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Designing for equitable participation in collaborative game-based learning environments

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Abstract: With the growing popularity of game-based learning, researchers should take steps to ensure that our designed technology-enhanced environments reflect our desire to implement equitable learning environments for all our students. Does our implementation of technology to motivate and encourage learning, at times result in some of our students having less of an opportunity to engage in the learning activity? This study focuses on a STEM-based game-based learning environment designed to facilitate equitable participation of learners. Through the analysis of game interaction log files, we explore time series plots and determine patterns of student participation. We highlight our findings using a case-study approach in which we focus on the interaction of a middle-school group collaborative activity as they engage in solving a problem embedded in a game-based learning environment.

Introduction

Game-based learning environments provide a rich avenue to support collaborative inquiry learning and in turn, can provide key insights into designing and analyzing group processes and interactions (Mislevy et al., 2014; Rupp et al., 2010). Although empirical research has focused on how these learning environments can increase motivational, cognitive, and affective outcomes (Connolly et al., 2012), there has been less attention on how to intentionally design for equitable participation. Game-based learning environments are often viewed as highly engaging for students since they represent a means through which rich learning activities can be accomplished with sustained student participation. However, there remains a question of equitable participation within these learning environments, as they may inadvertently allow those more experienced with gaming a greater advantage, or it may be presented as more attractive to particular groups of students (Buffum et al., 2016). In our work, equitable participation refers to the provision of equal opportunities to participate in classroom activities (Rasooli et al. 2018). Several authors have espoused similar sentiments, advocating for more equitable forms of participation to better reflect the capabilities of our learners (Poehner, 2011). However, educators and researchers alike often grapple with the implementation of these considerations. This is evident in game design where aspects of equity and inclusion should be addressed.

This paper seeks to explore these issues by examining the following research question: *How can we design for equitable opportunities to participate in a collaborative game-based learning environment?* We draw on an activity theory framework to guide our design and analysis of ECOJOURNEYS, a collaborative game-based learning environment designed for middle school ecosystems learning. We highlight how activity theory can be used to design equitable tasks and mediators that act as active modifiers that aid in creating new actionable pathways to learning (Poehner, 2011). Active modifiers are tools which serve to actively enhance students' understanding. A brainstorming board with rules for participation (designed to require each group member's participation to vote) and in-game chat (collaborative discussion of tasks where students are free to participate at will), both serve as active modifiers in this study. Drawing on students' in-game interactions as captured in log files, we adopted a social learning analytics approach and explored time series plots to discern patterns in how groups of students interacted in the designed tasks. Using these plots, we used an instrumental case study approach (Stake, 2008) to the extent to which designed opportunities learning supported student participation.

Equitable participation and activity theory

Classroom activities that adopt sociocultural perspective should involve participatory tasks and authentic inquiry (Danish & Gresalfi, 2018). Additionally, classroom activities that attend to equitable practices should focus on dimensions such as procedural elements (i.e., practices that give rise to equitable outcomes) and interactional justice (Rasooli et al., 2018). However, the question remains, how do we design for equitable opportunities to participate in these collaborative game-based learning environments?

Our work centers on the concept of activity theory and assumes equity as access to mediators (Poehner, 2011). Collaborative inquiry learning is assumed to be a joint cooperative activity wherein instruction and learning co-occurs through mediational means i.e., the resources used to construct knowledge (Holzman, 2018). Additionally, these frameworks should include multiple levels of activities and participation building towards the formulation of an argument. Thus, we draw on activity theory as a theoretical framework to designing and analyzing equitable tasks. In activity theory, the object or the collective goal plays a vital role in mediating and organizing interactions (Engeström, 1987). In working towards a collective object, an individual's activity is artifact-mediated, or influenced by tools, the division of labor and rules associated with each community. These mediators are historically and culturally shaped and transform the way that individuals can perform tasks. In the design of ECOJOURNEYS, the object or designed goal was to support students' collaborative inquiry. In this form of inquiry, students are expected to share their thoughts, and reflect on other students' ideas (Liu et al., 2016). However, this can be problematic when students are unaware of the steps in the inquiry process (Quintana et al., 2004). In our work, mediators are meant to encourage actions that students may not otherwise engage in and we attended to three elements: 1) mediational tools, 2) division of labor, and 3) rules that guide the inquiry process. Below, we unpack the design of these mediators.

