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DEVELOPMENT OF A GAMIFIED COMPUTER-ASSISTED PROGRAM FOR COLLABORATIVE ARGUMENTATION

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This design case details the ten-year (2014-present) iterative process to design and develop a graph-based computer-assisted program to support middle school students' development of collaborative argumentation. We begin by describing the first two iterations of the design and discuss how we learned from the process failures. This paper focuses on the most recent iteration of the graph-based computer-assisted program that has evolved to incorporate the multiplayer function to support the representation of collaborative scientific argumentation for middle school students. The students' and teacher's experiences using the multiplayer game-based computer-assisted program are documented.

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INTRODUCTION

This paper presents the ten-year design process of a gamified computer-assisted program to support collaborative argumentation for middle school students. We are a transdisciplinary team that involves faculty and students from the Instructional Technology program in the College of Education and the Department of Computer Science in the College of Liberal Arts and Sciences. We describe the development of the graph-based computer-assisted program in both the first and second iterations. We also share the users' experiences in both iterations of the prototype and indicate how we made revisions based on their experiences. The current paper describes users' experiences with the third iteration of the program. Additionally, in an otherwise straightforward instructional design, this case highlights the strong effect that process decisions can have on bringing a design to resolution and revising a core element of the design partway through. The description of process failures is focused on logistical, personnel, and software problems.

CONTEXT

The original design of the program was conceptualized by the first author, who is a faculty member in the Instructional Technology program at a state university located in

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Northern Illinois in the United States. In 2014, she surveyed graph-based computer-assisted programs used to support students' development of scientific argumentation. She identified a few programs, including Araucaria, Digalo, and Belvedere. These programs share a number of common features (Scheuer et al., 2010; Suthers et al., 2008). For example, contributions (e.g., claims, evidence) are displayed as boxes or nodes that represent argumentation components. The arrows represent the relationship between the argumentation components (e.g., supporting or refuting). The different components of argumentation and relations can be easily distinguished via their visual representation. However, these programs were inactive because no funding was available to maintain them. The author began adapting different proprietary online concept mapping programs such as Webspiration and Lucidchart to support middle school students' development of scientific argumentation (Hsu et al., 2016; Hsu et al., 2018a). While these programs could be tailored to support students' collaborative argumentation, over the years, both the teachers and students suggested she should develop a program to target middle school students' development of collaborative argumentation (Hsu et al., 2018a).

The Next Generation Science Standards (National Research Council, 2012) identified scientific argumentation as one of the eight essential science practices for students. Collaborative argumentation is a means of arriving at an agreed-upon position between members of a group (Andriessen & Baker, 2022). Research (Andriessen & Baker, 2022; Jonassen & Cho, 2011) has viewed collaborative argumentation as a key way in which students can learn critical thinking, elaboration, reasoning, and problem-solving. In this process, students learn how to argue the way the scientists build on and refute one another's theories and empirical research to arrive at scientific conclusions.

A number of researchers (e.g., McNeill et al., 2016) have defined essential elements of argumentation: claim, evidence, reasoning, counterargument, and rebuttal. Claim refers to an opinion or conclusion regarding the main question. Evidence is a separate idea or example that supports reason or counter-argument/rebuttal. Reasoning explains the importance and relevance of the evidence by linking it to a claim. Counterargument refers to an assertion that counters another position or gives an opposing reason. Rebuttal is an assertion that refutes a counterargument by demonstrating the counterargument is not valid, lacks as much force or correctness as the original argument, or is based on a false assumption. The design of the programs described below is based on these five essential elements.

ITERATION ONE

The first team consisted of three students, the first author, and one Digital Convergence Lab (hereafter referred to DCL) professional staff member in 2014. The DCL is an on-campus unit that brings new media and technology to support the creation of innovative applications and tools. The students on this team were interviewed and screened by the DCL professional staff member. The first author did not provide input during the interview and screening process. The student members consisted of one graduate student from the Department of Educational Technology, Research and Assessment (ETRA), one undergraduate student from the Department of Computer Science, and one undergraduate student from the Department of Communication Studies. The DCL staff member served as a coach.

