

Collective Immersive Simulations: A New Approach to Learning and Instruction of Complex Biology Topics

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Abstract: This paper presents the design of an immersive simulation and collective inquiry activity for exploring evolutionary concepts in a Grade 11 Biology course. Researchers and a high school science teacher co-designed a curriculum around a room-sized simulation of a rainforest. Using several large displays stitched together on each wall of the room, we created an immersive rainforest environment in which students worked collaboratively as “field researchers” to observe changes in life forms over two hundred million years and gathered evidence of evolution. The complex sequence of student interactions within the EvoRoom environment, as well as all materials, including large immersive displays, aggregated visualizations, and tablet applications were carefully designed as short inquiry activities that complemented the broader curriculum. This paper presents our designs over two iterations in terms of several key features that enhanced students’ collective immersive experience and learning of evolutionary biology.

Introduction

Educators and researchers have long struggled to help students achieve deep understanding of complex science concepts, and to help students refine reasoning and communication skills, such as critical thinking and collaboration (NSF Taskforce for Cyberlearning, 2008). In high school biology, concepts of evolution and biodiversity are notoriously challenging, due in part to their complex systemic nature (Slotta & Chi, 2006), their multidisciplinary nature (e.g., genetics, biogeography, paleontology), as well as students’ incoming ideas, which are often inconsistent with the scientific theory (Demastes, Good, & Peebles, 1995; Mayr, 2001).

Inquiry-based learning has been advanced as an instructional approach where students are encouraged to develop deep understandings and scientific reasoning, by emphasizing the posing of questions, collection and analysis of data, and construction of evidence-based arguments. Inquiry-based learning has shown promise for teaching evolution, as exemplified by projects like the Biology Guided Inquiry Learning Environment (BGuILE; Reiser et al., 2001) and GenScope™ (Horwitz et al., 1998).

In recent years, researchers have begun to reconsider the role of the physical learning environment and to experiment with augmenting learning activities in digitally augmented physical spaces (i.e., mixed-reality environments). These spaces offer new ways of engaging groups of co-located students with abstract science concepts that have traditionally been taught or addressed through more didactic forms of instruction (Price & Rogers, 2004). Moreover, such physical learning spaces, when used in combination with inquiry-based learning activities, have shown positive outcomes in facilitating creativity and reflection (e.g., Facer et al., 2004; Rogers & Muller, 2006) – offering a more hands-on approach compared to traditional inquiry-based learning where students typically work autonomously as individuals or pairs on single machines (Slotta & Linn, 2009).

Collective Inquiry and Smart Classrooms

The present study seeks to leverage technology-enhanced learning environments in support of more complex and participatory forms of scientific inquiry that engages co-located students in an investigation about evolution. Our goal is to create a comprehensive curriculum that embodies a pedagogical perspective known as Knowledge Community and Inquiry (KCI), where students are supported to work as a collective scientific body, creating a knowledge base and using it as a resource for subsequent inquiry (Slotta & Najafi, 2012).

Transforming classrooms into “knowledge communities” can engage students in more authentic scientific inquiry (Brown & Campione, 1990), for example with small groups of students working together like research teams within a broader scholarly community to jointly negotiate issues of a shared problem. By generating and building upon each other’s ideas, students take greater responsibility for ultimately fostering their own understanding. In previous KCI studies, wikis were used to support knowledge communities, with findings showing positive correlation between students’ contributions to collaborative inquiry and their achievements in the curriculum (Peters & Slotta, 2010). However, much like traditional inquiry-based learning, communications tended to be asynchronous and distributed, with students mostly working on their personal computers. To this end, we seek to engage students in collective inquiry as a knowledge community about evolutionary biology within a “smart classroom” environment, where the physical environment is intertwined with a set of digital tools and materials to scaffold seamless and dynamic collaboration and real-time face-to-face interactions while capturing the collective wisdom of the entire class (Slotta, 2010).