How mediators were embodied in the design

In ECOJOURNEYS, students participated in a cultural exchange program to learn about tilapia farming in the Philippines. There, the locals requested students to investigate why tilapia at the hatchery fell sick. Students worked in groups of four and engaged in two inquiry cycles that consisted of (1) collecting data from the in-game environment and talking to in-game stakeholders, and (2) sharing and negotiating their ideas with one another using a collaborative space (see Figure 1). The brainstorming board was an in-game collaborative space providing structure for students to share their observations and to reach a shared understanding about the problem they are facing (Saleh et al., 2019).

Mediational tools

As students explored the game-based learning environment, individual students collected information in the form of notes. After collecting these notes, students collaboratively used the brainstorming board to share notes. The board highlighted the components that tilapia fish need to survive (e.g., temperature, air, etc.). The main task was for students to move the notes onto the board and determine the extent to which the information in the note was relevant to the component. After moving the notes, students clicked on their peers' notes to evaluate the relevance of the note. A visual indicator denoted when students reached agreement on whether a note was relevant to the component in the system (i.e., green when all students agreed, red when one disagrees, orange for default, see Figure 1). Students also used an in-game chat to negotiate their ideas, especially if there was disagreement over where the notes should be placed. The brainstorming board thus actively modified how students could participate equitably in collaborative inquiry, by encouraging multiple opportunities for students to 1) share notes and engage with the information, 2) demonstrate their thinking about the relevance of the notes and negotiate with their peers.

Rules

We also designed several rules that supported the collaborative inquiry process. First, inquiry milestones consisted of individual data collection and collaborative sensemaking. Collaborative sensemaking at the board was triggered after all group members completed data collection. Second, all members were prompted to share their ideas during the process. This task was formalized as notes that students collected, but students were also encouraged to share information as they explored the environment. Third, the placement of the notes was also a crucial step in the process. By placing notes on the board, students demonstrated that the note was relevant to the component on the board. Fourth, students voted to indicate how the notes may or may not be relevant to the component. Finally, students were also required to come to a consensus on how the information should be sorted and whether they were ready to move on to the next phase of the inquiry. These rules supported equitable participation because each student was expected to engage in these actions in the collaborative game-based learning environment.

Division of labor

Each student had the role of sharing their individually collected notes and evaluating each other's ideas. This equal distribution of roles ensured that each student had explicit ways that they can contribute to collaborative inquiry. We also accounted for the role of the facilitator as part of the community. The facilitator supported the inquiry process by prompting for contributions in chat *and* to ensure that the tool-based interactions also occur. Facilitators provided support by marking information and questioning students, by asking for evidence and inviting participation. Additionally, facilitators and students engaged in socially shared regulation of learning, discussing norms for collaboration, deciding goals and planning actions related to solving the problem. These roles, however, were not explicitly designed interactions, but expected to emerge in collaborative discourse.

