In-class Collaborative Learning Environment for Middle School Children: A Usability Study

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ABSTRACT

Creating effective middle school STEM curricula requires a combination of individual and collaborative learning. Prior studies showed that finding a proper balance and providing uninterrupted knowledge transmission between different learning modes can be challenging in such mixed pedagogical approaches. In this paper, we present a multi-device interactive educational platform named SimSnap to teach biology curriculum to middle school children. SimSnap facilitates interactions among touchscreen Chromebooks to perform in-class individual and group activities. We present a usability analysis study with eight middle school children where they learn about the influence of temperature on tomato plant growth. Our study demonstrated that SimSnap facilitates group discussions to complete collaborative tasks. It also creates seamless knowledge propagation between prior to current tasks to learn about more complex concepts from previous simpler activities. Middle school children gave overall high usability ratings and positive feedback on SimSnap. This study also helped to outline some design recommendations for future improvements of SimSnap.

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CCS CONCEPTS

• **Human-centred computing**; • **Collaborative and social computing**; • **Collaborative and social computing theory, concepts, and paradigms**; • **Computer supported collaborative work.**;

KEYWORDS

Collaborative learning, classroom learning, middle school STEM education, multi-device interaction, middle school children, middle school biology curriculum

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1 INTRODUCTION AND MOTIVATION

In STEM education, effective learning can be achieved by learning from hands-on experiments and understanding the relationships between the experiment parameters and the experiment outcomes [7, 8, 11]. Prior studies have suggested that a combination of individual and collaborative small and large group learning in a classroom setting can provide the best outcomes for STEM education [6, 9, 11, 13, 14]. A prior ten-year long study on computer-supported

STEM curriculum emphasized that digital technologies can effectively facilitate both individual and collaborative learning in classrooms [12]. A major challenge of designing technology to provide such a learning environment is to maintain a proper balance and knowledge flow between individual and collaborative learning activities such that students get the full benefits of both pedagogical methodologies [21]. To address these challenges, some prior STEM education platforms opted for large displays to facilitate collaborative learning, which limited the scope of individual learning [1, 3, 10]. With other platforms that were designed around a shared workspace [17, 18], children were impacted and distracted by the constant presence of a shared workspace, hindering in-depth learning from individual work [20]. Classroom environments today most often leverage single-user displays like Chromebooks, equipped with groupware platforms like Google Classroom to support both individual and collaborative learning and for its effectiveness with data autonomy and affordability [15]. However, such platforms provide no explicit support for navigating between individual and collaborative STEM learning activities.

To address this challenge, we designed and developed a browser-based multi-device interactive educational technology platform called SimSnap to teach middle school Biology curricula [19]. Having a close collaboration with middle school Biology curriculum designers, educators, and learning sciences experts, we designed multi-device interactions that facilitate seamless transitions among individual, smaller group, and larger group settings, maintain the knowledge flow between these activities, and initiate group discussions for better STEM learning outcomes.

In this paper, we present a usability analysis study on the SimSnap system that evaluates the multi-device interactions and its impact on transitioning between individual and collaborative tasks and the relevant knowledge flow. Our study tasks were designed to support learning about the relationships between temperature and tomato plant growth, which is a part of middle school Biology curriculum. We recruited eight middle school children to conduct this study. Our study results demonstrated that middle school children find SimSnap to be a useful platform to learn about their Biology curriculum. Overall, students showed very positive acceptance towards SimSnap and rated the system with high usability scores. They also expressed their interest in using SimSnap in future, if deployed in their classroom. SimSnap facilitated knowledge flow between tasks and group dynamics to generate engagement and group discussions among the students. We also identified some difficulties that the students encountered while interacting with SimSnap that can guide us to design recommendations for future improvements.

2 SIMSNAP SYSTEM

In SimSnap, we implemented a tomato plant growth simulation model to run individually or collaboratively, varying the temperature. The goal of running such simulations is to teach the impact of temperature on tomato plant growth by integrating individual, small group, and large group learning through experimental tasks. Our learning and curriculum experts conducted a broad web search across agricultural, governmental, and scientific publications to quantifiably outline tomato plant growth in certain temperatures. We segmented the plant growth across various stages (as supported by the literature) and levels of plant health (from dead to thriving) and further refined the models with several agricultural engineers. The user interface was implemented with a cross-device application RE/Toolkit [2]. All connected devices interact through the WebSockets server. The underlying technical framework uses a MERN technology stack, primarily using the JavaScript programming language. The database uses MongoDB to store information about the students, devices, groups, and plant simulation data. The backend server is built with Node.js. The Express.js framework handles the information requests from each student interface. The student interface is built using the React.js and the Three.js library. The SimSnap user interface has two tabs: (1) simulation tab and (2) trials tab.