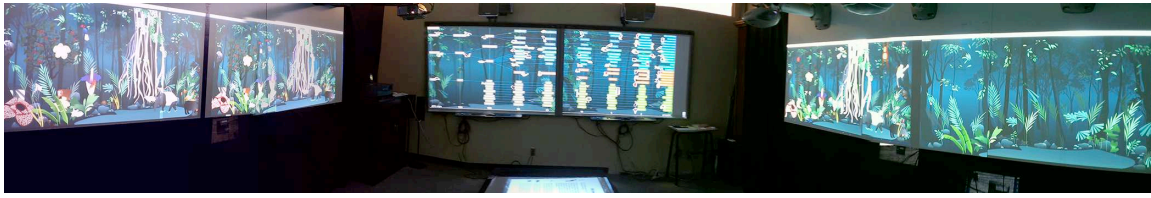


Figure 1. EvoRoom, an immersive simulation for teaching biodiversity and evolution, which consists six projected displays (three on each side) and two interactive whiteboards (middle).

Immersive Simulations

Inspired by the research tradition in immersive virtual worlds, such as River City (Dede, 2009) and Second Life, we are investigating a possible new educative role for immersive simulations, where the smart classroom is converted into a rich simulation, and conceptual content is embedded in ubiquitous technology to support co-located students in learning as a community (Figure 1). The immersive, room-sized environment is responsive to student observations (recorded via tablet devices), with real-time emergent visualizations that serve to capture and aggregate student observations for purposes of knowledge building and discourse. Our research is concerned with designing inquiry activities that complement and help to define such immersive environments, where students are engaged as a whole class, jointly negotiating problems and working towards a common goal. In this novel form of inquiry-based learning, called collective inquiry, students are encouraged to think deeply about materials and develop their own understandings, but with an emphasis on collective knowledge or progress over individual understandings (Peters & Slotta, 2010; Slotta, 2010).

Background & Related Work

Participatory Learning and Physical Digital Spaces

Wilensky and Resnick (1999) pioneered the use of embedded, ubiquitous computational media to support science learning, including the use of role-playing activities and non-desktop technologies. This is illustrated by the concept of participatory simulations, in which students themselves serve as the elements of a simulation (Colella, 2000). For example, Colella (2000) transformed students into potential virus carriers through wearable computers, with the mission of greeting as many peers as they could without becoming “sick”. Inspired by participatory simulations, another approach called Embedded Phenomena (EP; Moher, 2006) features a persistent scientific simulation that is “embedded” into the walls or floor. Students are tasked with discovering, monitoring and manipulating the state of the simulation and gathering evidence in the course of their inquiry about the phenomenon. Other examples of digitally augmented physical learning spaces include SMALLab, a room with digitally enhanced walls, floors and interactive technologies that supports new forms of student inquiry. For example, high school students studied geologic evolution by collaboratively constructing and monitoring the Earth’s crust, identifying uplift and erosion over time (Birchfield & Megowan-Romanowicz, 2009). Using various input devices (e.g., glowballs, Wii remotes, wireless game pads) and a projected interface on the ground, groups of students were responsible for building, maintaining or evaluating a cycle of the geologic clock. The intervention resulted in significant achievement gains, demonstrating the promise for further research regarding face-to-face interactions in a computationally augmented physical space, and distributed roles through a generative process that unfolds over time.

Our research is motivated by these projects, extending the role of immersive participatory simulations into a more coherent pedagogical framework, where students are engaged in scientific inquiry as a knowledge community (i.e., collective inquiry), and their experience within the simulation is carefully scripted within a broader curricular design. We designed an immersive simulation for teaching biodiversity and evolution topics in high-school biology courses to understand the following research questions:

- RQ1: How can an immersive simulation be designed to support students in understanding evolutionary biology?
 - 1a: How should an immersive simulation be designed within a broader set of curriculum activities?
 - 1b: What forms of activities and materials support student engagement with immersive media and drive reflection about evolutionary biology?
- RQ2: How can a collective experience within an immersive environment serve to advance a collective epistemology where students come to see their learning as a community effort?
 - 2a: How do we encourage students to respond meaningfully to ideas of their peers, in real-time?
 - 2b: How do we represent community progress and structure its advancement, such that students must engage productively with the aggregated products of their peers’ inquiry?