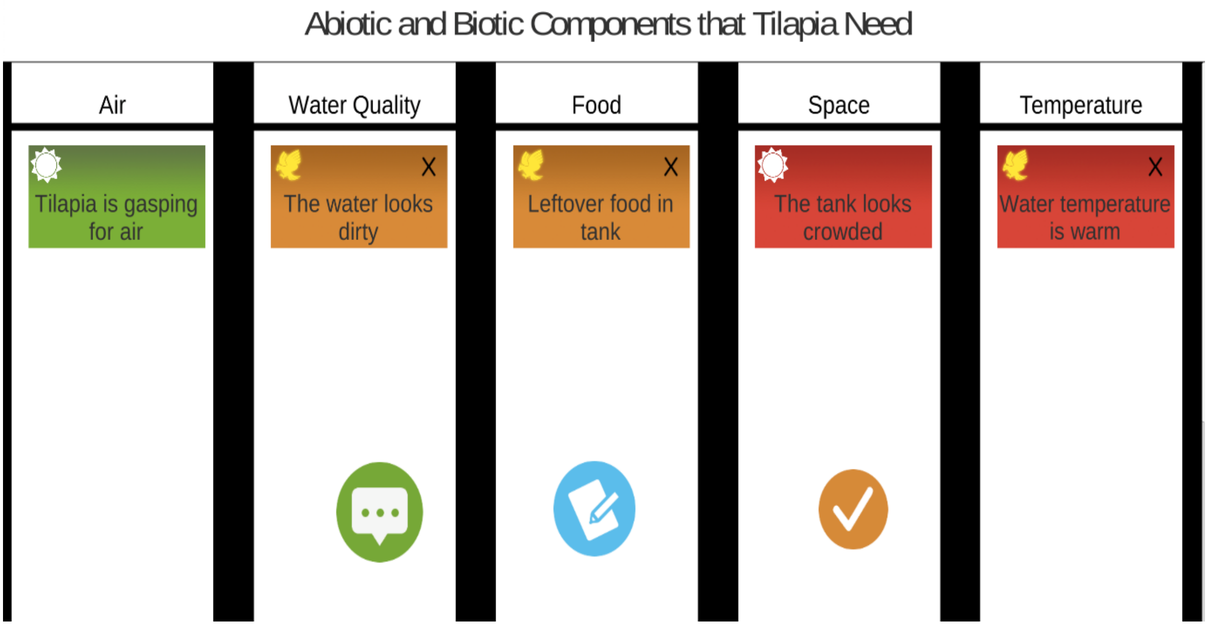

Figure 1. Overview of the brainstorming board

Methods

We drew on data from a classroom study with 29 students ranging from 11 to 13 years old (10 females, 19 males). Student demographics were as follows: 4 students identified as African/Americans, 4 as multi-racial, 2 as Asians/Pacific Islanders, 1 as Hispanic/Latinx, 1 as Native American/American Indian, and 17 as White. Students worked in groups of four and played ECOJOURNEYS in place of their science lesson. They participated in two sessions which were two-hours long. Students first took a survey where they shared demographic information and answered questions about familiarity with games. In the implementation, students engaged in two inquiry cycles of the game. Each group was assigned a facilitator who played the role of wizard or helper and supported group inquiry using the in-game chat. All students' in-game interactions were logged. In the last session, students were asked to draw a model explaining why the problem was occurring. Students also took a pre- and post-test that focused on their ecosystems understanding.

To understand the nature of participation, we examined the log files to focus on individual actions across time and in relation with other students. Individual in-game actions while using the board included 1) creating notes, 2) moving the notes, 3) voting on the notes, and 4) contribution to chat. These were used as indicators of equitable participation across students. To understand tool use, we aggregated group interactions at the board and chat, obtained frequency counts of individual game actions using the notes and examined the amount of time that students spent on reading notes, and quality of contributions to the in-game chat. To understand the division of labor among students and (in)equitable interactions among the different groups (i.e., rules), we generated time series plots. The time series plots feature the proportion of interactions contributed by each student over 50 events (i.e., 1 unit of X is 50 events). If student A contributed 20 of the last 50 interactions, their contribution value for that event index would be 40% (i.e., Y axis). We created two plots for each group: a plot of chat contributions, and a plot of board contributions. We qualitatively inspected these plots and engaged in qualitative case study analysis to further examine these patterns (Stake, 2008). Additionally, we also reviewed student chat utterances to determine which were off- or on-task. On-task utterances referred to instances when students discussed topics related to the science content or game-based learning environment whereas off task utterances were categorized based on whether students were socializing and discussing topics other than science or tasks related to the game-based learning environment.

Results

Paired t-test comparing the pre-test (M = 27, SD = 3.6) and post-test (M = 28.4, SD = 3.7) scores demonstrated that there were significant learning gains, $t(26) = 2.13$, p =.04. To understand how the design of the learning environment supported equitable participation, we present an overview of student interaction with our designed tools. We highlight how students use the notes at the brainstorming board and the chat tool, and then present the distribution of students' participation across the brainstorming board and chat activities (i.e., division of labor). Finally, the average frequency counts of student actions with creating, moving, and voting on the notes indicate whether the designed rules for interactions supported equitable student actions at the board. Table 1 provides summary statistics for each group's interactions at the brainstorming board, and contributions to chat.

Table 1; Summary statistics for each group.

