Exploring Evolutionary Concepts with Immersive Simulations

Michelle Lui, James D. Slotta,
University of Toronto, 252 Bloor Street West Toronto, Canada, ON,
Email: michelle.lui@utoronto.ca, jslotta@oise.utoronto.ca

Abstract: This paper presents two iterations of our design of an immersive simulation and inquiry activity for exploring evolutionary concepts in a Grade 11 Biology course. Interacting with large projected displays of animated rainforest flora and fauna, students worked as "field researchers" to observe changes in life forms occurring over a 200 million year span. Students gathered evidence of evolution using networked tablet computers that scaffolded their interactions with peers and with the room itself. Improvements from the first to the second design iteration focused on (1) improving content-focused interactions within the simulation; (2) improving the integration of the simulation activity into the overall curriculum; (3) improving embodied interactions of students working within the physical space. Student explanations from the second implementation demonstrated increased variation in evolutionary topics compared to those in the first iteration. Key design features from the two iterations are discussed with respect to the observed interaction patterns.

Introduction

Evolution has been described as a central idea in understanding biology, accounting for fundamental issues about how organisms came to their present form, explaining relatedness among different species, as well as how certain traits are passed down and accumulated over many generations (Kampourakis & Zogza, 2008; National Academies Press, 1998). There are also strong links to understanding evolution and learning about the nature of science (Rudolph & Stewart, 1998). However, science topics of biological evolution are well recognized as being challenging to teach, due in part to their complex systemic nature (Chi & Slotta, 2006), and students' incoming ideas, which are often inconsistent with the scientific theory (Demastes, Good, & Peebles, 1995; Mayr, 2002). The research literature on conceptual change in students' understanding of evolutionary biology promotes a constructivist approach that takes into account students' epistemic positions (see for example, Alters & Nelson, 2002; Anderson, 2007; Sandoval, 2003), yet it remains a challenge in determining how best to do achieve this.

One early example is that of the Biology Guided Inquiry Learning Environment (BGuILE), where students were presented with a scientific challenge concerning a Galapagos island ecosystem, where the task was to find out what was killing some of the finches on the island (Reiser et al. 2001). A technology environment prompted students to formulate an evidence-based argument, helping them articulate questions and support their explanations with data. BGuILE examined the causal claims made by students and how they warranted these claims. Results showed that students were able to adopt explanatory goals and that scaffolding students' attention to epistemic practices helped them to focus on evidence (Sandoval, 2003).

Expanding on these ideas, Chinn and Buckland (2012) advocate a model-based inquiry approach, as well as a stronger focus on macroevolution (i.e., evolution on a grand scale, as opposed to the smaller scale processes within microevolution, such as allele frequency changes). However, such evolutionary phenomena are not easily accessible to student manipulations within a classroom setting. The present study seeks to leverage technology-enhanced learning environments in support complex and participatory forms of scientific inquiry with macroevolutionary concepts. Our research group at the University of [*name withheld*] has advanced the concept of a "smart classroom," where the physical environment (e.g., walls, furniture, etc.) is infused with a set of digital tools and materials to support student interactions across physical, social and curricular dimensions. The room, together with various server and client technologies, serves to scaffold collaboration, enhancing real-time face-to-face interactions, capturing and representing the collective contributions of the entire class. Inspired by research in immersive virtual worlds, such as River City (Dede, 2009) and Second Life, we are investigating an educative role for such immersive simulations, where students are immersed within a room-sized simulation, and conceptual content is distributed across a spectrum of embedded technologies to support learning activities.

Reminiscent of how students adopt "avatars" within online immersive environments, participatory simulations also allow students to be embodied within particular roles. For example, students may become one element of a complex system, so that the emergent behavior of the system might be directly observed or experienced (Wilensky & Stroup, 1999). Such participatory role-playing can be augmented with networked technologies, such as wearable computers (e.g. "Thinking Tags") to help provide information to the participant during the simulation (Colella, 2000; Resnick, 1996). In Colella's work, wearable "Thinking Tags" transformed students into potential virus carriers whose mission was to greet as many people as they could without getting "sick." By participating in the process of viral transfer, Colella hoped that students could come to a deeper understanding of the underlying concepts (i.e., of disease progression). In another approach called Embedded