The objective was to complete the icon design, the design of the interface of the website, the development of the website, and the database by the end of 2014. The team planned to use HTML 5, JavaScript, CSS, JQuery, and PHP to design a dynamic interface for the website and MySQL to develop the database that stores students' and teachers' log-in information. The team was able to complete the icon and the interface of the website (as indicated in Figure 1). A total of 133 students commented on the icon design of each argumentation element and the interface design. All students agreed that the icon design represented each argumentation element well. For example, a flag is used to represent a claim (or a position or a stance); a magnifying glass is used to represent evidence; a lightbulb is used to represent a reason or reasoning; a crossed sword is used to represent a counterargument; and a shield is used to represent a rebuttal. The students also provided positive feedback about the potential of the design of the parent-child function to

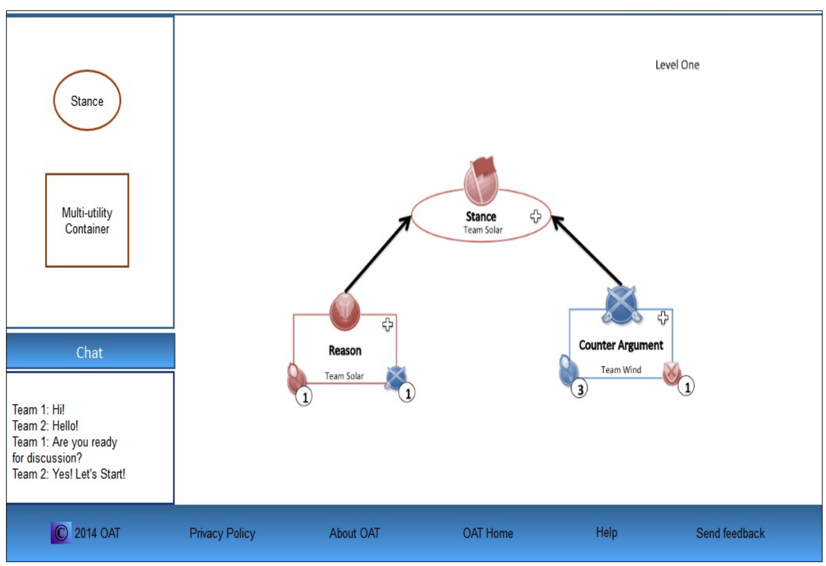

FIGURE 1. First Iteration of the Prototype Copyright 2024 by the Board of Trustees of Northern Illinois University. Reprinted with permission.

support collaborative argumentation in the Spring 2014 (Hsu et al., 2016).

In Fall 2014, the objective was to develop the website and the database. However, by the end of Fall 2014, the team wasn't able to achieve the objective and only completed the development of the login screen page, teacher registration page, and argumentation page. The team failed to complete the database and was not able to build the parent-child function into the argumentation page.

The team reflected on the process failures. The professional staff member and the student members agreed that they came up with good ideas for the icon design and the interface design in the Spring 2014. However, they lacked the technical knowledge and skills required to develop the parent-child function and the database. The professional staff member pointed out that she advised the student programmer to use HTML 5, JavaScript, CSS, JQuery, and PHP. The only student programmer struggled to use these programming languages to develop a website that could incorporate the parent-child function. The student programmer also struggled to use MySQL to develop the database. She wasn't sure if it was due to the lack of the student's knowledge or lack of time. Additionally, two team members, including the student programmer and the student from the Department of Communication Studies, planned to graduate that year, and it was difficult to schedule regular meetings to discuss struggles because of both students' busy schedules. The team invited the first author to attend their progress meetings twice: one in the middle of the semester and the second at the end of the semester. However, it was challenging for the first author to provide any feedback due to the lack of technical knowledge and skills in programming. The student members shared that developing a software program required more experienced members and more time. For the first iteration, personnel's lack of knowledge and time commitment contributed to the failure of its development.

Since the first iteration of the prototype failed, we were not able to explore the users' experience with it. While the teachers and students were disappointed, they encouraged the first author to continue the development of the program. The student members suggested the faculty member and the professional staff member should look into existing technical resources at the university, which could save time for trial and error. Thus, the professional staff member suggested the use of Adobe Connect to continue the development of the program and the first author agreed to give it a try.

ITERATION TWO

The following year, the first author and the two DCL professional staff members formed the second team. They decided not to involve any students because the DCL professional staff member who served as a coach shared it was difficult to recruit and manage students. The second DCL professional staff member had extensive experience with Adobe Connect. Both professional staff members proposed basing the design of the second iteration on Adobe Connect, a Flash-based program. The university had an Adobe Connect server, so it was easier for the first author to set up the classrooms without requesting administrative rights. The objective was to develop the parent-child function into the second iteration of the prototype and allow two teams to work on the prototype. Figure 2 shows the interface of the prototype. Within the parent-child function, users added new elements through an addition icon in the upper left or right corners of the parent container. For example, the students in the Red team can click on the Evidence icon (a magnifying glass symbol) of the upper left corner of the text box. A new child text box will show up and then they can type in the text box. Likewise, the students in the Blue team could click on the Counterargument icon (a crossed sword symbol) in the upper right corner of the text box. A new