Group	Total board actions	Total mins on notes	No. of created notes	No. of moved notes	Total count of votes	Student chat contributions
1	385	53	28	93	264	896
2	509	68	46	133	330	665
3	276	49	27	56	193	457
4	358	67	33	85	240	514
5	335	66	23	73	239	473
6	238	26	24	55	159	277
7	155	57	19	31	105	482
Mean	322	55	29	75	219	538
SD	113.6	14.8	8.85	32.9	73.6	194.5

How does tool use differ across the groups?

In terms of students' activities at the brainstorming board, summary statistics indicate that groups had an average of 322 actions at the brainstorming board, with group 2 recording the highest contributions, and group 7 the lowest. Group 2 similarly spent the highest amount of time on the notes. In terms of chat use, groups contributed an average of 538 lines, with group 1 recording the highest contributions to chat, and group 6 with the lowest. As we will demonstrate in our analysis later, the multiple ways of interacting with the designed tools indicate that there may be more opportunities to participate, thereby supporting equitable participation among students.

How did the designed rules influence student interactions at the board?

To better understand how the students participated in their groups, we inspected the time series plots for all groups as they interacted at the board and used the in-game chat. Because of space constraints and to ground our findings, we showcase the results from one team to provide a rich description of the findings. Group 2 was selected for this case study because (a) students' pattern of board use was relatively similar and had the highest amount of board interactions but (b) were diverse in terms of chat use, demographic data, and video game experience (see Table 3). The students in the group also scored in the lower range in their pre-test (see Table 1). The contrasting profiles in how the students in the group engaged in commercial video games and in the game-based learning environment was also another reason why the group was selected. Moreover, the students' interactions in the brainstorming and chat activities provided a rich illustration of how different students participated and how the mediators did or did not affect students' actions.

Table 2: Demographic data of Group 2 members

Name (Pseudo nyms)	Age	Gender	Race	Weekly hours gaming	Time spent on in-game notes (mins)	Chat	Pre-test score	Post-test score
Jacob	11	Male	White	10-20	9.6	17%	21	29
Olivia	11	Female	White	3-5	20.5	3%	26	26
Ethan	11	Male	White	5-10	3.2	65%	28	30
Rakesha	12	Female	African-American / Black	0-2	27.0	17%	25	30

Figure 2 illustrates the pattern of interactions at the brainstorming board among students in Group 2. The blue vertical line indicates the initial use of the board, whereas the yellow vertical line represents the end of the first brainstorming session. Each participant is represented by a different color horizontal line within the plot. The activities captured by use of the board include creating or placing a note on the board, moving a note from the board, voting on the relevance of the notes to the associated components (e.g., air, temperature, food, water quality etc. (see Figure. 1)) and voting on whether the irrelevant component should be removed as a possible explanation for the tilapia being sick.