Method

Following a design-based methodology (Brown, 1992; Design-Based Research Collective, 2003), the immersive simulation was designed and evaluated over two iterations as part of a Grade 11 Biology course. Prior to the first classroom enactment, our team of researchers, technology developers, and a high school teacher met regularly for approximately one year to co-design the curriculum activities and the immersive simulation itself. A pilot study prior to the first enactment was conducted to evaluate the immersive environment, including the accessibility of our materials and the relevance of activities to the topic of evolution (Lui & Slotta, 2013).

Participants included students from class sections of Grade 11 Biology taught by our co-design teacher. The first iteration included two sections totaling 45 students aged 14-16. The second trial occurred in the following academic year and included two sections totaling 54 students (aged 14-16). In both trials, a pre- and post-test was administered, and all student observations and notes were collected for analysis. As well, video and audio recordings served to capture patterns of interaction within the EvoRoom environment.

EvoRoom

EvoRoom is an immersive simulation of the rainforest ecosystem of Borneo and Sumatra. Implemented within a “smart classroom” research environment, the room is equipped with computers, servers, projection displays, and customized software to coordinate the flow of participants and content materials, as well as to collect data during the activity. During the collective inquiry activities, students take on the role of “field researchers,” working in various group configurations to complete tasks delivered to them on their personal tablet computers. The tablets help to place students in small groups, scaffold their activities, collect observations, and give real-time updates and resources. Student observations and reflections are aggregated and displayed on the interactive whiteboards in real-time.

The collective inquiry activities within the smart classroom were co-designed with the teacher to fit seamlessly within a broader high school biology curriculum, in topics of evolution and biodiversity. Running for approximately 10 to 12-weeks, the integrated curriculum includes in-class activities, homework, a field trip to the zoo, as well as two collective inquiry activities with immersive simulations. One of the collective inquiry activities focuses on the topic of evolution. Students work individually, in small groups, and as a whole-class to gather evidence of evolution by observing changes in life forms within the simulation as it is advanced (by the teacher) across two hundred million years. The second collective inquiry activity focuses on the topic of biodiversity. Prior to the activity, students are to make predictions about how certain environmental factors or changes (e.g., tsunami, earthquake, low rainfall) that occurred within a single season could change the biodiversity over a five-year time span. In the immersive environment, students are presented with four different versions (“scenarios”) of the rainforest ecosystem, challenging them to explore the differences between these four rainforests and to locate the scenario that resulted from the variable or factor they explored in their earlier predictions. The present paper focuses on the first EvoRoom activity, on topics of evolution, including the relevant in-class and homework assignments associated with the immersive experience.

Iteration 1: Design and Enactment

At the beginning of the unit, students were assigned to one of four specialist categories (plants & insects, birds, primates, and other mammals), which they held for the duration of the full curriculum. Students were provided with a field guide of a set of species that would appear in the rainforest ecosystem of our immersive simulation. As their pre-activity homework, students wrote a blog post about how their species were related to one another.

Students visited the EvoRoom in groups of between 10-12 students at a time. Within the EvoRoom, these students were split into four groups. Each student was provided a tablet computer for the duration of the activity with a custom designed application that navigated the students through the activity as well as scaffolded students to work together and in collecting data throughout the session. Students visited the smart classroom over two days (for approximately 45 minutes each time). For the first session, students examined the Borneo rainforest as it may have appeared at nine different time periods (i.e., 200, 150, 100, 50, 25, 10, 5, 2 million years ago, and present day). Students were asked to go to each station (from 200 to 2 million years ago) and look for their assigned specialty species as part of a larger team consisting of different specialists. If the species were not present, they were asked to identify their predecessors from a short list that popped up. Their answers were recorded, resulting in the emergence of an aggregated, interactive cladogram (a diagram showing relatedness among species) on the interactive white boards at the front of the room.

