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Collaborative and Interactive Online Simulation System for Secondary School Scientific Experiments

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Abstract: In this paper, we introduced a prototype collaborative and interactive online simulation system that will help learning STEM by simulation experiments. It especially benefits for studying phenomena that cannot be seen easily or requires unattainable resources. Our system supports self-learning process by guiding learners with systematic science experiment process: making claims, gathering data and results, and making conclusions. Learners can also collaborate with others to learn from each other. The system supports third-party simulations (currently PhET interactive simulation) using developed integration components. The primarily usability testing results showed potential of using the system in school. More than 50% of teacher participants were satisfied with our system and perceived that our system to be useful for their students. However, one third of participants needed more support on using the system, which seemed to be a little complex for them. Nevertheless, the study showed that the system is promising after little adjustment to the system.

Keywords: Web application, Interactive simulation, Inquiry-based learning, Science experiment

1. Introduction

Currently the Internet is the mainstream way to deliver contents, information, and various applications, including web application. With good user interface and design, web application can catch user attention and boost user motivation (Krug, 2014; Yan & Guo, 2010). There are various purposes for web applications: e-commerce, government, public/customer relations, entertainments, or even education. There are several educational materials that can be accessed and shared throughout the Internet. Many of these online materials potentially aid studies that require hardly-obtained resources to effectively demonstrate phenomena for students to understand the subjects; for example, in Science, Technology, Engineering, and Mathematic (STEM) study. Therefore, incorporating the right web application technology education is one of the method to enhance STEM learning in the 21st century.

Inquiry-based learning is one of effective learning methods in science study. Inquiry-based learning starts by asking an inquiry question and having students explored answer(s) for the question on their own (EducationalBroadcastingCorporation, 2004). Conducting experiments is one of methods in finding inquiry answers. By doing a hand-on experiment, students learn first-handed about phenomena and tend to understand the topic better. However, not every school can provide students with sufficient sets of lab equipment, resources, and time required to complete meaningful and varied experiments. Moreover, some phenomena such as light refraction is practically impossible for learners to experience with naked eyes (Niwat Srisawasdi & Siriporn Kroothkeaw, 2014). Therefore, to mitigate these practical limitations, science simulations can be used in place of real life experiments.

Computer simulation programs can model certain experiments and show learners results without requiring real equipment and resources. It can also reduce time to see the effects of scientific phenomena. In addition, it can visualize concept or phenomena that cannot be seen by naked eyes. This aspect of computer simulations helps student construct their scientific concept knowledge better than some real life experiments.(Emily B. Moore, Julia M. Chamberlain, Robert Parson, & Katherine K. Perkins, 2014; Niwat Srisawasdi & Siriporn Kroothkeaw, 2014)

Nevertheless, letting learners interact with computer simulations alone might not be fully effective as they might not have clear guidelines of how to adopt the technology into their learning. To help students focus on inquiry-based learning, systematic guidelines are needed. In this paper, we introduced a prototype of an interactive online simulation system for secondary school scientific experiments. The system helps guide students through a systematic scientific experiment method: making claims, finding evidences to support the claims, and reasoning to conclude their findings. We implemented a web application that a student can use to conduct experiments in or outside his/her classroom. Our system supports personalized and collaborative learning. Students can interact with the system on their own paces, while they can share their work for the group members to see and learn from each other. The system supports simulation entities developed in HTML5. We retrieved and recorded parameters in the simulations for a student as the student interacts with the simulations. Hence, the student can focus on doing the experiment itself to learn the subject, not on recording the right values from the experiment.

In this early stage of developing the system as a tool for students to learn science, we set our usability research questions to

1) How would teachers perceive the potential usability of the system as a tool to help students conduct collaborative and interactive scientific experiment?

2) How would we need to revise the system to make it effective to help students conduct collaborative and interactive scientific experiment?

The paper is organized as follows. Section 2 discusses related works. We explain the design of the system in details in section 3, and explain experimental method in section 4. Section 5 shows primary results and discussions. Finally, we conclude and suggest improvements in section 6.

2. Related Works

2.1 Inquiry-based learning with experiment

Inquiry-based learning is activity learning driven by learners. Inquiry-based learning usually starts with a teacher stating questions, problems or scenarios. Then learners have to plan their own investigations to find answers to the inquiry questions, problems or scenarios. This should make learners construct knowledge from what they find during the inquiring process.