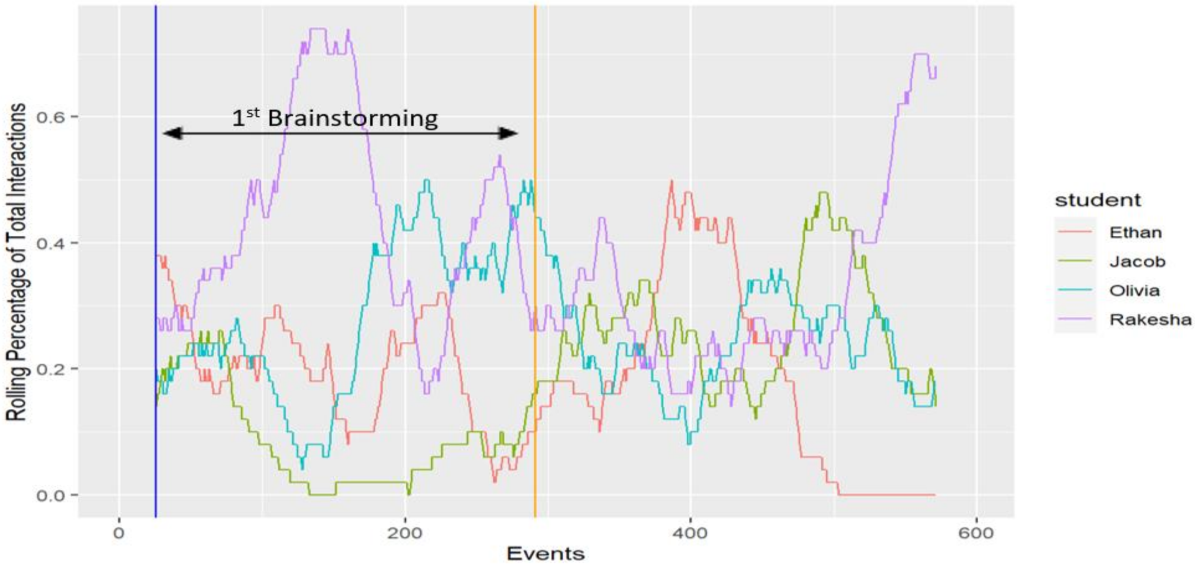

Figure 2. Group 2's use of the brainstorming board

In the first brainstorming session (i.e., after the blue line to about 250 events), Rakesha (pink line) appears to be the most active on the board. However, during the second session all students display approximately the same level of participation. This plot is representative of all groups' use of the board, there may be a few students who are more active in the first session. However, there is relatively similar board use in the second session across all groups. The difference observed between the two sessions is likely because all students collected the same five notes during their first exploration and students like Rakesha, who were quick to place items on the board tended to be more active. Moreover, once these notes are placed on the board, only the owner, in this case, Rakesha, will be able to move the notes. In Figure 2, student interactions during the second brainstorming session were relatively similar, apart from Ethan (in red). However, despite his late start, Ethan's actions mirror those of his peers (i.e., between 300-400 events) in their earlier interactions with the board (i.e., increase of actions before trending down). Although Ethan's actions reduce after the 400-event mark before logging out, the rest of his peers continue to engage with the board, repeating the pattern of upward and downward trend. The pattern of increased and decreased activity at the brainstorming board is likely triggered by the design features that are logged as these events, 1) creating the notes on the board, 2) the number of votes recorded, 3) placement of the notes, 4) consensus or lack of among the group, and 5) topics of discussion in the chat. Although we highlighted group 2's plot, plots for all groups depicted comparable patterns and symmetry across individual student's interactions at the board.

How was labor distributed among students across the chat and board activities?

These findings, however, are a contrast to the use of the chat feature of the game. Figure 3 represents student frequency and use of the chat feature with ECOJOURNEYS. Just as Figure 2, the blue and yellow vertical lines indicate the initial and subsequent use of the board. Based on the observed patterns in Figure 3, student participation in group 2 varied in frequency for both sessions of playing ECOJOURNEYS. Ethan appeared to be the most active in the chat for both whiteboard sessions. In both instances, Ethan, a self-identified white male who describes himself as a frequent video gamer, participates in the chat the most. In contrast, the student that contributes the least to chat is Olivia, a self-identified white female who plays video games occasionally. Comparatively, Rakesha, an African American female, who rarely plays video games and Jacob, another male student, had somewhat moderate and similar contributions to chat. Notably, both Rakesha and Jacob had the highest gains in their pre-post test scores (5- and 8-point gains), whereas Olivia maintained her score, and Ethan scored 2 points higher in the post-test.

