Yang, J. C. et al. (Eds.) (2018). Proceedings of the 26th International Conference on Computers in Education. Philippines: Asia-Pacific Society for Computers in Education

Using Mobile Game-like Simulation to Promote Inquiry-based Laboratory Learning in Elementary School Science

Daranee JAIMEETHAM[a*], & Niwat SRISAWASDI[b*]
[a]*Municipal 1 Pho Si School, Division of Udon Thani Local Administration, Thailand*
[b]*Division of Science, Mathematics, and Technology Education, Faculty of Education, Khon Kaen University, Thailand*
*niwsri@kku.ac.th

Abstract: We report on a pre-experimental research study that was conducted with elementary school students over a month. It chronicles the development and implementation of *SmartFarm*, a game-based interactive simulation for promoting elementary school students' inquiry-based laboratory learning of factors affecting plant growth. In order to facilitate the inquiry-based learning with the simulation on the scientific concept of plant growth, *SmartFarm* is a digital card-oriented role-playing simulation that consists of science experiment activities involving different factors related to the growth of plant, i.e. soil, light, water, and gas. It aims to promote a playful inquiry-based laboratory in science for elementary school students, and thus enhances scientific understanding and their science motivation. In this paper, we describe the development of *SmartFarm* mobile game-like simulation as an innovative inquiry tool in elementary school science and its implementation with 32 of fourth-grade students in a public elementary school located in northeastern region of Thailand. We analyzed the students' scientific understanding by comparing before and after receiving the intervention and their performance of scientific explanation during participating the inquiry lessons. The results indicated that the mobile game-like simulation integrated into inquiry-based laboratory learning could promote Thai elementary school students' better scientific understanding of and support their ability to explain scientific phenomena on factors affecting plant growth. Based on this finding, the use of mobile game-like simulation as a cognitive tool with the facilitation of inquiry learning process by teacher is an effective way to promote science laboratory learning for new-generation learners in 21st century education era.

Keywords: Digital game, simulation, inquiry, science laboratory, primary education

1. Introduction

During the elementary grades, children are exposed to and build understandings of biological concepts through their interactions with the world around them (National Research Council, 1996). In the Basic Education Core Curriculum of Thailand, the factors affecting plant growth is fundamental biological science concept illustrated in the national science education curriculum, and it also plays an important role in international science education standard and framework in elementary school science. When examining plant growth needs, students' ideas and conceptions become more complex, resulting in the emergence of various misconceptions (Anderson, Ellis, & Jones, 2014). For example, students will often describe that plants need food in the same way that people need food (Anderson, Ellis, & Jones, 2013). The difficulty of conceptual learning on this scientific phenomenon is related to its highly complicated and abstraction, and we also cannot observe the phenomena of plant growth directly because of its long period of time. According to its complicated situation, Tunnicliffe and Reiss (2000) have found that student understanding of plants and what plants need to grow is often limited. When considering what plants need to grow, ideas can become even more complicated for elementary school students (Barman et al., 2003). Additionally, student misconceptions arise is in their conflation of ideas around what plant needs are provided by people (e.g., house plants, gardens) as opposed to what plants receive from their environment

(Barman et al., 2006). To facilitate the learning of abstract and complicated science concepts and phenomena, digital technologies has become cognitive tools for enhancing science learning in current research and development.

