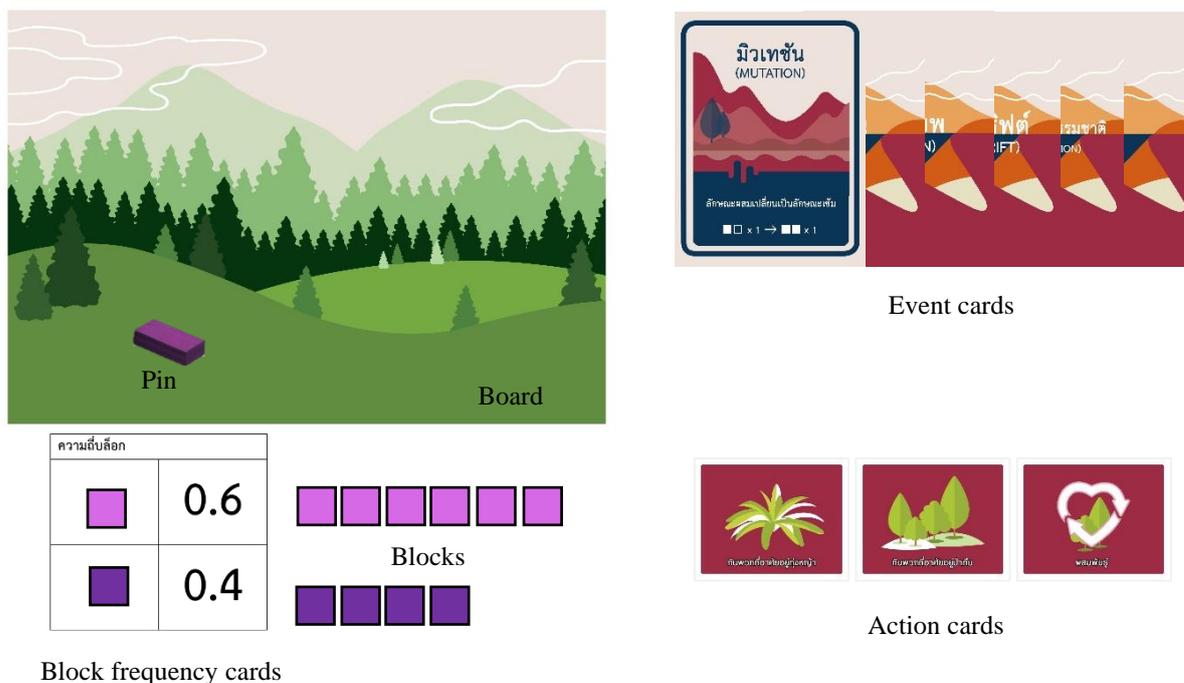


Figure 2 The MicroEvo game

[1095]



3.2 Population and sample

The participants were 79 10th graders who enrolled in the science-math program. They were selected by a convenience sampling method. They were all selected by their class teacher 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. Once they all agreed, they were teamed up in a group of 3-4 members to proceed with the set activities.

3.3 Research instrument and data analysis

Both the pre-test and post-test were assessed by a two-tier protocol. While the first tier, containing ten 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 ten follow-up questions with four 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, perceived levels of use of MicroEvo game-based activity was evaluated using a frequency analysis based on the selection of one statement that best captured their commitment to using this developed activity in their study.

3.4 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, followed by the package 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.

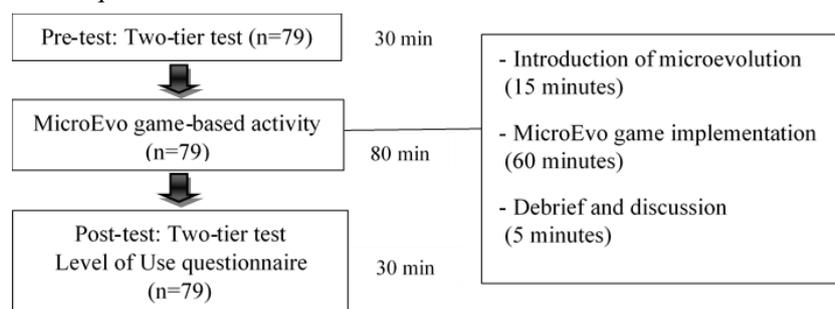


Figure 3 Research design

4. Results and Discussion

4.1 Conceptual development

According to the comparison between pre-test and post-test mean scores of the participants (n = 79), the dependent t-test is denied because it was not a normal distribution. Therefore, the Wilcoxon signed-rank test is accepted and shows that the null hypothesis should be rejected, meaning that the post-test mean score ($\bar{x} = 15.39$) was statistically higher than the pre-test mean score ($\bar{x} = 12.35$). The finding suggests that the developed MicroEvo game-based activity can effectively 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). Besides, this study points out that even though the concept of microevolution is rather challenging to understand, through the aid of game-based learning, this challenge can be lessened.