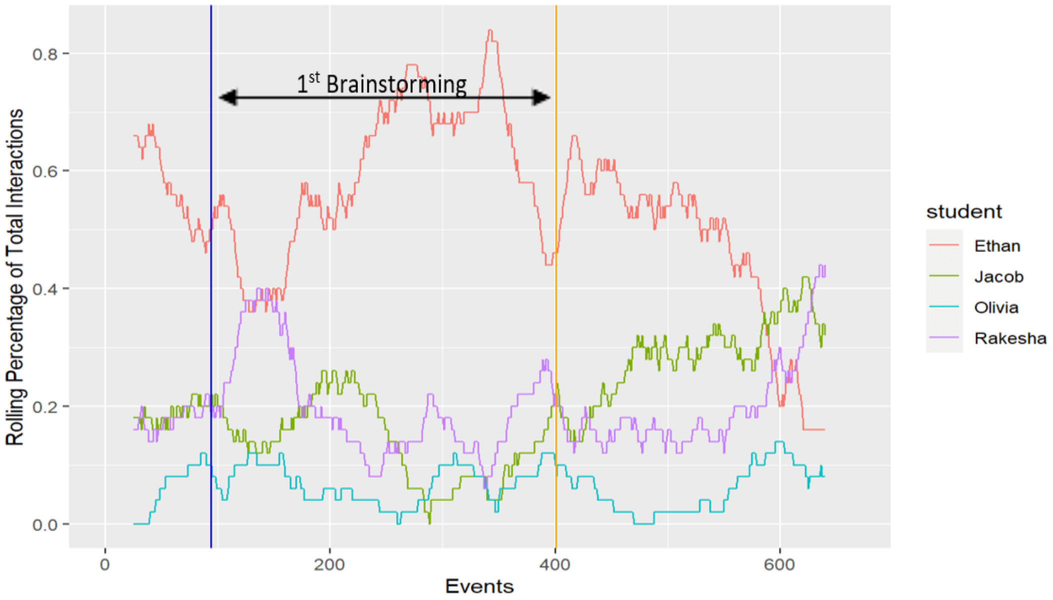

Figure 3. Group 2's contribution to chat when using the brainstorming board

Students' chat statistics also mirror the students' participation across time, corroborating students' quantitative contributions. However, when analyzing students' contributions, Ethan's utterances were on task 73% (i.e., content and game-oriented talk) and 27% off-task of the times, whereas Olivia and Rakesha were on task for all their contributions. Jacob's contribution on the other hand, was approximately distributed equally between on-task and off-task utterances. To illustrate students' conversations, consider their contributions to talk in excerpt 1 below.

Table 3: Group 2's in-game discussion in chat about water quality

	Time	User	In-game chat
1	12:56:44.8	Jacob	so water quality is pretty good i think
2	12:56:59.7	Jacob	i dont really think theres any problems
3	12:57:05.1	Ethan	dude,
4	12:57:06.9	Ethan	last time
5	12:57:08.1	Ethan	remember
6	12:57:14.4	Ethan	theres to much of whatever its called
7	12:57:18.2	Olivia	it said the water looked cloudy
8	12:57:18.2	Ethan	and its making the water
9	12:57:21.9	Ethan	yea
10	12:57:24.0	Ethan	what olivia said
11	12:57:34.0	Facilitator	Okay, water is cloudy
12	12:57:34.8	Rakesha	cynabacteri
13	12:57:43.1	Facilitator	What makes water cloudy?
14	12:57:52.7	Ethan	to much cynabacteri
15	12:57:52.9	Rakesha	cynabacteria
16	12:58:23.4	Facilitator	what is cyanobacteria?
17	12:58:37.8	Ethan	its a thing thats good for tiapia
18	12:58:40.5	Ethan	but to much of it
19	12:58:44.0	Ethan	polutes the water
20	12:58:50.4	Jacob	yea that
21	12:59:03.7	Jacob	water gets sick fish get sick sick fish die

Jacob begins by positing that there was no problem with water quality but was countered by Ethan and Olivia (lines 3-10). Although Olivia's contribution is succinct, she gets her point across, and Ethan agrees with her assertion (line 8). Rakesha then extends this by noting that cyanobacteria are the cause of the cloudiness (lines 12 and 15). Ethan and Jacob were then able to build on these contributions to explain how the cyanobacteria can affect the fish (lines 17-21). This excerpt highlights that despite her lower contributions to chat, Olivia provides critical information for her peers. Closer inspection of Olivia's participation at the brainstorming board moreover indicated that she spent approximately 20 minutes reviewing the notes, compared to Ethan, who spent about 3 minutes on the notes (see Table 2). This additional data along with the board participation (Figure 2), suggests that the chat data only provides one aspect of engagement. In designing ECOJOURNEYS, we intentionally created numerous ways in which students would be able to participate within their groups to help build an argument and effectively solve the problem at hand. Equitable participation was encouraged through the design and implementation of these variable pathways for participation in the learning environment. This allowed individuals equal opportunities to share and showcase their knowledge through diverse means. To help us gain a better idea of student understanding of the system, consider the students' representations of what may be causing the tilapia illness. Figures 4 and 5 below illustrate the models drawn by Olivia, and Ethan, respectively.