In the second session, students entered the rainforest with its “state” set to two million years ago, which approximated Sundaland, a region in Southeast Asia predating Borneo and Sumatra. At this point the teacher used a teacher control tablet to “accelerate time” and showed the resulting geologic events in the Sundaland landscape. Over the span of two million years, sea level changes broke Sundaland’s central landmass into a peninsula and several islands, which included Borneo and Sumatra. Setting the room’s timeline to present day, one side of the room now showed Borneo’s ecosystem, while the other side showed Sumatra’s flora and fauna.

Students noted the presence of their assigned species in this new context and in the final step, the students came together in their teams to collectively document evidence of evolutionary differences they "observed" between Borneo and Sumatra (i.e., resulting from their separated state). Students were encouraged to discuss their ideas with others and to post ideas about evolution processes that might have occurred. Their notes were aggregated to the interactive whiteboard, which visibly represented the collective knowledge base of the students at the end of the activity. The teacher was able to use the content of this display, which allowed interactive filtering of the notes by evolutionary concepts and species, to lead a synthesizing discussion.

Iteration 1: Outcomes

Pre/Post-test

The Concept Inventory of Natural Selection (CINS; Anderson, Fisher, & Norman, 2002) was used as a source of the conceptual elements on the pre-/post-assessments. A paired-samples t-test was conducted on the pre- and post-CINS questions to evaluate whether the curriculum supported students in understanding evolution concepts. 33 of 45 students completed both tests. The mean post-test score ($M=78.94$, $SD=15.95$) was significantly greater than the mean pre-test score, for CINS items ($M=56.34$, $SD=17.16$), $t(32) = 7.14$, $p < 0.001$. Because these items have been developed and validated by assessment researchers as a measure of the evolutionary processes concerned with natural selection, we are satisfied that this overall curriculum engaged students and helped them to learn within this notoriously challenging domain.

Curriculum and Activity Artifacts

To understand how students engaged with various components of EvoRoom we tracked their participation and completion throughout the curriculum. 60% of the students wrote a blog post about how their assigned specialist species were related to one another as their pre-activity homework, while 31% completed their post-activity homework. As a benchmark comparison, 69% of students completed a similar assignment as part of the evolution unit (but not related to EvoRoom) that was graded by the teacher for completion. As part of our analysis of student performance during the collective inquiry activity, we examined how well students did when asked: *Which of the following is most likely [their assigned] organism's ancestor?* Of 1112 answers collected by the student tablets, 78% were correct, with an upward trend of accuracy compared to time period (Figure 2). Since the evolutionary lineages of most organisms present become less ambiguous as the time periods reach closer to present-day, we feel that the students' observation accuracy indicates that students were indeed paying attention to the task at hand and engaging with the media appropriately.

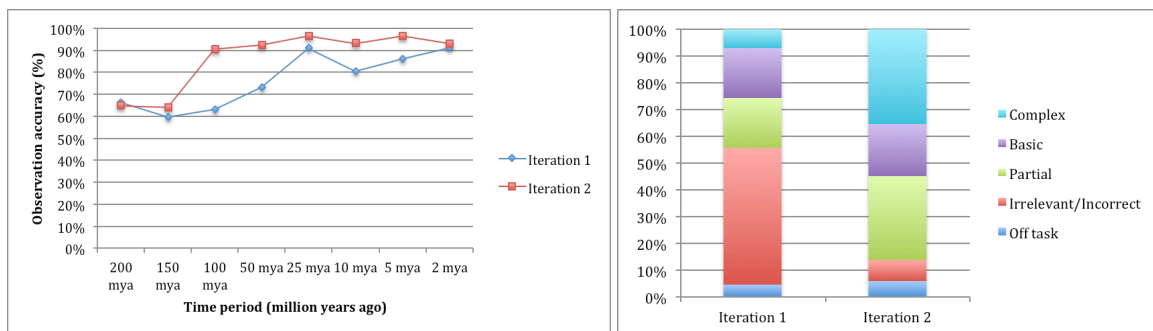


Figure 2. Observation accuracy by time period. Figure 3. Distribution of evolution explanations' KI scores.