2.1 Simulation Tab

The simulation tab features: (1) *Possible Friends* menu, (2) input panel, (3) plant simulation, and (4) output panel (Figure 1(a)).

Possible Friends Menu is used to create new groups or join and leave from an existing group. Students can choose other available students from the *Free Friends* submenu to create a new group (Figure 2(a)). Otherwise, they can choose an existing group from the *Groups of Friends* submenu to join them (Figure 2(b)). To leave a group, students click on *Disconnect* from this menu (Figure 2). Once a group is formed, their screens are mirrored with each other. Any interactions with SimSnap in a single device are reflected in all group member's screens, thus students can work and learn together.

Input Panel consists of the temperature slider, simulate button, reset simulation button, and reset camera button (Figure 1(a)). The *Temperature Slider* is used to input the temperature. Clicking the *Simulate* button runs the plant simulation (a visual representation of the plant growth) for that temperature. Once the plant simulation is completed, students can click on the *Reset Sim* button to rewatch the plant growth simulation. Students can also zoom and rotate the 3D plant model for closer inspection of the plant. *Reset Camera* button returns to the initial plant view.

Plant Simulation shows the plant growth in five stages: pre-germination, seeding, vegetative, budding/flowering, and final stage (Figure 3). The stage slider indicates the current plant growth stage as the simulation proceeds. The slider can be moved to revisit and inspect different plant growth stages.

Output Panel provides additional textual information to summarize the impact of the selected temperature on plant growth, yield, rate of photosynthesis, number of flowers, and number of fruits (Figure 1(a)).

2.2 Trials Tab

The trials tab consists of a tabular summary of the simulations (trials) that have been conducted by a user, either individually or in groups. Each row shows temperature, yield, rate of photosynthesis, number of flowers, and number of fruits for that trial (Figure 1(b)). Students can mark a trial as their favourite and save additional trial notes at the bottom of this tab. As the students collaboratively learn about temperature and plant growth, accessing information from both individual and group trials allows students to reflect on their prior individual and group activities.

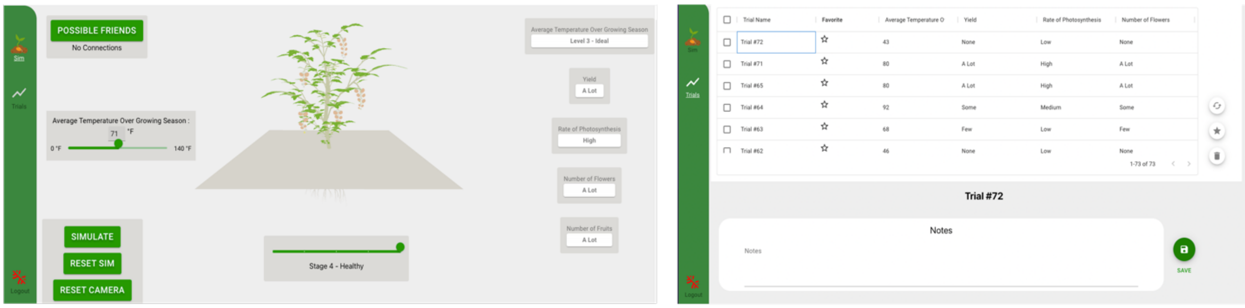

Figure 1: (a) SimSnap simulation tab. (b) SimSnap trials tab.

Figure 2: (a) Create a new group from the *Free Friends* list. (b) Join an existing group from the *Groups of Friends* list.

3 METHODS

We recruited eight middle school children as our study participants, where each study session had four students. All tasks were completed with Chromebook Flex 5 laptops using the touchscreen features. We recorded participants' screens to have a better understanding of the SimSnap interaction. Study sessions were also video recorded to capture participants' verbal interactions with each other. We instructed the students to think aloud while they interacted with SimSnap.

3.1 Procedure and Tasks

Each study session began with a brief introduction to the SimSnap system. Once they were familiar with the system, students were asked to log in. We followed the Jigsaw model [5] to facilitate learning through sequential individual and group tasks. The tasks were designed to transmit individual and group insight from prior tasks to the current ones. Table 1 and Figure 4 show the task sequence and the group dynamics.

Task 1 was an individual task where students were asked to run the plant simulation at a specific temperature (34° F).