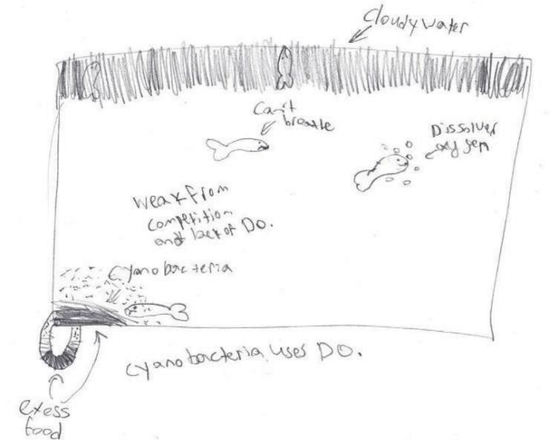

Figure 4. Olivia's model

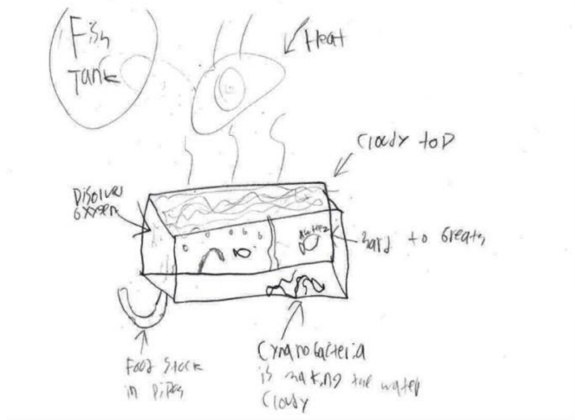

Figure 5. Ethan's model

Olivia's model (Figure 4) depicts several key facts of the system. It highlights the use of dissolved oxygen by both cyanobacteria and fish, which results in fish being weak (or ill) due to competition of resources (lack of dissolved oxygen), and presumably how the fish waste and food adds to the build-up of material in the water. Ethan's model (Figure 5) on the other hand, depicts components (heat, cloudy water, dissolved oxygen, food and cyanobacteria), but no indication of relationships among the components other than that the cyanobacteria make the water cloudy. Based on their patterns of participation, it is likely that the designed tools such as the brainstorming board facilitated student interactions with the learning material in their own ways. For example, it is likely that Olivia represented her knowledge of the system based on her use of the in-game notes, whereas Ethan may have benefitted more from his in-game interactions with his peers. In this way, the design considerations of this game may have encouraged and supported different forms participation among group members. It is clear from the data obtained from this study that low participation in chat features of ECOJOURNEYS, is not indicative of student engagement in learning activities and that equitable participation can be achieved through various means within game-based learning.

Discussion and implications

In designing this collaborative videogame, we focused on design features which would help promote equitable participation in each group. Although we have adopted a narrow definition of equitable participation, it is a crucial initial step in designing various activities through which students could engage in multiple pathways toward problem solving and work collaboratively with peers. From the structured design of the board, to the free use of the chat, to provisions of content material within the game, we designed with various student preferences and comfort levels of gaming in mind. Working collaboratively, allows students to bring their strengths, weaknesses, knowledge, and misconceptions to problem-based learning, so that together group members can build a strong argument and solve the problem at hand. However, if students are not afforded the opportunity to be encouraged and to feel comfortable enough to participate, then equitable student participation within collaborative game-based learning would be difficult to achieve.

With the popularity of game-based learning, designers and researchers need to attend to equity and inclusion. We should design learning spaces for all students, in which they are encouraged to participate through various forms of collaborative activity. Equitable participation should be at the forefront of collaborative game-based learning design as we seek to design for all learners. The diverse features of the game-based learning environment and the rules employed to foster equitable participation amongst group members, facilitated a learning environment in which all students were able to engage in the collaborative activities. Because some students may not use chat, we needed to design an alternative pathway for these students to express their understanding and contribute to the group. Working from the socio-cultural perspective, we need to consider backgrounds and preferences of learners when designing, which includes the development of multiple activities for participants. Learning activities and design features must engage students as we seek to make their learning and skills visible and valued to encourage equitable participation for all learners.

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