Over the past few decades, digital technologies and learning resources have important roles in science-based education (Dorji, Panjaburee, & Srisawasdi, 2015; Lee & Chen, 2009). Recent research found that digital game-based learning could promote students' interest, motivation, attitude, and enhance conceptual learning outcome (Giannakos, 2013; Lokayut & Srisawasdi, 2014; Nantakaew & Srisawasdi, 2014). Moreover, researchers reveal that the digital technologies can effectively support teachers' teaching practices in integrating inquiry-based instruction into science class (Meesuk & Srisawasdi, 2014; Nantakeaw & Srisawasdi, 2014). Additionally, educational researchers mentioned that implementing technology-based learning environment could raise students' cognitive engagement and learning performance (Srisawasdi & Panjaburee, 2015; Kanyaprasit & Srisawasdi, 2014). Due to features of technology, the support of students' visualization and imagination skill is important for science learning in school science level. Regarding rapid growth of digital learning technology in science, game-like simulation is an effective digital media for enhancing science teaching and learning through the combination of computer-simulated experiment and digital game. This learning technology could promote students' motivation and attitude as well as increase their comprehensive understanding of science concepts (Udomrat & Srisawasdi, 2015; Ruttanasaeng, Srisawadi, & Kanjak, 2015). According to the above mentioned, to engage students' science learning in classroom and prepare new generation to have skills in 21st century society, especially children or younger generation who like to play game as a favorite activity (Lokayut & Srisawasdi, 2015). So that, the purpose of this study was to develop a visual-aid learning technology of game-like science simulation representing plant growth experiment as innovative learning tool with guided inquiry learning to study elementary school students' conceptual understanding and their scientific explanation.

2. Related Principle and Work

Nowadays, information technologies have changed rapidly. Digital learning becomes a learning trend, because it can record students' learning situation on the learning system and help teachers to understand and manage students' learning portfolio. Owing to the rapid development of digital technology, digital games and simulation are popular now. In recent years, a combination of digital game and simulation, shortly called game-based simulation, for learning has become an important research topic in educational research and development. Now there are many researchers and scholars advocate to develop digital game-based simulation for promoting favorable and positive learning and enhancing the better learning competency for students. By the game-based simulation learning, we can live up to educate children while having fun with them at the same time and increase their learning achievement (Meesuk & Srisawasdi, 2014; Ruttanasaeng, Srisawadi, & Kanjak, 2015).

Computer simulations, which contain visualization and features for representing a high abstract thing, can help student adjust variable in simulation and observe phenomenon (Chen-Chung Liu, 2011), these features have been recognized as an effective tool for teaching and learning method in science (Khan 2011; Wellington 2004). As such, computer simulation can be effective instructional practices in promoting science content knowledge, developing process skills (Smetana & Bell, 2012) and promoting students' perceptions of learning (Kamtoom & Srisawasdi, 2014). Interactive computer simulations allow learners to conduct virtual experiments that cannot easily be conducted in real-life situations (Chang, 2016). Learners can change the parameters and values of the simulation to test their hypotheses and theories. For the benefit features of digital game is challenge, rewarding and enjoyment (Meesuk & Srisawasdi, 2014; Papastergiou, 2009). Researchers revealed that digital game-like learning could promote students' interest, motivation, attitude, and enhance conceptual learning outcome (Lokayut & Srisawasdi, 2014; Nantakaew & Srisawasdi, 2014). According to both feature above, game-based simulation is an effective digital media for enhancing science teaching and learning through the combination of computer simulation and digital game. This learning technology could promote students' motivation and attitude as well

as increase their comprehensive understanding of science concepts (Udomrat & Srisawasdi, 2015; Ruttanasaeng, Srisawadi, & Kanjak, 2015).

3. SmartFarm: A Mobile Game-based Simulation on Plant Growth

In this study, the researchers have developed a visual-aid learning technology of game-like simulation representing plant growth experiment. The game-like simulation has been developed to use as an android mobile application for mobile devices, both smartphones and tablets. The application used for the study, Smart Farm, is briefly introduced here. The game was designed by the authors and implemented in Unity 3D with the assistance of a software developer. It is a role-playing game that aims to engage elementary school students in science learning of plant growth. The main scenario of the simulation is related to smart farming emphasizing how to grow plant in an indoor garden environment. The player takes on the role of a smart farmer (the main character in the game-like simulation).