Experimenting is the one of the methods to find answer in an inquiry process. This research uses the 3-step experiment process: pre-experiment, experiment and post-experiment (Niwat Srisawasdi & Siriporn Kroothkeaw, 2014) as a base. In the pre-experiment, a teacher asks an inquiry question, then gives students scientific background essential to do an experiment. Then students start making hypotheses. Next, during an experiment, students must design the procedure of the experiment, then collect data from the experiment. In the post-experiment step, students discuss and share their findings. Then they reason, by using their claim(s) and experimental data to make conclusions. Our system was designed to allow students and teachers to follow this process easily.

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2.2 Interactive simulation

An interactive simulation is a simulation that a user can interact with a simulated environment and see the consequence of that interaction in real time. An interactive simulation can be used to fix misconception problems in difficult topics with using simulation-based learning strategies (Yu-Lung Chen, Pei-Rong Pan, Yao-Ting Sung, & Kuo-En Chang, 2013). An interactive simulation also helps students construct scientific knowledge on invisible phenomena such as light refraction by using simulation along with a scientific experiment (Niwat Srisawasdi & Siriporn Kroothkeaw, 2014).

Currently, there are many interactive simulations available, such as algodoo, a 2D physic simulation software (“Algodoo,” n.d.), HTML5 simulations from Boston University (“Simulation list,” n.d.), PhET HTML5 simulations from University of Colorado (“PhET Interactive Simulations,” n.d.). However, in this work, we focused on incorporating simulations developed using HTML5 technology that can be displayed on a webpage. We chose PhET simulation as a pilot simulation because they are designed to be easily comprehended. PhET simulations also provide many HTML5 opensource science and mathematics simulations that has been research and tested (Emily B. Moore et al., 2014; “PhET Development Overview,” n.d.; “PhET Interactive Simulations,” n.d.). Moreover, they are also available in Thai language; thus we can test with local teachers and students.

2.3 Usability testing

A usable system is a subjective term that depends on the context of the system. Usability testing is developed to measure how much system is usable for targeted users. Usability testing becomes an important process in developing a system that requires human interaction, to find out whether the developed system is matched with user needs and expectations. Great usability of a system are usually effective, easy to learn, easy to remember, less problem and satisfaction (Yan & Guo, 2010). The standard ISO 9241-11 has a process to evaluate usability from effectiveness, efficiency, satisfaction (“ISO 9241-11:1998(en), Ergonomic requirements for office work with visual display terminals (VDTs) — Part 11: Guidance on usability,” n.d.).

This research use System Usability Scale (SUS) as a usability testing method. SUS had 10 short simple questions that measure usability of the system (Bangor, Kortum, & Miller, 2009; John, n.d.). It consists of positive and negative questions placed alternatively to prevent bias responses. These questions provoke user’s extreme response, covering various aspect of usability such as complexity, need of support and training. SUS should be administered to participants right after they finish their task(s). This should give us an instant responses of participants’ impression about a system. We are using SUS because of its short 10 questions which should put less work for participants. Moreover, we have enough participant required for SUS questionnaire.

3. System Design

3.1 System overview

The collaborative and interactive online simulation system was designed as a web application. It guides a student on a systematic science experimental process: making claims (setting hypotheses), conducting experiments to gather evidences by using simulations, and finally justifying reasons to conclude findings. Students can do the simulated experiments as a group or individual. If done in group, students in the same group can explore topics using simulations, and share claims, simulation results, and conclusions to learn from each other. Moreover, teachers can monitor individual student’s work, and can make suggestions outside of the system to help students understand better on the topic.

There are three main tabs (pages) within the web application: introduction, experimentation, and conclusion. The web application was designed as a single page application (SPA), which requires a client to request for pages only once instead of making many individual requests for pages. This method reduces response time when changing a page within a website and also reduces a server load. In the introduction tab, there is information about a particular experiment, such as objectives and a summary of the involved theories. In the experimentation tab, a student needs to make his/her own claim(s), interact with a simulation and save desired results in the data table. Finally, in the conclusion tab, a student can match the claim(s) and experiment result(s) (evidences) they saved previously and justify reasons to make conclusion(s) to the experiment.