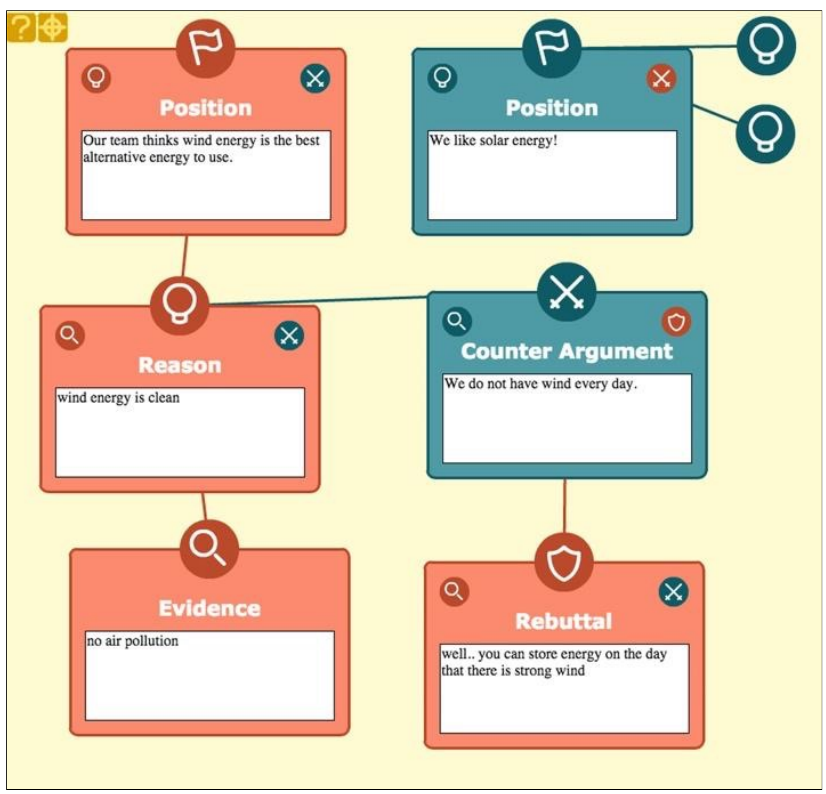

FIGURE 2. Interface in the Second Iteration of the Prototype Copyright 2024 by the Board of Trustees of Northern Illinois University. Reprinted with permission.

child text box will show up and the students can type in the text box. The DCL professional staff member met with the first author and asked for input twice a semester: one in the middle of the semester and one at the end of the semester.

The first author explored the users' experience at the individual and group levels. At the individual level, we asked each of the six students to navigate the interface and use the parent-child function to build their argumentation. Each student was able to navigate the interface and find essential features to support the representation of scientific argumentation. The students felt the prototype was user-friendly. They were able to click on icons to enable the parent-child function. The boxes were there for them, and one box automatically connected to another box (Hsu et al., 2018b). Then the first author explored the users' experience at the group level. The purpose was to understand how a group of students could engage in verbal argumentation with the support of this prototype to track their group's thinking and argue against the other team. There were 34 student teams, approximately 119 students. We assigned two to three students to a team. We asked each team to build their own team's argumentation. The student teams found the parent-child function provided a structure to guide their development of argumentation. They could collaborate with their team members, decide which text they would type into the text boxes, and click on icons as well as type in text to develop their evidence, reasoning, counterargument, and rebuttal.

The users' experiences confirmed that the design idea of the parent-child function in the second iteration has the potential to support students' development of collaborative argumentation. However, we considered it a failure for two reasons. First, when we implemented the second prototype in the classroom, we found that students' collaborative argumentation usually lasted for a week, and without a saving feature, the student teams had to restart their activity every time they logged in. With that, students' collaborative argumentation activities could not be saved. The first author had a discussion with the DCL professional staff member. The DCL professional staff member indicated that he had no knowledge about a database on Adobe Connect, a Flash-based program, and wasn't able to solve the issue. The personnel's lack of knowledge about the software contributed to the failure of the development. Second, the university discontinued Adobe Connect after that year, and the prototype was deleted from the university's server. The logistics problem contributed to the failure of the development. While disappointed, the students and teachers encouraged the first author to continue to identify the right programming languages to develop the program. With a better understanding of the required technical resources (e.g., more student programmers), she reached out to a faculty member in the computer science program who specialized in creating student learning programs.