Phenomenon, a persistent scientific simulation is embedded within the walls or floor of the classroom (Moher, 2008). Students are tasked with monitoring and manipulating the state of the simulation, requiring physical interactions within their learning environment: observing and measuring aspects of the simulation, forming hypotheses, and gathering evidence to solve problem or answer questions

Our own design of an immersive simulation builds upon this previous research, incorporating aspects of participatory simulations within our learning activities and a sense of full-body immersion though our projected displays (together with audio and other ambient media). The goal is to help students deeply engage in scientific inquiry, providing them with opportunities to experience evolutionary phenomena that would be geographically (Borneo) and temporally (200 million years) inaccessible to them, otherwise. This paper addresses the following research question: *How can immersive environments and embodied interactions support a co-located group of students to collaboratively develop their understanding of evolutionary concepts?* We designed EvoRoom, an immersive simulation of evolutionary biology in a Borneo rainforest, where students can observe changes in flora and fauna over a 200 million year time period. In addition to the immersive environment itself, we designed a set of learning activities for use within and outside the immersive simulation, and worked closely with the teacher to tailor her curriculum so that the activities fit well in the sequence of topic coverage (i.e., that the time spent in EvoRoom played a meaningful role in the curriculum sequence). The smart classroom technology environment served to orchestrate our complex interaction design, delivering all materials, collecting student interactions, and supporting collaborations within EvoRoom as well as at home and in the classroom. Here, we report on two iterations of our design-based research project, with findings from the first incorporated into the second. We report on students' inquiry experience, examine the content of their explanations, and discuss the features of our environment and interactions that made it successful.

EvoRoom Design

To help students learn about evolution, we required a rich context that would engage them in the exploration of macro-level evolutionary concepts while allowing enough flexibility to be tailored within our partner teacher's curriculum. We decided on the context of a tropical rainforest, due to its clear connections to our target topics of biodiversity and evolution, as well as the range of interesting features that would be well suited to an immersive environment. Ultimately, we achieved EvoRoom (see Figure 1) where students enter a simulated rainforest as a team of "field researchers," gathering evidence of evolution by comparing simulations from a range of time periods. Working individually and in groups, students observed changes in life forms over time, consolidated their findings as a collective community, and developed hypotheses about the evolutionary changes that might have taken place. Students observations (e.g., of ancestral relationships or patterns amongst species), their consultation of field guides, their written reflections, and other activities were scaffolded throughout the activity using tablet computers that and custom software application. At the front of the room were located two interactive white boards, where we aggregated observations from all students, at all time periods, for purposes of student reflection and teacher-led discussions.

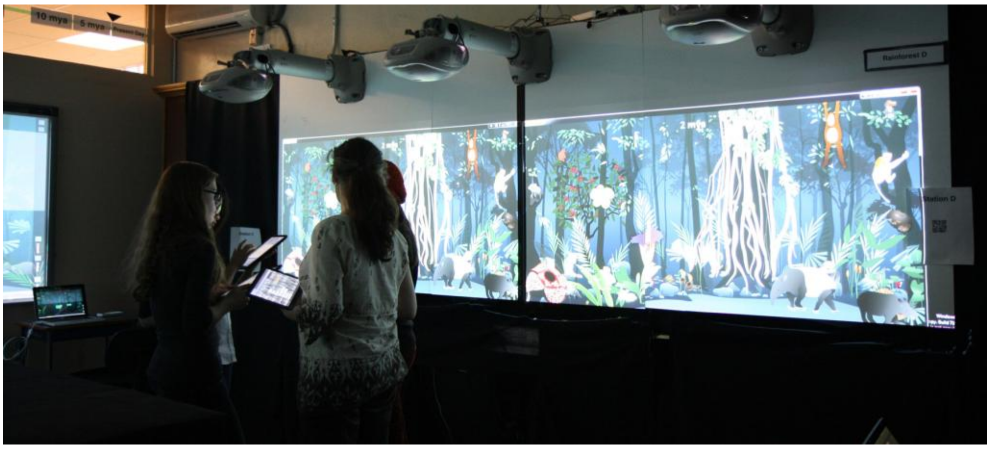

Figure 1. Large screen projections around the room displaying the immersive simulation, as well as audio tracks of natural rainforest sounds transform a smart classroom into a rainforest in Southeast Asia.