On a separate page, a teacher can inspect student experiments from a student list. If a student did an experiment as a group, a teacher can see experiment details of individual students. We can see that our the collaborative and interactive online simulation system can guide students through scientific experimental process, with teachers' monitoring and coaching, whether they are in classroom or outside. Since the system can integrate third-party HTML5 simulations, this system is also useful for other fields in STEM, not only for science experiment.

3.2 System architecture

The system consists of two main parts: server side and client side. The server side contains server script, database, simulation files and simulation configuration files. The client side contains a web application for students and teachers, and client scripts as experiment integration components, as shown in Figure 1.

There is an authentication process before one can access the system. If a user logs in as a teacher, the server will send a list of students the teacher can examine. If a user logs in as a student, the server script will generate and send a webpage with a single-page application (SPA) to the client. The default page is the experiment list for a student to choose to do an experiment individually or as a group. When the client accesses the experimentation tab, the client's simulation integration component downloads a specific simulation file and a simulation configuration file from the server. Then the client initializes a script for that simulation to start fetching pre-defined parameters. It then shows the parameter values so that students can record parameters from the experiment. Data in this table can be shared among students in the same group as well as to responsible teachers. Having the system automatically fetched result values from the simulation helps students focus on learning phenomena itself rather than worrying about manually recording correct result values.

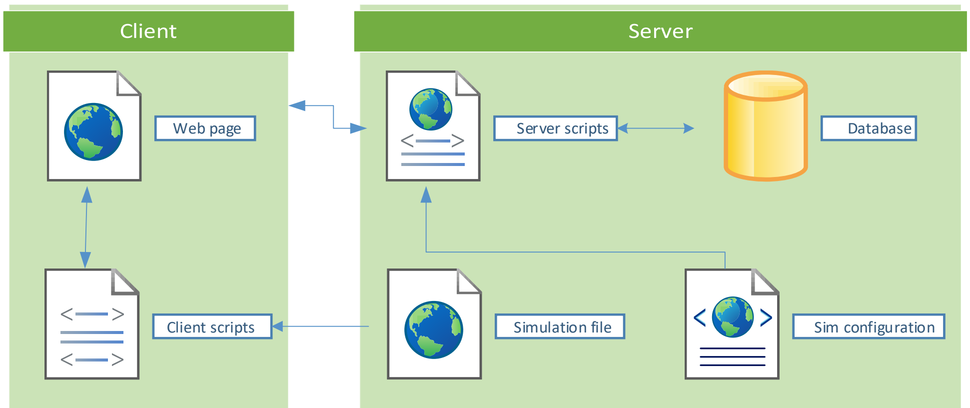

Figure 1 The framework overview

The system supports the integration of a third-party HTML5 simulation such as PhET simulation. To integrate a simulation into the system and fetch parameter values from the simulation, the client downloaded the simulation configuration file along with other files (html, JavaScript, CSS) from the server. The simulation configuration file contains labels, units and JavaScript codes of all parameters. On the client, the simulation is running inside an iframe tag, while the JavaScript code is periodically accessing labels, units, and parameter values from the simulation. Then it shows the values for a student to learn and save them into the system. As the system can retrieve parameters directly from an iframe object, any HTML5 media should be able to be integrated into our system. Currently, a developer needs to examine the simulation code and extract desired parameters from a simulation to automatically show and record relevant parameter values in a result table. However, in the future, we need to define APIs for a simulation developer to automatically deliver relevant values to be shown and/or recorded in the result table

As for the claims and the conclusion, the system provides textboxes that can be saved into the database. A student will finally matched claims made earlier and evidences recorded from the simulation to make conclusions to the particular experiment. As well as other information, group members and responsible teachers can fetch conclusions to view and mutually learn from the database.

Once the web page, client script and simulation files are downloaded for the first time, these files are cached in the client web browser. This means that the next time the client opens the web page or do the same experiment, almost everything is already on client side; thus, saving data transfer time and resources.

3.3 User interface design

We designed the system such that each learning task is contained within a single page: introduction, experimentation, and conclusion. Necessary information can be found on a corresponding page so that a user does not have to switch pages back and forth. As shown in Figure 2, making a claim (b1) and experimenting with simulations (b2) are on the same page. This is to allow a student to focus on how he/she should conduct an experiment according to the claims he/she made earlier. Same as in Figure 3, which shows the conclusion page, a student can access the claim(s) and evidence(s) he/she made earlier, such that the student has all information necessary to conclude the experiment. Moreover, in the experimentation and conclusion pages, a student can explore the group member’s experiments and conclusions via the button “member” in corresponding sections to support collaborative learning.