In ***Task 2a and 2b***, students were asked to pair with another student using the grouping feature. One of the pairs was asked to find the minimum temperature to grow any number of tomatoes and the other pair was asked to find the maximum temperature to do the same. Students looked for answers by generating the plant simulation with different temperatures. Once they reached an agreement as a pair, they were asked to mark that trial as a favourite trial. At the end of the task, students were asked to unpair.

In ***Task 3***, students were asked to form a group of four, where two students had been paired to find the minimum and the other two had been paired to find the maximum temperature in the previous task. They were asked to find the temperature range to get the best tomato yields. They were encouraged to engage in group discussions to find their answers. Once they reached a group agreement, they were asked to mark the upper and lower bounds of the temperature range as their favourite trials. The task sequence was followed by a verbal group interview and an individual post-study questionnaire to identify any usability issues with SimSnap.

4 RESULTS

4.1 Post-study Questionnaire

Our post-study questionnaire was extended from the system usability scale [4] to identify usability related issues with the SimSnap features. Each question was answered with a Likert-type scale (1 = awful, 5 = fantastic). We replaced the numbers in the questionnaire with smiley faces to make it more appealing to the children [16]. Descriptive statistics (mean(SD)) was applied to analyze the usability scores (Figure 5). All participants gave higher ratings (between 4.0(0.93)-4.5(0.53) out of 5) for the input panel, plant simulation, output panel, and trial tab features. The login, grouping, and ungrouping features received average ratings (between 3(0.76)-3.88(0.99) out of 5).

4.2 Observation from Video and Screen Recordings

Our findings from video and screen recordings closely aligned with the results from the post-study questionnaire.

Grouping and Ungrouping. We noticed some difficulties with pairing/grouping. Some students needed to refresh the *Free Friends* list to see the available students as the list was not visible initially. Ungrouping went relatively smoothly. However, if a student refreshed any tab, all members were automatically disconnected from their group.

Input and Output. Controlling the temperature slider and running the plant simulation worked without any difficulties. One group wanted to restart an ongoing simulation but could not find how to do that.

Collaborative Interactions. SimSnap initiated excellent collaborations and discussions among the group members. Students became very excited to see their mirrored screens and the reflection of another group member's interaction on their own screen. We observed different group interactions for finding the temperature range in task 3. One group worked on their answer from the previous information available in the trials tab. The other group relied

Figure 3: Plant simulation in five stages: germination, seeding, vegetative, budding/flowering, and final stage.

Table 1: Task Sequence of our study

Task	Description	Individual/Collaborative
1	Generate plant growth simulation at 34° F	Individual
2a	Find the minimum temperature required to grow any number of tomatoes	Paired
2b	Find the maximum temperature required to grow any number of tomatoes	Paired
3	Find the temperature range to have tomato yields	Group of four

on their memory to reflect on the previous trial information and went with multiple trials-and-errors.

4.3 Verbal Interview

In the verbal group interview, we asked questions about the most and least helpful features, most and least likeable features, possible improvements, and their overall impression of SimSnap.

Useful Features. All students expressed that they enjoyed learning together about the impact of temperature on tomato plant growth with SimSnap. They enjoyed most of the group forming and input/output features, particularly learning by visualizing the plant growth at different stages and being able to zoom-in and rotate the plant for closer inspection of fruits and below ground nutrients. Seven out of eight students appreciated the detailed plant growth information provided in the output panel. All students expressed that they look forward to using SimSnap for learning if it is deployed in the classroom in future. One of them commented that they will apply their knowledge from this study in real life gardening. All students also thought that their friends from the same class will like SimSnap to learn about temperature and plant growth.

Features to Improve. Some features of SimSnap can be improved for better interaction, e.g., displaying own username on the screen, displaying the usernames of the group members who are controlling the input features, changing the *Reset Sim* button label to something intuitive, notifying before refreshing a tab, not deleting an ongoing trial data if a tab is refreshed, and avoiding freezing the system if multiple interactions are happening at the same time in a group setting. A few students commented that they would like to see real plant growth video with higher resolution, instead of seeing images of the five stages of growth. Students also had some suggestions on the future improvement of SimSnap, e.g., have a broader temperature range, include simulation models for other plants, especially the ones that grow underground.