The player must know the goal of the game-like simulation (i.e., to evaluate related factors of a plant growth) and what rules to follow, which can be found at any time in the main scene of the simulation. With the use of the proposed game-like simulation as an inquiry tool to conduct scientific experiment in a smart farm, players can control their own learning from playing the simulation representing plant growth experiment by (1) adjusting several variables in the experiment, (2) observing the phenomena, and (3) investigating how the plant growth based on their own experiment. In addition, the players can have a physical activity by using a smartphone or tablet to read QR code from several cards for adding target variables in the plant growth experiment. Figure 1 shows example of the mobile game-based simulation on plant growth.

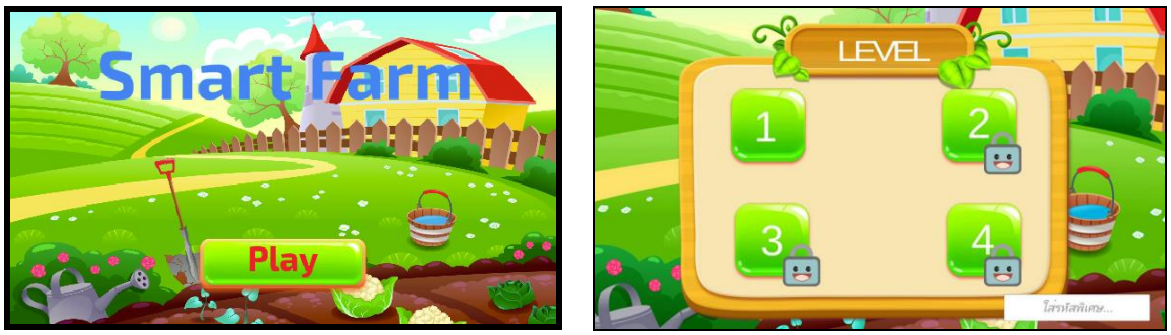

Figure 1. Screen illustration of the game-like simulation on plant growth: main screen of the simulation (left) and the screen of level-based sequence regarding factors affecting plant growth (right)

As seen in Figure 1, the game-like science simulation of plant growth experiment employed the scenario of smart farm to engage elementary school student for their biological science learning. To conduct the science experiment, they need to scan QR code cards to add variables affected to the growing of plant or select the type of plants for conducting their own investigation. Figure 2 shows an illustration of how to scan the QR code card and the plant growth experiment screen displayed in the mobile application.

Figure 2. An illustration of plant growth experiment in the game-like simulation: the front-back QR code card for cabbage plant (left), an indoor garden environment visualizing cabbage growth phenomena (right)

In this game-based simulation, it was divided into four series regarding the factors of plant growth. The main factors of plant growth included soil, water, light, and gas. In this simulation, students have to play and pass each series in a sequence. Student can get score and it depends on the accuracy of the experimental results. After completing the experiment with the game-based simulation, students were interacted with a worksheet.

4. Context of the Study

4.1 Research Design

The purpose of the present study was to investigate the effect of mobile game-based simulation integrated into inquiry-based laboratory learning on elementary school students' scientific understanding of plant growth concepts, and their scientific explanation in a biological science course. To investigate the impact of mobile game-based simulation integrated into inquiry-based laboratory learning, a pre-experimental research method regarding one group pretest-posttest was used for the study.

4.2 Study Participants

The participant of this study included 32 of fourth-grade students, aged between 9 - 10 years old, in a local public elementary school located at northeastern region of Thailand. They were 11 boys and 21 girls from similar economic background and they all have basic skills in using smartphone and tablet personal computer, but they have no experience yet using a simulation in science learning. This implied that they are heterogeneous before interacting with the experimental study.

4.3 Instrument and Measures

Seven two-tier multiple-choice conceptual questions was produced based on a summary of students' common misconceptions about plant reported by Wynn et al. (2017). The misconceptions related factors affecting plant growth has been transformed into conceptual questions for the test in this study. For instance, a misconception hold by students is that "Plants always need light." and then the researchers transformed the misconception into a conceptual question that "Can a plant grow only under light illumination? and why?". For the test, the scoring were one and two points for the corrected answer on first and second tier, respectively, and the maximum score is 21 points.