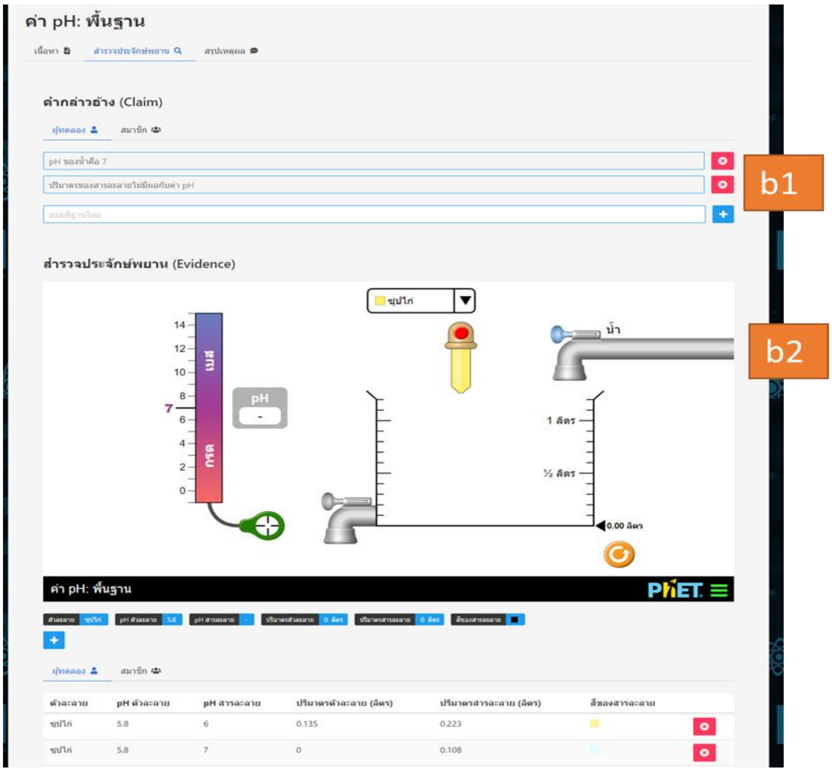

Figure 2 Experimentation page - claim, simulation, parameters and results

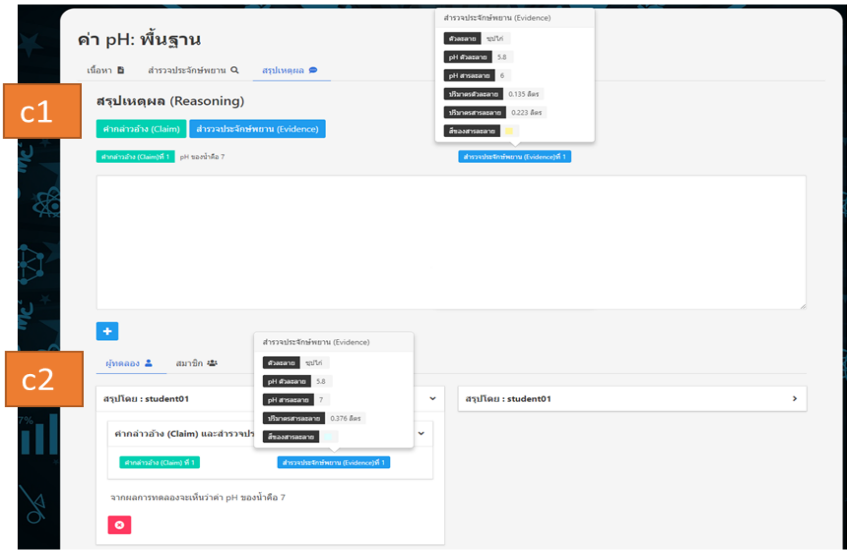

Figure 3 Conclusion page - reasoning and conclusions

Besides, we designed the system's user interface with a conventional layout and kept elements on pages to minimum. This design choice should reduce a cognitive load and learning curve for users when starting to use the system. For the color schemes, our system uses mostly blue and turquoise. Blue color represents feeling of reliability, and it also associates with science (Jiang, Feng, Liu, & Liu, 2008). Turquoise is a color in a shade of green which give feeling of freshness and youth (Jiang et al., 2008). In addition, throughout the system, we consistently used buttons and colors to represent specific tasks. For example, we use blue buttons for main functions such as recording results (with "+") and editing experiments, and red buttons with "x" for data deletion.