ITERATION THREE

With two failed prototypes, the first author reached out to a faculty member in the Department of Computer Science in the College of Liberal Arts and Sciences in 2019. We formed a team that involved students from the Instructional Technology program in the College of Education and the Department of Computer Science in the College of Liberal Arts and Sciences. We adopted the Agile methodology (Al-Saqqa et al., 2020) to guide the design and development process. As the Agile methodology focuses on the collaborative effort of cross-functional teams in the software development process, this process requires a longer development timeframe. All team members participated in the interview process to determine which student programmer applicant best suited the project goal. When the team was formed, all members met for two hours per week. Before the COVID-19 pandemic outbreak, the team met in person. During the outbreak, the team met online in Microsoft Teams. Since 2023, we have met with the student programmer in person for one hour and with the student programmer and the three alumni who participated in the programming process in Microsoft Teams for an additional hour. The three alumni became consultants and provided input about the process. We used GitHub as a repository and asked the student programmers to provide detailed documentation of their code before they graduated and left the university. With that knowledge, another student programmer could pick up the existing design and continue to develop the program.

Since 2019, most of the student programmers have been online gamers and are interested in developing online games. When we revisited two failures from previous prototypes, they introduced the idea of a "multiplayer function" while keeping the parent-child function to facilitate collaborative argumentation. The multiplayer function is commonly known in online games and allows people from different sites to join the same game (Galli et al., 2021). The student programmers suggested Unity to develop the parent-teacher function and Photon to develop the multiplayer function. As such, this game-based computer-assisted program extended the design features of the previous computer-assisted programs (e.g., Araucaria, Digalo, Belvedere) and employed game design elements such as progression, collaboration, and competition to scaffold students' development of collaborative argumentation (Arnab et al., 2015).

The collaborative scientific argumentation process incorporates the three-game mechanics of *progression*, *collaboration*, and *competition* (Kim, 2015; Hsu et al., 2022; Huang et al., 2020). Figure 3 shows a sample collaborative scientific argumentation process incorporating the two game mechanics of *progression* and *collaboration*. The hierarchical structure focuses on a parent-child relationship and presentation of the various scientific argumentation components. When the prototype was tested in the classroom, two teams of students were assigned to work on the same page using different color icons with multiplayer functions using one or more computers per team. Figure 3 shows the Blue team and the Green team engaged in collaborative scientific argumentation. To facilitate students' development of collaborative argumentation, the game mechanics of *progression* and *collaboration* were built into the program. *Progression* and *collaboration* are manifested in the boxes that represent claim, evidence, and reasoning. For example, the Claim box for each team appears on the screen when students log into the application. They type their claim into the white space in the Claim box. The students on the Blue team have to click on the small Evidence icon (a magnifier symbol) in the lower-left corner of the Claim box. After the Evidence box appears, they add evidence to their claim. The same procedure applies to the progression for Reasoning (a lightbulb symbol). With *progression and collaboration*, students begin with a claim, followed by a piece of evidence, and then reasons. They cannot skip evidence by clicking on the Reasoning icon.

The Green team can click on the small Counterargument icon (a sword symbol) in the lower-right corner of the Blue team's Claim box to make a Counterargument box appear, as indicated in Figure 4. The Green team can enter their counterargument and provide their reasoning and evidence. Then the Blue team can click on the small Rebuttal icon (a shield symbol) in the lower-right corner of the Counterargument box, so a Rebuttal box appears. The Green team is able to provide a counterargument based on the Claim the Blue team developed. The Blue team is then able to provide a rebuttal based on the counterargument the Green team provided.

USERS' EXPERIENCE OF THE PROTOTYPE

Science Teachers' Experience

We recruited seven middle school science teachers from a school district located in a suburban northern Illinois area in the U.S. This school district serves students from underrepresented populations and diverse ethnic student populations (i.e., African American 20%, Hispanic 52%). The purpose of the evaluations was to examine whether each science teacher was able to navigate the interface and identify essential features to support teaching their students to develop collaborative scientific argumentation. We met with each science teacher in their classroom. Each teacher and the first author set up computers and logged into the program. The first author was assigned to the Blue team, while the teacher was assigned to the Green team. Because all teachers were familiar with the definition of each element of scientific argumentation, the first author briefly explained the association between scientific argumentation components and each icon in the game-based computer-assisted program. The first author intentionally provided minimal instructions to