4.4 Data Collection and Analysis

The procedure of this study was an investigation of students' scientific understanding of factors affecting plant growth as the result of the inquiry-based laboratory learning with the proposed

mobile game-like simulation. The students were assigned to 30-minutes pretest to complete the two-tier multiple-choice test before performing the game-based simulation experiment of plant growth. Then students were exposed to interact with a guided-inquiry science laboratory learning with the support of mobile game-like simulation representing plant growth experiment for 960 minutes within four weeks. After completing the experiment, they were asked to complete the two-tier multiple-choice test again as posttest, as illustrates in Figure 3. In addition, a number of students has been asked to volunteer participating in an individual interview.

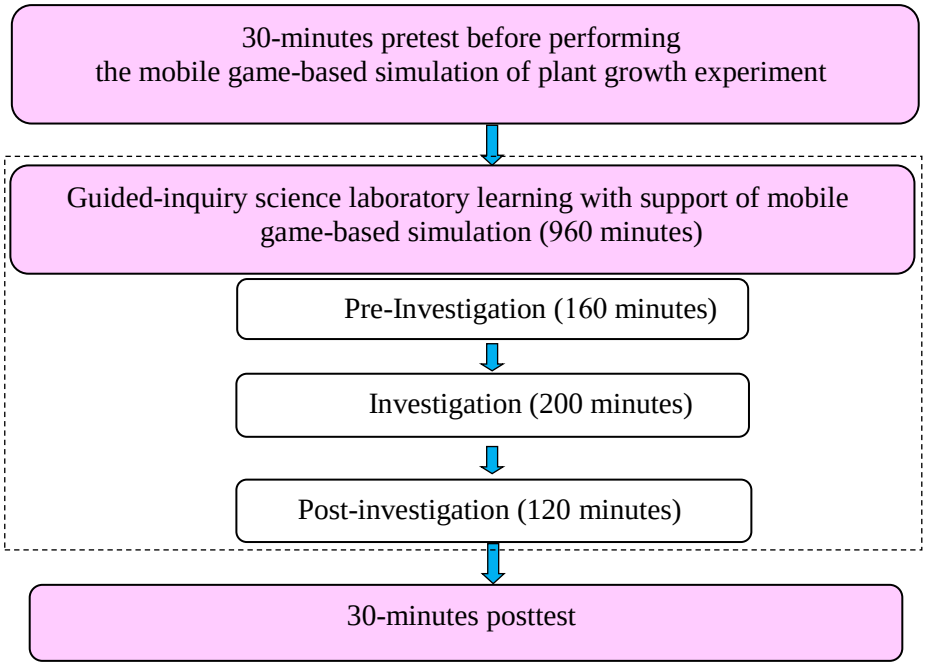

Figure 3. A diagram of the experimental procedure in this study

5. Results

To examine the influence of guided-inquiry laboratory learning with mobile game-based simulation in this study, a comparison between pre- and post-test conceptual understanding scores has been performed to reflect its influence on elementary school students' learning. The comparative results of pre- and post-test showed that students showed a significant difference on their scientific understanding of plant growth score. The posttest mean score (Mean = 15.53, S.D. = 6.36) was significantly higher ($t = 15.259$, $p = .000$, $p < .05$) than the pretest mean score (Mean = 8.72, S.D. = 1.41), as shows in Table 1.

Table 1

Descriptive statistics and paired t-test results to compare students' scientific understanding in overall

Test	No. of student	Mean	S.D.	t-score	*p*
Pretest	32	8.72	1.41	15.259	.000*
Posttest	32	15.53	6.36		

*significant difference at .05 ($p<0.05$)

To be more precise, the pretest and posttest of each concept for all seven scientific concepts about factors affecting plant growth has been analyzed using the paired t-test. The t-test was used to compare both test scores in order to investigate the particular influence of mobile game-based simulation integrated into inquiry-based laboratory learning. Table 2 presents the comparative results of individual scientific concept.