At the end of the activity, students were asked to contribute to the following question: *What evolutionary forces do you think were at play (in this environment)?* Students chose concepts from a predefined list and explained their answers with evidence of their thinking. 43 explanations were collected from the first study which were scored using a 0-5 Knowledge Integration (KI) scale that rewards valid scientific connections between concepts (Linn & Eylon, 2011). The average KI score was 2.7 ($SD=1.05$) with an average of 33.3 words per explanation ($SD=33.28$). The distribution of the scores indicates that a large proportion of the notes were scored as Irrelevant/Incorrect (Figure 3).

Design Iteration

Outcomes from our first iteration of the EvoRoom design showed that students significantly improved their understanding about evolution (based on their pre-/post-test results). While the effects cannot be attributed to our EvoRoom alone, these results demonstrated a positive conceptual change when students learned about evolution in a curriculum that included EvoRoom. To further understand how EvoRoom itself impacted

students' ideas about evolution, we needed to revise the pre- and post-test assessment to include deeper conceptual questions targeted to the pedagogical goals of the activities.

In terms of the curriculum activities that preceded students' experience in the immersive environment, we wanted to improve completion rates but did not want to include a competitive mentality such as that evoked by teacher-graded assessments. We sought to encourage a sense of student ownership in the project. Instead of asking students to *review* a field guide, we asked students to collectively *create* the field guide they would be using in subsequent activities. In addition, we wanted students to feel that they had actually had a hand in the design of the immersive environment. Therefore, we revised the curriculum activities that included students researching the Borneo rainforest environment through two hundred million years.

During their collective inquiry activities, students showed considerable focus in their interactions with the materials, but we realized that students had spent more time as individuals in the immersive environment (working towards a collective goal) rather than engaging in the collaboration and deep reflective practices that we had envisioned for our co-located immersive inquiry environment. For example, in the portion of the activity that asked students to locate their assigned organism's evolutionary predecessors, their efforts were displayed in a cladogram that all students in the room effectively created together, but the designed interactions tended to be focused on individual students observing the rainforest "walls" and reviewing materials on their tablet, and then recording their answers. For the second iteration, we sought to improve student-to-student interactions within the immersive environment and while encouraging them to collaborate on more reflective activities.



Figure 4. Cladogram created from observations in iteration 2.

Iteration 2: Design and Enactment

The second iteration of the EvoRoom curriculum began with a short lecture delivered by the researchers about the changing nature of science discussing the merits of large scale collaborations (using the Human Genome Project as an example) and were introduced to ideas about themselves working in a knowledge community. Student were again assigned to one of four specialist categories (plants & insects, birds, primates, and other mammals), but was asked to work with other students (across two class sections of Grade 11 Biology) to complete a field guide on a wiki page on their class website. Each student was assigned specific species and categories (e.g., habitat, life cycle, physiology) that they would research. Students were also told that they would collectively create an immersive environment that they would experience together by researching their assigned species' role in the Borneo rainforest over two hundred million years. The premise of the collective inquiry activity, and its organization were similar to that of the first iteration, with a few important changes:

- Two 45-minute sessions were consolidated into one 75-minute session
- When students were asked to identify their assigned species' evolutionary predecessor at stations that displayed the rainforest at different time periods, a student guide (acting like a docent at a museum) was present to help with the task.
- Teams of different species specialists actively compared adjacent time periods (e.g., 200 vs. 150 million years ago) with reflective question prompts. Additional information about the time periods augmenting the rainforest "walls" were provided to students.
- The final step where students discussed and posted ideas about evolutionary processes was further structured to ask students to think about specific species as well as to include artifacts as their evidence. There was also explicit instruction to review the collective cladogram (Figure 4) as part of their reflective process.

During the second iteration, two of four sessions used paper handouts instead of tablet computers due to technology issues, and one session was prevented from receiving the intervention at all.

Iteration 2: Outcomes

Pre/Post-test

For iteration 2's assessment, we asked students the following questions:

1. What is evolution? How do you think it works?
2. How might evolution shape a species of red fox after 500 generations (approximately 1000 years)?
Elaborate on the ideas from your previous answer. Feel free to speculate on the conditions surrounding their evolution.