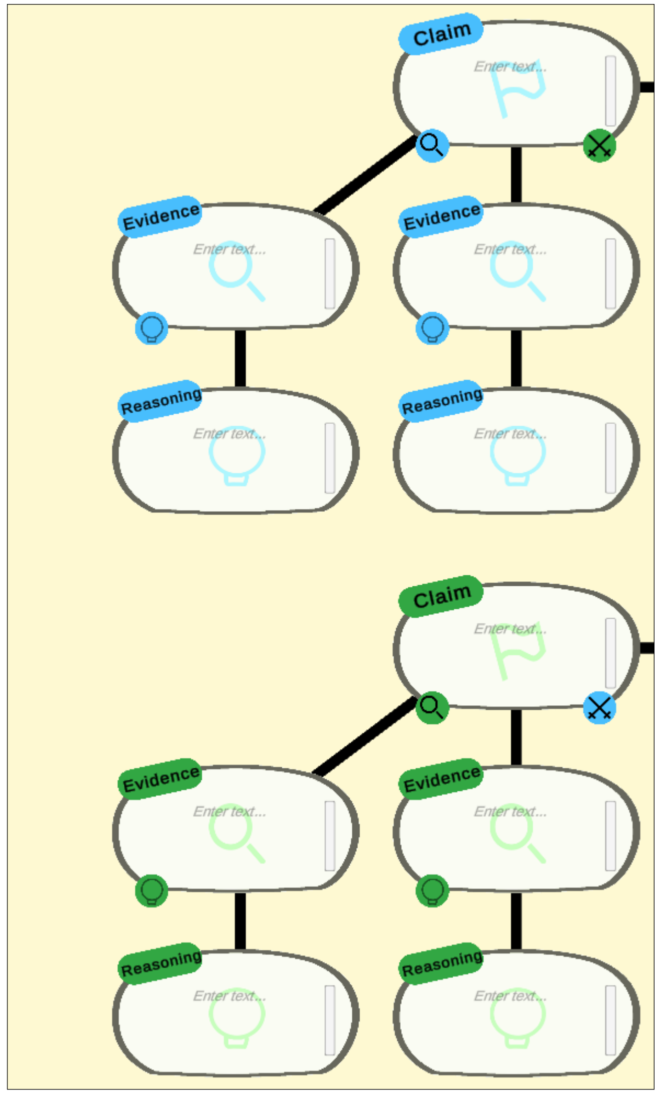

FIGURE 3. Sample collaborative argumentation page one. Copyright 2024 by the Board of Trustees of Northern Illinois University.

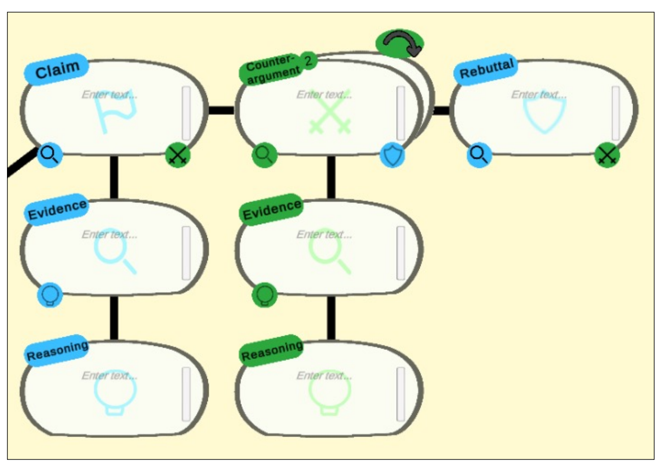

FIGURE 4. Sample collaborative argumentation page two. Copyright 2024 by the Board of Trustees of Northern Illinois University.

examine if the teachers could navigate the program without any problems during the activity. The objective was to examine if all teachers were able to come up with one Evidence box, one Reasoning box, one Counterargument box, and one Rebuttal box. The first author ended the observation experience with each teacher and informed them that he or she accomplished the objective. The first author intervened and provided more instruction when the teachers were stuck during the process. The 20-minute program was based on the topic: "Should students bring a cell phone to school?". The team video-recorded the interactions between each teacher and the game-based computer-assisted program. The team also conducted an interview with each teacher, about 20 minutes, after they completed the collaborative scientific argumentation activity. The interview questions included:

- How easy is it to move around the program?
- How would you use it in your classroom to teach collaborative scientific argumentation?
- What do you wish this program could do?

The observation and interview data were recorded. The interview took place while the program was still open.