Table 2

Descriptive statistics and paired t-test results to compare students' scientific understanding for each concept

Code	**Concept**	**Pretest**		**Posttest**		**t-score**	***p***
		Mean	S.D.	Mean	S.D.		
C1	Nutrient	1.88	1.18	2.84	0.51	4.360	.000*
C2	Water	1.28	0.81	2.75	0.62	8.747	.000*
C3	Light	1.06	0.71	2.78	0.61	10.944	.000*
C4	Gas	1.06	0.80	2.38	0.83	6.466	.000*
C5	Combination between nutrient & water	1.38	0.79	2.69	0.69	7.974	.000*
C6	Combination between light & gas	0.81	0.59	2.25	0.92	8.901	.000*
C7	Combination of all factors	0.63	0.55	1.88	0.94	7.721	.000*

Table 2 showed reveals the t-test scores of both tests, showing the differences in students' conceptual learning achievement in the guided-inquiry laboratory learning with mobile game-based simulation of plant growth. For the nutrient factor concept (C1), the mean score results of C1 implied that students were more able (Mean = 2.84, SD = 0.51) to learn as compared to the pretest (Mean = 1.88, SD = 1.18). The t-test results further indicate a significant difference between the pretest and posttest for C1 ($t = 4.360$, $p = .000$, $p < .05$). For the concept of water factor (C2), the mean score results of C2 implied that students were more able (Mean = 2.75, SD = 0.62) to understand as compared to the pretest (Mean = 1.28, SD = .81). The t-test results further indicate a significant difference between the pretest and posttest for C2 ($t = 8.747$, $p = .000$, $p < .05$). For the concept of light factor (C3), the posttest score (Mean = 2.78, S.D. = 0.61) was higher than the pretest (Mean = 1.06, S.D. = 0.71) that the result implied significantly better understanding of this concept ($t = 10.944$, $p = .000$, $p < .05$) as compared to the initial status of understanding. For the last single affecting variable of gas factor concept (C4), the mean score results of C4 implied that students developed better understanding (Mean = 2.38, SD = 0.83), as compared to the pretest (Mean = 1.06, SD = 0.80), at the end of their learning. The t-test results further indicate a significant difference between the pretest and posttest for C4 ($t = 6.466$, $p = .000$, $p < .05$).

In this study, we also investigate the effect of the intervention in a context of multiple variables in science experiment. The result on C5-C7 represented students' scientific understanding on the multiple variables experiment regarding factors of plant growth. For the combination between nutrient and water factors concept (C5), the mean score results of C5 implied that students were more able (Mean = 2.69, SD = 0.69) to learn the multiple variables of plant growth experiment as compared to the pretest (Mean = 1.38, SD = 0.79), and the t-test results further indicate a significant difference between the pretest and posttest for C5 ($t = 7.974$, $p = .000$, $p < .05$). Similar to the learning of C5, students showed better understanding (Mean = 2.25, SD = 0.92) of multiple variables of plant growth experiment on C6 as compared to the pretest (Mean = 0.81, SD = 0.59). The t-test results further indicate a significant difference between the pretest and posttest for C6 ($t = 8.901$, $p = .000$, $p < .05$). To evaluate the students' big idea of factor affecting plant growth, the C7 was used to measure that big idea and the result on C7 implied that students developed better understanding (Mean = 1.88, SD = 0.94), as compared to the pretest (Mean = 0.63, SD = 0.55), at the end of their learning ($t = 7.721$, $p = .000$, $p < .05$).

In order to gain better understanding of the influence of mobile game-like simulation integrated into guided-inquiry laboratory learning, we have conducted a semi-structured informal interview with some of students. According to the individual interview, some of interview data reflected their cognitive gaining with the intervention. Some evidences of their attitudes could be illustrated as follows.