The items were scored using a KI scale, designed to reveal deep conceptual understanding of evolution, which found that the mean post-test score ($M=3.40$, $SD=0.92$) was significantly greater than the mean pre-test score ($M=2.58$, $SD=0.75$), $t(24) = 3.91$, $p < 0.002$. An inter-rater reliability was performed on 17% of data, where 75% agreement ($Kappa = 0.49$, $p < 0.005$) was achieved at first pass. Once discrepancies were resolved 100% agreement was reached and the rubric revised to account for the differences.

Curriculum and Activity Artifacts

Prior to their participation in the collective inquiry activity, we found that of the 490 sections in the field guide, 84% were complete, however the wiki page documenting the rainforest at various time periods was only slightly more than half complete (58%). For the session that used tablet computers, we were able to examine how well students performed with the help of a guide when asked: *Which of the following is most likely your organism's ancestor?* Of 335 answers collected by the tablets, 84% were accurate. Similar to our results in iteration 1, there was an upward trend of accuracy compared to time period. However in iteration 2, over 90% accuracy was reached by "100 million years ago" whereas in iteration 1, over 90% accuracy was only reached at two time periods (25 and 2 million years ago; Figure 2). We also examined how student groups made comparisons between time periods, which included the following prompt: "As a team, you will compare the environment between 200 & 150 million years ago."

1. Discuss the following with your group members and record your answers below.
2. What are the major differences between the two time periods?
3. What species appeared in this time period that wasn't there before? Consider climate, habitat, animals, and plants.
4. What evolutionary processes might have occurred during this time period? How were these processes related to the climate, habitats or other species at the time?

In the sessions that were given paper handouts, only 67% of the comparisons were complete. While in the sessions utilizing tablets, all of the assigned comparisons were made. Student responses were scored using a KI scale, which found the mean KI score in the tablet sessions ($M=3.33$, $SD=0.60$) higher than that from the paper sessions ($M=1.9$, $SD=0.69$).

Due to time and technological constraints, students were unable to complete the final step discussing and posting ideas about evolutionary processes. This was remedied by asking students to answer an analogous question as a post-activity assignment: *Choose an organism from the Borneo ecosystem and discuss the evolutionary forces you think are at play thorough 200 millions years?* Responses were coded using the KI scale, which found that students who participated in the second iteration achieved a mean KI score of 3.7 ($M=3.74$, $SD=1.14$). Over 50% of the notes were coded either as Basic or Complex (Figure 3).

Discussion

Disciplinary Content Knowledge

Pre/post assessments indicate that overall curriculum engaged students and helped them to learn within the evolutionary biology domain. Although the effects may be attributed to instruction of the entire unit, analysis of in-activity artifacts, especially those asking students to think deeply about underlying mechanisms of evolution and what constitutes as evidence for evolutionary processes, served as confirmation of our design's impact on disciplinary content knowledge. It is interesting to note that knowledge integration scores for students' explanation of evolutionary processes in iteration 2 were significantly higher than those in iteration 1. This may be due in part to the activity design or to their being completed after the activity, with more time for reflection. This could also be due to the phrasing of the question, which included more scaffolding in asking students to review the cladogram and choose about a specific species to reflect upon.

Engagement with Immersive Media

Reviewing students' participation and how well they paid attention to the media, observation accuracy rates suggest that students were paying attention to the content on the walls and those on the tablet. In the session utilizing paper handouts (in iteration 2), completion rate for making comparisons between time periods (e.g., 200 vs. 150 million years ago) were lower than the same question being answered on tablet devices, however

students in both session types were observed to be engaged with the content of immersive walls. One reason might be that on tablet devices, students did not have an option of not answering the question before moving forward in the activity. Another reason might be that the students in the paper group were asked to make comparisons between all time periods while the students in the tablet group were only asked to make two comparisons. It is also interesting to note that answers tended to be more complete with significantly higher KI scores ($M=3.33$, $SD=0.60$) than those in the paper group ($M=1.90$, $SD=0.69$), $p < 0.05$. Video analysis currently underway will serve to further elucidate how students engaged with the immersive media and how they influence student interactions that lead to productive knowledge co-construction.