Methods

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. Using a co-design method (Penuel, Roschelle, Shechtman, 2007), our team of researchers, designers, technology developers, and a high school teacher met regularly since January 2011 to develop curriculum activities and the immersive simulation itself. The first iteration was evaluated in June 2011 as a pilot study, with the second iteration implemented in the following Fall/Winter (2011-2012) semester as part of the Biology course.

Participants

The first iteration was conducted with eight high-school student volunteers who had completed Grade 11 Biology. The second iteration was an evaluative study, including 45 students from two class sections of Grade 11 Biology (taught by our co-design teacher). For both design iterations, students completed pre-/post-activity questionnaires. During the activity, video recordings captured student interactions, while knowledge artifacts created by students (e.g., notes) were collected as measures of the quality of student ideas.

Procedure

The first study was conducted in a single 2-hour session, which took part in the smart classroom one week after the end of the academic school year, while the second study lasted 12-weeks and included three visits to EvoRoom, along with a set of in-class and homework activities (Table 1). The full design and expanded the curriculum are detailed in a separate paper (AUTHORS, 2012). For the purposes of examining student ideas about evolutionary concepts (and for linking ideas made in the first study), the present analysis focuses on the relevant EvoRoom sessions, each of which lasted approximately 45 minutes.

Activity Design

Iteration 1 (implemented in June 2011) was quite basic, with students entering the smart classroom to find the large displays set up as *Sundaland*, a region in Southeast Asia predating Borneo and Sumatra, about two million years ago. After the premise of the activity was introduced, and the historical context of the rainforest environment explained, students were scaffolded by their tablets to observe individual species and use the Field Guide application.

After approximately 15 minutes, the teacher used her own tablet computer (with teacher controls) to “accelerate time,” revealing a sequence of geologic events that affected the Sundaland landscape over the span of two million years. On the interactive white boards at the front of the room, students observed changes in sea level that broke Sundaland’s central landmass into a peninsula and several islands, including Borneo and Sumatra. When the teacher then set the room’s timeline to “present day”, the two sides of the simulation were updated: one side of the room (3 large projectors “stitched” together, as shown in Figure 1) now showed Borneo’s ecosystem, while the other side showed Sumatra’s. Students spent another 15 minutes making observations in this new context. At the end of the observation phase, students were divided into two field researcher teams: Borneo and Sumatra. Each group answered a set of questions designed to have students review and compare notes about their individual observations (e.g., in the Borneo group, students were asked *What common species were found in both Sundaland and Borneo?*).

In the final step, the two teams came together to collectively document evidence of evolution. Students were encouraged to discuss their ideas with others and to post ideas about evolution concepts. The posts were aggregated to the interactive white board, which served to visibly represent the collective knowledge base of the students at the end of the activity. The teacher was able to use the content of this display to lead a synthesis discussion to close the activity.

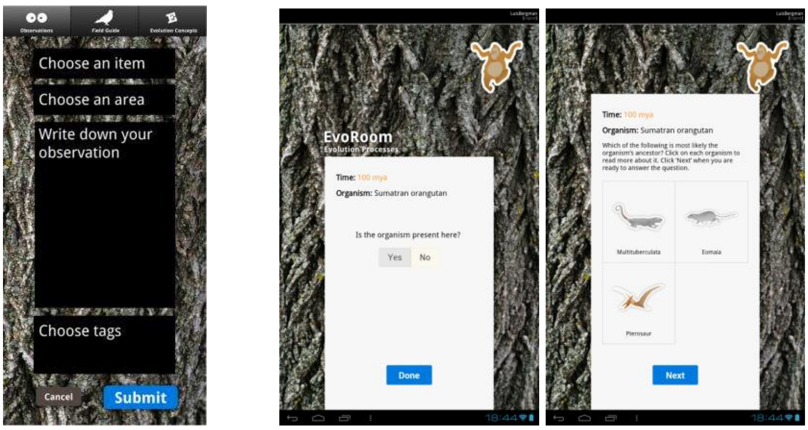

Figure 2. Tablet computer screens for iteration 1 (left) and iteration 2 (right). Note the open-ended nature of tasks given in the first iteration versus more structured format in the second.

The second iteration of the curriculum was informed by our observations and analysis of student interactions within the first. In particular, the EvoRoom activities were more deeply integrated within the broader curriculum, and interactions refined to focus on topics of evolution and biodiversity (see Table 1).