In terms of how easy it was to move around the program, the observation data indicated all seven teachers needed prompts when they were asked to figure out where to type text in the Claim box and how to progress to the Evidence box from the Claim box. As soon as they were given the prompts, they were able to type text in the Evidence, Reasoning, Counterargument, and Rebuttal boxes and were able to progress to the Reasoning, Counterargument, and Rebuttal boxes. Four teachers paused to ask how many boxes of Evidence, Counterargument, and Rebuttal could be produced before they continued to click. We responded that the program could produce up to six boxes of Evidence, up to six boxes of Counterargument, and up to two boxes of Rebuttal. Then they continued to explore and said they asked their students to share at least three pieces of Evidence on their worksheets. All seven teachers indicated that the stack form of the Counterargument box (Figure 5; see Hsu et al., 2022) was innovative. They all commented that their students should be able to use the game-based computer-assisted program without minimal training. They also suggested adding a feature that would allow them to monitor all students' work in the program.

In terms of how they could use it to teach collaborative argumentation, all seven teachers indicated this program could be easily integrated into most of the units in their curriculum. Example topics included "Why is it so hot in summer?" and "Patterns in the Sky." Instead of having students individually engage in scientific argumentation through writing on a worksheet, this program would allow students to work in teams or in pairs and engage in collaborative

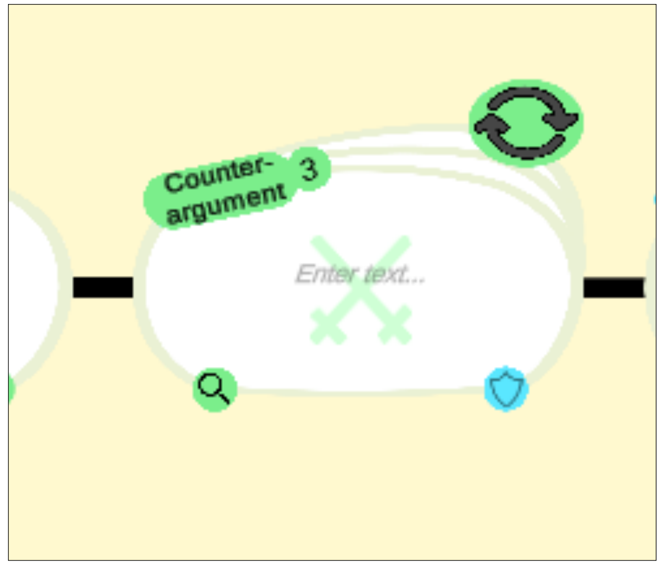

FIGURE 5. Stack form of the Counterargument box. Copyright 2024 by the Board of Trustees of Northern Illinois University.

scientific argumentation. Additionally, the visual representation of scientific argumentation would appeal to students with different learning preferences such as visual learners or English as a Second Language learners (ESL), and would enable different modes of communication. They also added that when students collaborate via the multiplayer function, they would be much more engaged and motivated than working individually. They suggested adding features that could visually compare two teams' progress for students (e.g., progress bar, badges), which would create competition among them. Two teachers called that "healthy competition."

Middle School Students' Experience

We were able to recruit 15 students from a school in the same school district where more than 70% of students come from low-income families. We explored whether the students were able to navigate the interface of the game-based computer-assisted program and leverage the essential features to support their development of collaborative scientific argumentation.

All student names are pseudonyms. We assigned the 15 students to work in teams of two to four persons. There were six teams. We paired two teams to engage in collaborative scientific argumentation with the support of the game-based computer-assisted program in three separate class periods (sixth, seventh, and eighth). We met with the first pair of teams in a classroom and the other two pairs of teams in a study lounge. Each team set up one of the students' Chromebooks and logged into the program. When each team logged in, the program automatically assigned one team as Blue and the other as Green. The first author briefly explained the definition of collaborative scientific argumentation and the association between the scientific argumentation components and each icon in the program. The team intentionally provided minimal instructions to explore if students could navigate the program without any problems during the activity. We used the program to engage them in collaborative argumentation on the topic "Should a cell phone be banned in school?" for 20 minutes. We examined students' experiences by observing how they navigated the program. The sample tasks included: type your claim in your Claim box, click on the Evidence icon for your claim box, add a second piece of evidence, and give a counterargument to another team's claim.

We also conducted observations of the process using two professors and two research assistants. We video-recorded the interactions between each team and the program as well as how the team members collaborated. We positioned one video camcorder in the back of each team, and one monitored by each of the research assistants. The objective was to examine if each team was able to come up with one Evidence box, one Reasoning box, one Counterargument box, and one Rebuttal box. The first author ended the observation experience with each team and informed them that their team accomplished the objective.