Collaboration and Collective Progress

Structured Community Progress and Dependencies

We were able to structure community progress and student's dependency on their peers' work in two ways: 1) species specializations and teams with different specialists, and 2) giving students distinct roles during collaborative activities

1) A key design feature of the collective inquiry activity is the use of specializations (e.g., birds, primates) kept by the students throughout the curriculum. It offered students the opportunity to have an authoritative voice during collaborative discussions (since only they would have enlightened information about their specialty species). This was carefully designed into collaborative steps of the activity. It also allowed many students to work towards a shared artifact for further exploration. Over 50 students collectively completed a field guide in iteration 2. Several sessions of ten to fourteen students worked together to create a map of the evolutionary lineages of the species in the simulated rainforest ecosystem, and in both cases individual students had their own piece of the larger puzzle that they were responsible for. However, in order for them to really feel like "experts" in their specialization, students needed to engage in pre-activity assignments. Engagement was not enforced nor was effort graded, which might have led to lack of external motivation to complete tasks.

2) Another way we designed interdependency is to specify task-based roles within the activity (as opposed to content expertise). In iteration 2, when students collaborated to answer explanation questions, such as comparing time periods, they were asked to designate a specific person to act as the scribe of the group (for a particular question), as well time period specialists (i.e., responsible for looking up resources about the rainforest at each specific time). Another example of roles being designated was the use of guides in iteration 2.

Students Responding Meaningfully to Ideas of their Peers, in Real-Time

A more meaningful, but difficult, interdependency is to encourage students to respond meaningfully to ideas of their peers. This can be designed into the activity, to the extent that certain pieces of information may be discovered by different people participating such that only by collaborating will they see the big picture. Relevant pedagogical information can be carefully scripted to emerge at the right time. In EvoRoom, different evolutionary mechanisms were designed for different species specialists to discover. For example, those specializing in plants and insects should become aware of the co-evolutionary relationship between flowering plants and pollen spreading insects, leading them to discover the symbiotic relationship between the fig tree and the fig wasp. This type of dependency was most difficult to achieve, since the revelation of one insight could rely on an emergent artifact that may or may not depict the correct information. The collective cladogram was one such artifact. The cladogram in both iterations showed conflicting information particularly in the earlier time periods. The facilitating teacher had to think swiftly on her feet when reading and trying to launch relevant discussions from emergent artifacts at the same time. However, our teacher demonstrated in both iterations that these emergent, aggregative artifacts can be a powerful teaching tool. Discrepancies in an emergent artifact led to interesting discussion. In one session, the mistakes in the earlier times of the cladogram prompted students to think about what constitute as evidence for evolution (e.g., fossil records), and that which records are more or less likely to survive, and what led to our current understanding of evolution.

Conclusion

Overall, we found that EvoRoom enabled students to think deeply about evolutionary biology mechanisms. With respect to the broader curriculum, assigning expertise (e.g., species) was an important aspect of the design but recognized that not everyone "bought-in" to their assigned roles, resulting in different levels of effort put into their work within the broader curriculum. This led to a varied range of expertise during collective inquiry activities (i.e., one "primate expert" having more insight than another), which would impact their group or sessions' collective success. In both iterations, we found that students paid careful attention to the immersive media as well as other media components (tablet software, visualizations) in the immersive simulation. Much of the within-activity artifacts that demonstrated student reflection about evolutionary biology resulted from interactions with immersive walls as well as with discussion with students' group members. However, this was as much a feature of our pedagogical design as the media's influence. Further audio and video analysis is now

underway to measure students' thinking behind their written explanations. During the collective inquiry activity, visualizations that aggregated students' collective observations served as an important tool as a shared artifact to encourage deeper discussions and drive further reflection. From the early results, successful design features of our immersive simulation include: visualizing the rainforest, displaying the collective knowledge (i.e., in the form of a cladogram), and incorporating collaboration to the core of the activity.

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