Table 1 Pre-test and post-test mean scores

Test	Mean (20 points)	SD
Pre-test	12.3544	3.18
Post-test	15.3924	2.75

A possible mechanism in the developed game that is believed to be a major reason for such positive development is the rule of game (Nadolny, Alaswad, Culver, & Wang, 2017) Due to the fact that when the students played the game, in order to compete in it, they had to understand the rule of the game and how it works. Since the rule of this MicroEvo is content-led, every action in the game can be linked to the scientific concept. Through repetition, students got to become more familiar with the rule. 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 (5 minutes) because the students, in fact, discussed along the way as they proceeded with the game. They interacted with the concept while playing automatically. Therefore, this session pretty much served 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. The same principle of the design of the 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.

Further analysis was carried out to investigate how students developed their conceptual understanding in each of the subtopics. It shows that the students significantly improved on their knowledge about the definition of microevolution and how allele frequency can be linked to microevolutionary phenomena. Besides, another subtopic on factors causing changes in allele frequency shows some ambiguous results. According to the theory of evolution, four main causes can bring about the alteration of allele frequency, composing of genetic mutation, migration, genetic drift, natural selection and non-random mating. Due to the complication of the game design, in its current form, MicroEvo does not incorporate the concept of non-random mating in, leaving the remaining of 4 factors. The analysis shows that 3 out of 4 were comprehended by the student participants consisting of genetic mutation, migration and genetic drift. However, the concept of natural selection did not gain a statistically significant improvement after the students participating in the activity. Therefore, this may be an aspect of development for future work so that MicroEvo can be effective as much as it is supposed to be

4.2 Perceived levels of use

According to Table 2, the result shows that while over 40% of the student participants chose the second level which is the expression of their initial interest in using this educational game in their study (preparatory stage), as small as 3.8% perceived that this activity is of no use. It is also interesting to see that this is followed by those choosing the stages of orientation (15.19%) and mechanical use (12.66%). These two levels indicate a high degree of engagement among end-users. Therefore, taking all together, almost 70% chose one of the primary stages of future use (levels 2, 3 and 4).

It should not be surprising that average students tend not to choose the fifth level upwards because these last four levels indicate a high degree of engagement among developers (i.e. teachers in this sense). These levels expect people to use the developed activity regularly and even to develop one on their own for their own use. This expectation is not realistic among learners since the students do not have to teach this topic to others. Also, there is no need for them to develop this for learning other topics. Therefore, it is already



satisfactory that the majority of the students chose the first three levels and that points to their positive attitudes towards the developed game.

This finding is similar to that of Threekunprapa, and Yasri (2020a) that the majority of high school students improved their understanding of computer science concepts and computational thinking after playing unplugged coding using flowcharts. In contrast, the majority of them perceived the usefulness of the activity in the level of mechanical use. Likewise, another study also shows the same trend of result with the use of AR technology to assist the students in learning computer programming using unplugged activities (Threekunprapa & Yasri, 2020b).

Table 2 Frequency analysis of the level of use in each item

No.	Frequencies	Percentage (%)
1	3	3.80
2	33	41.77
3	12	15.19
4	10	12.66
5	4	5.06
6	10	12.66
7	3	3.80
8	4	5.06

5. Conclusion

Microevolution is a difficult topic in biology, as it is both conceptually and emotionally challenging. In terms of cognitive challenges, this topic involves submicroscopic understanding of allele frequency and factors causing it to change, including natural selection, genetic mutation, migration, and genetic drift. In terms of emotional challenges, due to the complication of the concept itself, students find learning it through the means of passive teaching not engaging. Therefore, this study developed an educational game called MicroEvo to teach the 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, after participating in the game, the majority rated their perceived level of the usefulness of the game at a satisfactory level. Therefore, the findings indicated that the developed game has proven effective in promoting conceptual understanding and perceived usefulness of the game. It is recommended for other teachers to use game-based learning as a way to solve difficulties in their profession pedagogically. Besides, this study is limited to the context of students in Thailand, especially high school students learning biology. Therefore, it is recommended for other researchers to continue to explore how game-based learning can help enhance students' learning in other subject matters, across different age groups, and in other educational settings.

6. Acknowledgments

This study has been supported by the promotion of science and mathematics talented teachers (PSMT). Moreover, a million thanks are given to the instructors in the Institute for Innovative Learning, Mahidol university for helping suggest to make the research method and analysis proper.