We developed and followed a protocol for the observation, including the following items:

- Whether the students were able to associate the icons and scientific argumentation components
- Whether they used a touchscreen or touchpad
- Whether they were able to zoom in or zoom out to view all boxes
- How they edit their statements after seeing the other team's argumentation
- Whether they switched roles in the process

We conducted a focus group discussion after they completed the tasks. The focus group discussion took place while the program was still open.

The focus group questions included:

- How easy is it to move around the program?
- What do you wish this program could do?
- What game does this remind you of?
- Did it work well to use this program as a group?

In terms of navigating the program, the observation data showed that in all three class periods, all students in each team were able to find the Evidence, Reasoning, Counterargument, and Rebuttal icons and click on them. They also were able to add second Evidence, Reasoning, Counterargument, and Rebuttal boxes.

The students used different methods to navigate the program. In the sixth class period, Linda and Santiago on the Blue team mostly used the touchpad on their Chromebooks to zoom in to view the Evidence, Reasoning, Counterargument, and Rebuttal boxes and type text into each box. Meanwhile, they used the touchscreen to move to different sections of argumentation and to see both teams' argumentation. Santiago sometimes struggled using a touchscreen, so he went back to using the touchpad. Similarly, in the sixth class period, Daniel and Francisco on the Green team used the touchscreen or touchpad to zoom in to see all the boxes and used the touchscreen to move around the program. In the seventh class period, Christina, Michael, Diego, and Jaliyah – the Green team – adopted similar methods to navigate the program. However, in the same class period, Mikaela, Alondra, and Martin – the Blue team – used the touchpad to zoom in and out to see the argumentation. They never used a touchscreen. In the eighth class period, Brendon and Trenton, the Green team, mostly used the touchscreen to navigate the program. On the contrary, Samantha and Rafael – Blue team – mostly used the touchpad to navigate the program. Samantha only used the touchscreen to click on the Evidence icon and to click the arrow button on the top of the Counterargument box. This observation helped confirm our design decision that allows the program to support all modes of interaction on Chromebooks. We planned to implement the program in different school districts. Most school districts have adopted Chromebooks.

All teams were able to easily switch between multiple counterarguments. Initially, two teams clicked on the arrow button on the top of the Counterargument box. The Counterargument boxes did not change, so they were discouraged and thought it was not the correct button (Figure 5; see Hsu et al., 2022). However, after several trials and with the teachers' help, the students were able to find the correct arrow button to switch back and forward in the Counterarguments. The teachers had to guide them to click on the right spot so the Counterargument boxes would switch.

Additionally, we found that the cursor in each box was not always visible. Not all teams saw the cursor when they viewed the box. They did not know they could type, so they kept clicking on it. Then they eventually realized they could type. However, not all students figured out they could use the scrollbar to scroll up and down to see more text. In the eighth class period, Samantha figured out how to use the arrow and down buttons to see the text that disappeared on the top of the box. After they typed in lengthy texts, the texts seemed as if they disappeared because the texts were scrolled to the top and were not visible in the boxes.

In terms of how the program supports collaborative argumentation, the observation data indicated different dynamics of collaboration were supported by the multiplayer function of the game-based computer-assisted program. The program worked for a team that consisted of two to three students, but it became too crowded when there were more than three students on the team. All teams figured out their own way of collaborating. Three teams switched roles and three teams did not. Some had a designated typist/computer handler who was usually the owner of the Chromebook. For example, during the sixth class period, Linda and Santiago took turns typing on Santiago's Chromebook. Daniel and Francisco also took turns typing on Francisco's Chromebook. Trenton and Brendon took turns typing on Brendon's Chromebook. Initially, Francisco used his fingers to direct Daniel's attention to different sections of argumentation on the screen. After ten minutes, Daniel learned from him and began to use his fingers as well. They sat together and had the person in the middle type in the program. In the seventh class period, Alondra also used fingers to direct Mikaela's attention to the Counterargument box. Mikaela said, "It was good to use one Chromebook." Three teams passed their Chromebooks among their members to type in the program. Trenton and Brendon also liked the idea of sharing one Chromebook. Samantha and Rafael also commented that they preferred to share the Chromebook. A few students suggested that each member could open their own Chromebook and have two members observe while one person typed in their claim, evidence, reasoning, counterarguments, and rebuttals. They agreed that the program could create better collaboration because all members were able to see argumentation clearly on their own Chromebooks. Santiago said, "One of us could talk, one of us could observe the other team's response, and one of us could type. It is easier."