"I think, I would like to conduct the experiment in science subject by using game-like simulation again. Because it is the quick way to reach the result and if I made mistake I can practice again and again until my practice is correct. Moreover, I can understand scientific concept of plant growth quickly. In addition, I can understand better about the variables in experiment by try to adjust variables in various ways to reach the correct result." (A female student)

"With the use of game-like simulation to conducting the experiment activity, it is better way for me to observe phenomena of plant growth which influenced by adjust variables, so it made me more interesting in science learning class, because I can understand the lesson from doing the experiment by myself, so it caused to me more self-confidence to do the experiment next time." (A female student)

"I love to learn science by doing the experiment in the simulation. It was very fun, and I can finish the experiment faster than conventional experiment. Normally I love to play the game every day, then from doing the experiment in this simulation, it made me understand the lesson easily. Moreover, I can teach my friends who cannot understand how to play the game-like simulation, it made me proud." (A male student)

6. Concluding Discussion

This was a pre-experimental research study that examined the technology-pedagogy integration of mobile game-like simulation and inquiry-based laboratory learning of elementary school students in a Thai public elementary school class setting. In terms of students' scientific understanding, the finding of students' pretest-posttest comparison shows that students gained much better understanding after interacting with the proposed intervention. The fact shows that the posttest mean scores of all items of students' scientific understanding are higher than the pretest. Moreover, the interview data also revealed that students felt more competent as they had more opportunities to take ownership of their learning with the mobile game-like simulation. The findings are coherent with that of Schmitz et al. (2015), whereby a mobile simulation game application can support learners' understanding of content and the learning of the intended process or structure. This finding implied that the visual-aid game-based simulation on mobile addressing biological science concept of factors affecting plants growth integrated into guided-inquiry laboratory learning could promote elementary school students' scientific understanding effectively. This indicated that the use of mobile game-like simulation as a cognitive tool with the facilitation of inquiry learning process by teacher is an effective way to promote science laboratory learning for new-generation learners in 21st century education era.

Acknowledgements

This work was financially supported by Graduated School and KKU Smart Learning Academy at Khon Kaen University, Thailand. Any opinions, findings and conclusions or recommendations expressed in this material are of the authors and do not necessarily reflect the view of both organizations. I would like to thank all members of Frontiers of Educational Science and Technology (FEST) Research Network, Thailand for their academic supports and inspiration about technology-enhanced learning in science.

References

Barkatsas, A. T., Kasimatis, K., & Gialamas, V. (2009) Learning secondary mathematics with technology: Exploring the complex interrelationship between students' attitudes, engagement, gender and achievement. *Computers & Education, 52*, 562-570.

Barman, C. R., Stein, M., Barman, N., & McNair, S. (2003). Assessing students' ideas about plants. *Science and Children, 10*(1), 25-29

Barman, C. R., Stein, M., McNair, S., Barman, S. (2006). Students' ideas about plants and plant growth. *The American Biology Teacher, 68*(2), 73-79

Chaipidech, P., & Srisawasdi, N. (2016). Mobile technology-enhanced flipped learning for scientific inquiry laboratory: A comparison of students' perceptions and engagement. In *Proceedings of the 24th International Conference on Computers in Education (ICCE2016)*, Asia-Pacific Society for Computers in Education, November 28 - December 2, 2016, Mumbai, India.

Chang, H.-Y. (2016). How to augment the learning impact of computer simulations? The designs and effects of interactivity and scaffolding. *Interactive Learning Environments*. doi:10.1080/10494820.2016.1250222.

Dorji, U., Panjaburee, P., & Srisawasdi, N. (2015). A learning cycle approach to developing educational computer game for improving students' learning and awareness in electric energy consumption and conservation. *Journal of Educational Technology & Society*, *18*(1), 91-105.

Giannakos, M. N. (2013). Enjoy and learn with educational games: Examining factors affecting learning performance. *Computers & Education, 68*, 429-439.

Kamtoom, K. & Srisawasdi, N. (2014). Technology-enhanced chemistry learning and students' perceptions: A comparison of microcomputer-based laboratory and web-based inquiry science environment. In Liu, C–C.et al. (Eds.). *Proceedings of the 22nd International Conference on Computers in Education*. Japan: Asia-Pacific Society for Computers in Education. Nara: ICCE 2014 Organizing Committee, Japan.