Moreover, additional effort was placed in mapping particular inquiry objects to different areas of the room. Students were assigned to one of four specialist categories (i.e. plants & insects, birds, primates, and other mammals), which they held for the duration of the curriculum. Two EvoRoom sessions were developed. For the first session, we greatly extended the timeline, such that 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), as opposed to just two (i.e., 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 evolutionary predecessors from a short list that popped up (scaffolded by a Field Guide application). Their answers were recorded by the tablets and – via the smart room software – aggregated in real-time on the interactive white board at the front of the room, resulting in an interactive cladogram (a diagram showing descendancy relations amongst species over time). In the second session, students again focused on evolution, working as a team in their assigned species groups on activities with similar goals as in the first iteration, but with more structured and scaffolded tasks than had occurred in the first iteration (Figure 2).

Table 1. Summary of the activity sequence for iteration 2: in-class (I), homework (H), and smart classroom (S)

Week	Description	Curricular goals
1	• Introduction (I) • Assign groups and specialty categories (i.e., plants & insects, birds, primates, and other mammals; I) • Review field guide (H) • Zoo field trip group assignment (I)	• Become familiar with assigned organisms • Understand scientific connections (e.g. taxonomy and phylogeny) between related species
2	• Collaborative food web activity (I) • Assign environmental impact variable (I) • Prediction analysis group assignment (H)	• Understand relationships among a set of species (e.g., in the Borneo rainforest) • Understand how environmental factors (e.g., high/low rainfall, tsunami, earthquake) affect ecosystems
3	• EvoRoom: Biodiversity activity (S) • EvoRoom debrief discussion (I) • Personal reflection (H)	• Improve understanding of complex interrelationships within an ecosystem and implications of environmental factors on biodiversity
4	• Traditional teaching on the origin of life, contributions to the theory of evolution	
5	• Traditional teaching on molecular evidence of evolution and microevolution	
6	• Traditional teaching on variation, selective advantage, natural selection	
7	• Traditional teaching on mechanisms of evolution, including sexual selection, gene flow, genetic drift	
8	• Understanding of evolution survey (H)	• Reflect on personal understanding of evolution
9	• Relatedness of species in Borneo and Sumatra assignment (H)	• Understand concept of "relatedness" and how assigned species are related to each other
10	• EvoRoom: Evolution processes day 1 (S) • Evolutionary mechanisms tagging (H)	• Make connections between evolutionary mechanisms (learned in class) to the organisms in a specific ecosystem • Improve understanding of different organisms' lineages with respect to evolutionary forces over millions of years
11	• EvoRoom: Evolution processes day 2 (S)	
12	• Personal reflection (H)	

Findings

Student Observations

In iteration one, students were asked to make free-form observations about any organism shown in the simulation. A total of 157 observations were made, with 49% about the species at two million years ago, 27% about those in present day Borneo environment and 24% about the species in Sumatra. Students wrote an average of 13 words per observation (*SD*=24). These notes were analyzed following Chi's (1997) method for content analysis. Using the "observation posting" as a unit of analysis, we coded for content type and nature of the content. An inter-rater reliability analysis using the Kappa statistic was found to be Kappa = 0.80 ($p < 0.001$), indicating substantial agreement. The notes tended to be about physical characteristics of certain organisms (41%) or about the animal's behavior (57%) – see Figure 3 for a complete distribution of coded categories. In iteration two, students made structured observations about whether their assigned organisms were present at different time points, and if not, which ancient is most likely its predecessor. These observations were scored for accuracy: with a total of 1047 entries, 81% (*SD*=10.33) were correct.

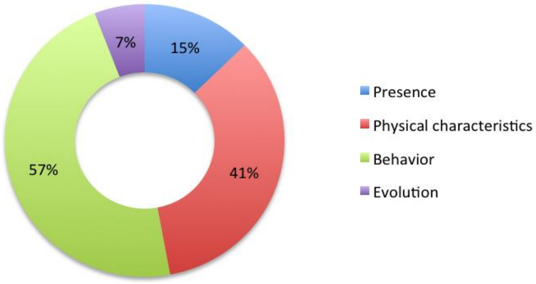

Figure 3. Content distribution of iteration one's observations may be categorized as Presence (e.g., about the presence of species in a specific location), Physical characteristics, Behavior, or Evolution.