Figure 4 shows a teacher page, in which a teacher can click on each student name to inspect the student's experiments, whether done in group or individually. If the chosen experiments were done in group, the teacher will see information of all group members. In the current implementation, a teacher cannot give feedback within the system yet. He/she needs to give feedbacks to students outside of the system. The feature may be available in the future.

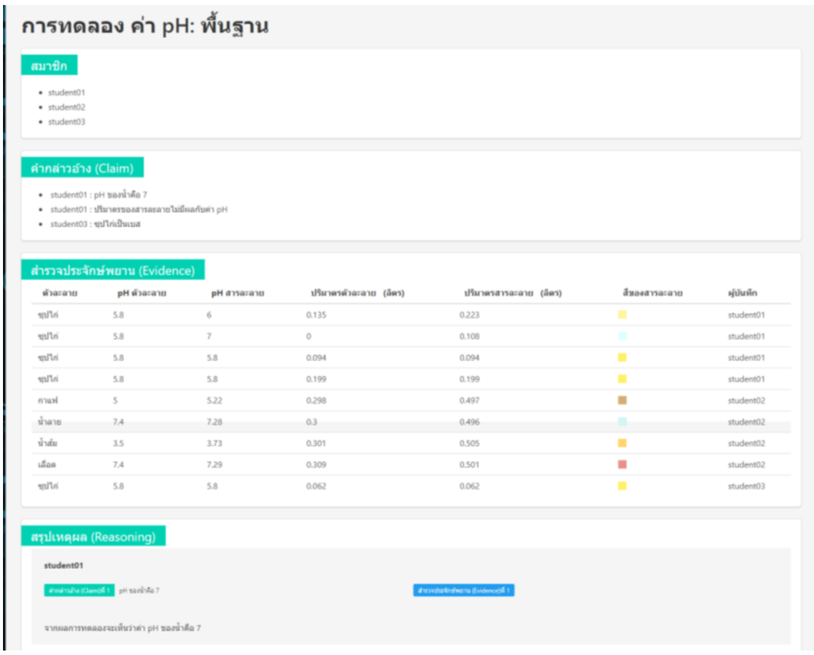

Figure 4 Teacher page - experiment report

4. Experimental Method

4.1 Participants and data collection

Since the system was in the early stage of development, in this paper we tested the system usability with teachers first to assess initial feedbacks for improvement. Moreover, this group of teachers will need to adopt the system in their science class in the future. Teacher participants were from schools in the North-Eastern region of Thailand who have participated in the Khon Kaen University Smart Learning Academy program (KKU-SLA). There were 289 teachers, who were 241 females and 48 males. The participant's ages were ranging from 22-59 years old with teaching experience from less than 1 year to 44 years. Participants are teaching science in secondary schools (grade 7-9). The data were collected in May 2018 and July 2018.

In our experiment, we first gave instructions on how to use the system, while the participants were exploring the system along. They used the system as a student role first, then a teacher role. We conducted the experiment for approximately 1 hour and 30 minutes. The SUS usability test was administered at the end of the session. There was also an open-ended question at the end of questionnaire for participants to openly give their feedbacks that the questionnaire may not cover. Age, gender and teaching experience were also collected.

4.2 Data Analysis

We analyzed our data by using quantitative statistics on SUS scores collected from participants. There were 10 questions for the SUS evaluation. Each question was scored from 0-4. We summed scores from all 10 questions and multiplied by 2.5 to get the full 100 SUS scores. We also analyzed individual questions to obtain specific feedback for precise improvements. We cleaned invalid data out, such as invalid ages and the numbers of years in service.

5. Results and Discussions

As mentioned before, we conducted user tests to primarily find out how teachers would perceive the potential usability of the system as a tool to help student conduct collaborative and interactive scientific experiment, and how we would need to revise the system to make it affective to help student conduct collaborative and interactive scientific experiment.

To measure the overall usability of our system, we looked at the overall SUS scores. The average SUS score was 51.53, while the median and mode were at around 50. The standard deviation was 11.295. The distribution of the score was non-skewed bell graph with scores are mostly concentrated at the center. According to (Bangor et al., 2009), if the mean score is between 51-68, the SUS score is considered just "ok". To find out more details about potential improvements, we examined scores for each SUS question in Table 1.