Kanyaprasit, K., & Srisawasdi, N. (2014). Development of digital game-like biology learning experience on cell cycle through DSLM instructional approach. In *Proceedings of the 22nd International Conference on Computers in Education*, Asia-Pacific Society for Computers in Education, 857-866.

Khan, S. (2011). New pedagogies on teaching science with computer simulations. *Journal of Science Education and Technology*, *20*(3): 215-232.

Lee, Y. C, & Chen, P. M. (2009). A computer game as a context for non-routine mathematical problem solving: The effects of type of question prompt and level of prior knowledge. *Computers & Education, 52*(3), 530-542.

Lokayut, J., & Srisawasdi, N. (2014). Designing educational computer game for human circulatory system: A pilot study. In *Proceedings of the 22nd International Conference on Computers in Education*, Asia-Pacific Society for Computers in Education, 571-578.

Meesuk, K. & Srisawasdi, N. (2014). Implementation of student-associated game-like open inquiry in chemistry education: Results on Students' Perception and Motivation. In *Proceedings of the 22nd International Conference on Computers in Education*. Japan: Asia-Pacific Society for Computers in Education. 219-226.

Nantakaew, N. & Srisawasdi, N. (2014). Investigating correlation between attitude toward chemistry and motivation within educational digital game-like learning. In *Proceeding of the 22nd International Conference on Computers in Education*. Asia-Pacific Society for Computers in Education, Japan.

Papastergiou, M. (2009). Digital game-like learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education*, *52*(1), 1-12.

Peng, H., Chuang, P.-Y., Hwang, G.-J., Chu, H.-C., Wu, T.-T., & Huang, S.-X. (2009). Ubiquitous performance-support system as Mindtool: A case study of instructional decision making and learning assistant. *Educational Technology & Society*, *72*(1), 107-120.

Permthaisong, S., & Srisawasdi, N. (2016). A comparative study of students' perceptions and engagements toward smartphone-based inquiry laboratory on solution concentration. In *Proceedings of the 24th International Conference on Computers in Education (ICCE2016)*, Asia-Pacific Society for Computers in Education, November 28 - December 2, 2016, Mumbai, India.

Ruttanasaeng, S., Srisawasdi, N. & Kanjak, I. (2015). An exploration of relationship between motivation and perceptions in physics learning of light through game-based simulation and its impact on the gender gap. In *Proceedings of the 23nd International Conference on Computers in Education*, ICT Unit, Center for Graduate Education Initiative, Japan Advanced Institute of Science and Technology, 160-169.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337-1370.

Srisawasdi, N. & Panjaburee, P. (2015). Exploring effectiveness of simulation-based inquiry learning in science with integration of formative assessment. *Journal of Computers in Education, 2*(3), 323-352.

Tunnicliffe, S.D., and M.J. Reiss. 2000. Building a model of the environment: How do children see plants? *Journal of Biological Education*, *34*(4): 172-177.

Udomrat, C., & Srisawasdi, N. (2015). Evaluation of secondary school students' perceptions toward combination of digital learning technology for physics learning. In *Proceedings of the 23nd International Conference on Computers in Education*, Asia-Pacific Society for Computers in Education. Nara: ICCE 2015 Organizing Committee, Chaina, 252-258

Wellington, J. (2004). Using ICT in teaching and learning science. In R. Holliman and E. Scanlon (Eds.), *Mediating Science Learning through Information and Communications Technology*. London and New York: Open University Press.

Wynn, A. N., Pan, I. L., Rueschhoff, E. E., Herman, M. A., & Archer, E. K. (2017). Student misconceptions about plants – A first step in building a teaching resource. *Journal of Microbiology & Biology Education, 18*(1), 1-4 doi: 10.1128/jmbe.v18i1.1253.