Everyone participated in the collaborative argumentation except for one student who was on the team which consisted of four people. She sat on the edge and could not really see the Chromebook screen.

Three teams deleted and rewrote an entire sentence after they reviewed the other team's statements. For the second Evidence box, if they did not have time to fill it in, sometimes they would go back and fill it in later. In the sixth class period, Linda and Santiago went back to complete the text in the Reasoning box while they waited for the other team to complete their counterargument. In the seventh class period, Mikaela, Alondra, and Martin went back to complete the second Evidence box. In the eighth class period, Rafael went back to complete the second Evidence box and the Counterargument box.

Among the 15 students, 12 said that it was easy to navigate the game-based computer-assisted program. In the seventh class period, Michael on the Green team said, "It was semi-easy." In the eighth class period, Trenton and Brendon shared that it took some time to learn how to navigate the program. Among the 15 students, 14 played games regularly such as shooting games, Roblox, Sandbox, or Minecraft. With prior experience in online games, they did not have any problem navigating this game-based computer-assisted program and interacting with other players in the same game.

The students commented that "it was more fun than sitting there" and handwriting scientific argumentation by themselves. In this game-based computer-assisted program with multiplayer function, they could talk to their friends who sat in the other corner of the classroom, a way of being a little bit more competitive to see whose argumentation was better. This observation showed that they were serious about the topic. They read the other team's statements very carefully and then came back to see how they could revise their statements. With this game-based computer-assisted program, they were excited about putting collaborative scientific argumentation into practice and enjoyed the learning experience a little more.

DESIGN REFLECTIONS

Based on the results of our trial runs, the design idea of the parent-child function and multiplayer function to support collaborative argumentation remained consistent since the beginning of the project. This design case shows how the knowledge and the experience of student team members shaped the design decisions. In the third iteration, the student programmers had the programming knowledge to bring both the parent-child function and the multiplayer function together. In the third and current iteration, we discovered a number of issues during the design process, which may offer insight to fine-tune the program. The issues included an invisible cursor and scrollbar. We also planned to add more game mechanics based on our observations. Because the teachers asked about ways to monitor students' progress, we planned to add a dashboard to show each team's progress. Additionally, the students had to zoom in and zoom out of both teams' argumentation to track the collaborative argumentation process, so we also plan to add a leaderboard that shows the current scores of both teams.

Throughout the design and development of the three iterations, we made many technical and process decisions. Table 1 summarizes some of the major decisions made during each phase. Each iteration has a crucial issue. In the first iteration, the critical issue was the lack of audit regarding the resources needed for the development of the prototype. The first author didn't have much experience in project management of software development and wasn't aware of the importance of audit of resources, including personnel's expertise and time commitment. She realized that the two check-ups of the team's progress in a semester weren't sufficient. For the second iteration, the problem was the sustainability of the technology choices. Flash-based Adobe Connect was no longer supported by the university. The

YEAR	PROCESS DECISIONS
2014	• Use web applications such as HTML5. • No project management in place.
2015	• Use a flashed-based program-Adobe Connect. • No project management in place.
2019	• Use the Unity and Photon. • Adopt Agile project management.

TABLE 1. Technical and Process Decisions in Three Iterations of the Prototype.

prototype itself was unable to save the activity for learners after restarting it. The first author was also aware that she had limited knowledge about software development. To address the issues in the first two iterations, the first author decided to collaborate with a faculty who has sufficient knowledge of software development and who has access to students with expertise in software development for the third iteration. When she formed the team for the third iteration, she was upfront with all team members, shared her failures from two iterations, and explained why she adopted agile project management. The team agreed that meeting every week and receiving timely feedback are essential in the process.

SUMMARY

This case details a ten-year (2014-present) iterative process to design and develop a graph-based computer-supported program to support middle school students' development of collaborative argumentation. The first author has learned several lessons from this design case. First, it takes several trials and errors to identify an appropriate platform to achieve the goal of the project. Learning from failure is a valuable experience and facilitates clarification of the project goal. Second, project management is critical to ensure the design and development can be on track. There was no project management in the early years of the project, which might have contributed to the failure of the first two iterations of the prototype. Agile project management is time-consuming; however, it is effective in facilitating the progress of a team that consists of faculty and students in different programs and colleges. After ten years, we are excited that we finally developed a prototype that can be implemented in the science classroom and continue to refine the program.

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