According to Table 1, our SUS questions are divided into positive and negative statements in the alternate order. Agreeable scores are ranged from 1 to 5, where 1 is strongly disagree and 5 is strongly agree with the given question statement. At a glance, users answered questions with mostly neutral opinions toward the system. We suspected that it might be because there was not sufficient time during the experiment for participant to carefully evaluate the system. Therefore, we will focus on analyzing the 1, 2, 4, and 5 scores.

Table 1

SUS responses from positive and negative questions

Positive questions	**Agreement Score**				
	1	**2**	**3**	**4**	**5**
1. I think that I would like to use this system frequently.	3.46%	17.65%	38.41%	24.91%	15.57%
3. I thought the system was easy to use.	7.27%	30.80%	36.33%	19.03%	6.57%

5. I found the various functions in this system were well integrated.	3.11%	21.11%	32.87%	33.22%	9.69%
7. I would imagine that most people would learn to use this system very quickly.	6.92%	28.37%	37.37%	20.76%	6.57%
9. I felt very confident using the system.	7.61%	27.68%	38.06%	20.42%	6.23%
Negative questions	**Agreement Score**				
	1	**2**	**3**	**4**	**5**
2. I found the system unnecessarily complex.	5.88%	30.10%	42.56%	14.88%	6.57%
4. I think that I would need the support of a technical person to be able to use this system.	5.19%	21.11%	36.33%	24.22%	13.15%
6. I thought there was too much inconsistency in this system.	15.92%	39.10%	29.41%	12.46%	3.11%
8. I found the system very cumbersome to use.	8.65%	30.45%	37.02%	17.99%	5.88%
10. I needed to learn a lot of things before I could get going with this system.	5.19%	18.34%	36.68%	21.80%	17.99%

We analyzed the usability of the system by groups of related questions. There were 40.48% of users would like to use this system frequently. There were 42.91% and 55.02% of users perceived that each of our system feature and design were well integrated and consistent. These showed that our system has a good potential to be accepted as a tool to help student conduct collaborative and interactive scientific experiment.

On the complexity of the system usage, there were 38.07% of users at least disagreed that the system was easy to use (positive question), but 35.98% at least disagreed that it was not unnecessary complex (negative question). This contradiction means that users thought that the system might have to be complexed by nature. There were 37.37% of users needed more support. Therefore, to make the full use of this system, we need to modify the system to be more intuitive and arrange more supports for users.

We speculated that the complexity problem might be caused by the collaborative feature (creating an experiment as a group experiment). The collaborative feature requires more of group member communications when creating an experiment. This process might be viewed as excess complexity for users. But the main feature of the system, which is an interactive experiment, should have positive impression on usefulness, as 40.48% of participants would like to use this system frequently.

During our experiment, we found that participants' technological skill was quite lacking. Many participants were struggling with basic e-mail authentication, and even with browsing through their web browsers. In the previous usability research, (Yan & Guo, 2010) stated that the important of usability is context. In our context, the user model is teacher using the system from the student's perspective so that they can point out the problem that their students might have. So, the lacking of the teacher technological skill might have also affected our experiment results in that they found the system complex.

On the learning curve of using the system, users' feedbacks were mixed. This means that although users thought the system should not be cumbersome to use, they needed to learn a lot before they can use the system efficiently. These results are consistent with the complexity evaluation. We also asked users to evaluate our system openly. The results were consistent with the SUS results. That is, participants stated that they wished to use the system in their classes, but it might be a little complex to use. Therefore, we need to provide better instructions for users. One of the solutions could be adding more visual cue and an on-page live tutorial where the system explicitly guides users what to do.

6. Conclusions

We proposed the prototype of the collaborative and interactive online simulation system. It was developed to support inquiry-based learning by using experiment process. The system is a web-based that guides students through a systematic science experiment using interactive simulation. It also supports collaboration among students and the system can integrate any HTML5 simulations.

In our primarily usability testing, we found that participate teachers had positive views on the system but they still had a problem learning how to use the system due to its complexity. This evaluation gave us a good direction on how we should improve the system in the future. In addition to improve the system, we need to conduct experiments in real classrooms to assess the effect of the system on students' learning.

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