5 DISCUSSION AND CONCLUSIONS

SimSnap facilitated very engaging collaborative learning environment for middle school Biology curriculum. The visual representation of plant growth, along with detailed textual information in the output panel and trials tab catered to students' individual learning styles and helped them toward achieving a common learning goal. These findings highlight that the wide range of features provided by SimSnap are useful for diverse learning styles, and thus can

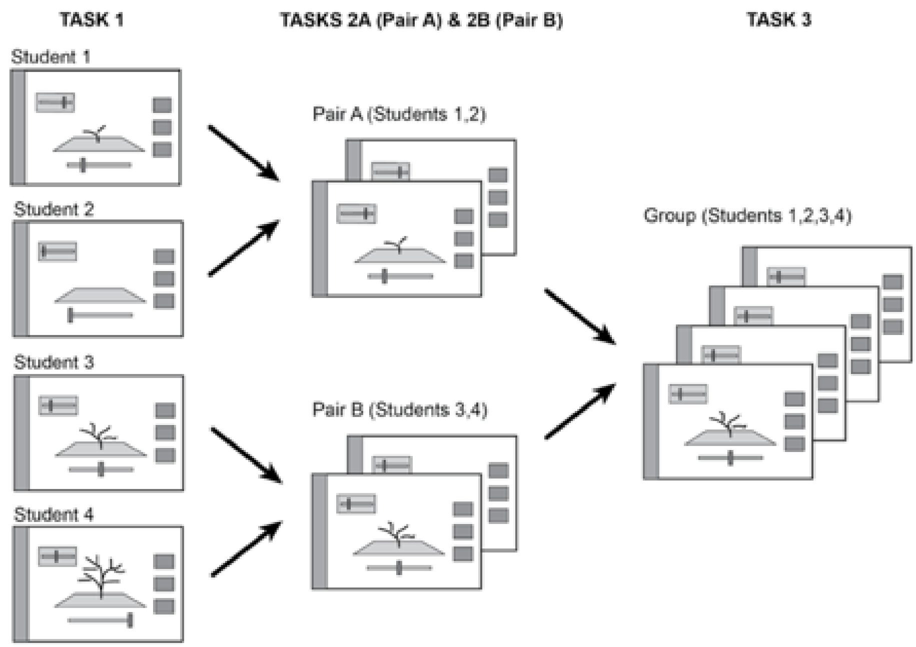

Figure 4: Task sequence of our study. Task 1 is done individually, followed by Tasks 2a and 2b done in pairs. The final task (Task 3) is done in a group of four students. When devices are grouped, their screens are mirrored with each other.

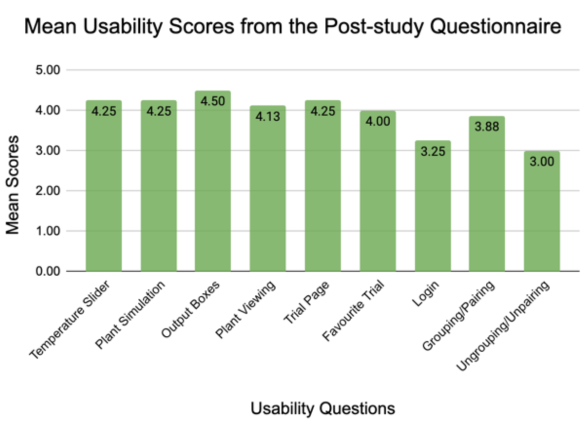

Figure 5: Results from the post-study questionnaire.

improve both individual and group learning. SimSnap supported uninterrupted transitions between individual, paired, and group collaborations that is essential for STEM-related classroom activates. SimSnap also created seamless knowledge flow between tasks such that students can bring insight gained in prior smaller tasks to learn about more complex concepts. Middle school children gave higher ratings on the usability of the SimSnap features. They also gave very positive feedback on the effectiveness of SimSnap for learning about temperature and plant growth. All of these findings validate the potential of SimSnap as a learning platform for middle school STEM curricula.

Our usability study generated useful insight on improving some of the SimSnap features and interactions. In our next iteration of development, we will consider these findings for future improvements. We will add usernames on the screens, along with their group members' names. We will also provide a log tab that will record who initiated an interaction and who is currently controlling the input features. We will also design system feedback to notify the users if they are about to be disconnected from their group. Some of the possible improvements suggested by the students are already a part of the SimSnap system or are currently in development. For example, we already developed plant growth models for watermelon and bell pepper with temperature and water. Students suggested incorporating high resolution plant images; however, the current version of SimSnap slows down significantly if high resolution images are simultaneously loaded on a large number of devices. One of our future directions will be improving the WebSocket connections to facilitate robust connections between multiple devices. Another future goal is to improve the scalability of SimSnap for large classroom settings.

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