7. References

- Butsarakam, N. & Yasri, P. (2019). The effectiveness of the female reproductive (FeREP) board game on 10th-grade students' conceptual understanding and attitudes towards the learning of the menstrual cycle. *Scholar: Human Sciences*, 11(1), 248-258.
- Gundy, M. S., & Berger, M. J. (2016). Towards a Model Supporting Educational Change. *International*



- Journal of Information and Education Technology*, 6(3), 232–236. doi: 10.7763/IJET.2016.V6.691
- Luttikhuisen, P. C. (2018). Teaching evolution using a card game: negative frequency-dependent selection. *Journal of Biological Education*, 52(2), 122–129.
- Nadolny, L., Alaswad, Z., Culver, D., & Wang, W. (2017). Designing With Game-Based Learning : Game Mechanics From Middle School to Higher Education. *Simulation & Gaming*, 48(6), 814–831.
- Nicholson, S. (2012). Completing the Experience: Debriefing in Experiential Educational Games. In *the Proceedings of The 3rd International Conference on Society and Information Technologies* (pp. 117-121). Winter Garden, Florida: International Institute of Informatics and Systemics.
- Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, 50(4), 258–283.
- Praputpittaya, T., Chalermsean, A., & Yasri, P. (2020). A categorisation of positions on the relationship between biological evolution and biblical creation: A review for educational implications. *International Journal of Scientific and Technology Research*, 9(1), 2568–2571.
- Raven, P. H., Johnson, G. B., Mason, K. A., Losos, J. B., & Singer, S. R. (2011). *Biology* (9th ed): *Genes within population*. New York: The McGraw-Hill.
- Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., Jackson, R. B. & Campbell, N. A. (2014). *Campbell biology* (10th ed). Boston: Pearson.
- Seangdeang, K. and Yasri, P. (2019). Enhance lower secondary students' scientific literacy and conceptual understanding of tonicity through blended learning. In: Cheung, S., Jiao, J., Lee, L. K., Zhang, X., Li, K., Zhan, Z. (Eds) *Technology in Education: Pedagogical Innovations. ICTE 2019. Communications in Computer and Information Science*, 1048. Singapore: Springer,.
- Selvi, M., & Öztürk Çoşan, A. (2018). The Effect of Using Educational Games in Teaching Kingdoms of Living Things. *Universal Journal of Educational Research*, 6(9), 2019–2028.
- Sirironnarong, N., & Yasri, P. (2018, April 6-8). An Educational Board Game for Learning Plant Internal Transport and Mineral Nutrients. In *Proceeding of the 2018 International Conference on Education, Psychology, and Learning* (pp. 116-119). Nagoya, Japan: Nagoya Institute of Technology.
- Su, T., Cheng, M., & Lin, S. (2014). Investigating the Effectiveness of an Educational Card Game for Learning How Human Immunology Is Regulated. *CBE Life Sciences Education*, 13(3), 504–515.
- Suriyabutr, A., & Yasri, P. (2018, April 6-8). Self-Determination Theory: A Psychology Framework for Learning. In *Proceeding of the 2018 International Conference on Education, Psychology, and Learning* (pp. 111-115). Nagoya, Japan: Nagoya Institute of Technology.
- Threekunprapa, A. & Yasri, P. (2020a). Unplugged coding using flowblocks for promoting computational thinking and programming among secondary school students. *International Journal of Instruction*. (In press).
- Threekunprapa, A. & Yasri, P. (2020b). The Role of Augmented Reality Based Unplugged Computer Programming Approach in the Effectiveness of Computational Thinking. *International Journal of Mobile Learning and Organisation*. (In press).
- Tunks, J. and Weller, K. (2009). Changing practice, changing minds, from arithmetical to algebraic thinking: An application of the concerns-based adoption model (CBAM). *Educational Studies in Mathematics*, 72(2), 161–183.
- Yamanoi, T., Suzuki, K., Takemura, M., & Sakura, O. (2012). Improved “origami Bird” Protocol Enhances Japanese Students' Understanding of Evolution by Natural Selection: A Novel Approach Linking DNA Alteration to Phenotype Change. *Evolution: Education and Outreach*, 5(2), 292–300. doi: 10.1007/s12052-012-0388-z
- Yasri, P. (2014). A systematic classification of student misconceptions in biological evolution. *International Journal of Biology Education*, 3(2) 31-41.
- Yates, T. B., & Marek, E. A. (2014). Teachers teaching misconceptions: A study of factors contributing to high school biology students' acquisition of biological evolution-related misconceptions. *Evolution: Education and Outreach*, 7(1), 1–18.