Students' Conceptual Learning: Explanations of Evolution

At the end of the activity, in both iterations, students were asked to contribute to the following question: *What evolutionary forces do you think were at play in this environment?* Students were asked to choose an evolution concept from a predefined list and explain their answers with sufficient evidence. 14 explanations were collected from the first study, while the second yielded 43 (Table 2). Figure 4 shows the distribution of evolutionary concepts that the explanations attempted to address. Explanations from the first iteration were predominately about adaptation (36%), with topics from the "Other" category comprising of: coevolution (21%), sexual selection (21%), and reproductive isolation (14%). While explanations from iteration two covered a wider range of evolutionary concepts, with the highest levels of explanations focused on natural selection (33%) and adaptation (26%). Topics from the "Other" category comprised of: sexual selection (12%), co-evolution (7%), reproductive isolation (7%), gene flow (5%), and miscellaneous topics (12%).

Table 2. Descriptive summary of student explanations to the question, w*hat evolutionary forces do you think were at play in this environment?*

	Iteration 1 (n=8)	Iteration 2 (n=45)
Number of explanations	14	43
Average word count	24 (*SD*=14.58)	33.28 (*SD*=29.51)
Average KI score	2.36 (*SD*=0.75)	2.72 (*SD*=1.05)

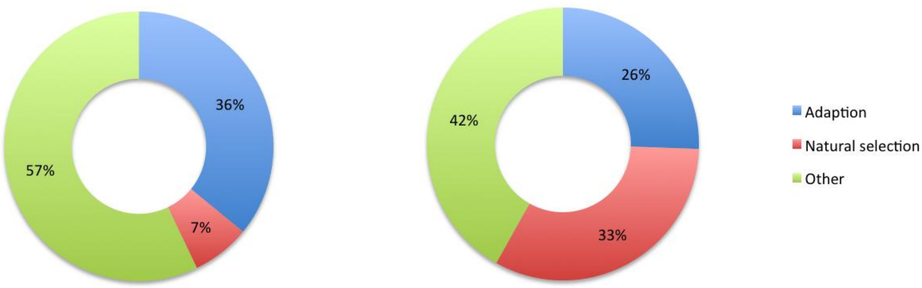

Figure 4. Distribution of evolutionary concepts that the explanations from the first (left) and second (right) iterations attempted to address.

The explanations were scored using a 0-5 Knowledge Integration (KI) scale that rewards valid scientific connections between concepts (Table 4; Linn & Elyon, 2011). The explanations from iteration two attained higher average scores (*M*=2.72, *SD*=1.05) than those from iteration one (*M*=2.36, *SD*=0.75), although no significant difference was found. In general, there was an increase in the complexity and sophistication of explanations from iteration one (34%) to iteration two (43%). Figure 5 displays the distribution of explanations based on their KI scores.

Table 4. KI rubric used to score student explanations. From Linn & Elyon, 2011.

Score	KI level	Description
0	No answer	
1	Off task	• Response is irrelevant or "I don't know" • Student writes some text, but it does not answer the question being asked
2	Irrelevant/Incorrect	• Have relevant ideas but fail to recognize links between them • Make links between relevant and irrelevant ideas • Have incorrect/irrelevant ideas
3	Partial	• Have relevant ideas but do not fully elaborate links between them in a given context
4	Basic	• Elaborate a scientifically valid link between two ideas relevant to a given context
5	Complex	• Elaborate two or more scientifically valid links among ideas relevant to a given context

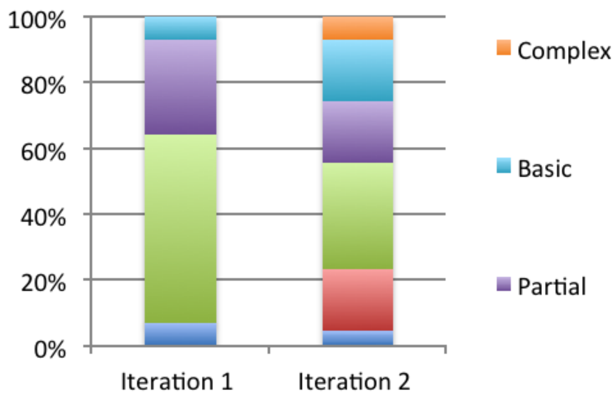

Figure 5. Distribution of student explanations' KI scores.

Discussion

From "Free Formed" to Structured Observations

When we first reviewed the observations from the first iteration, we noticed them to be rather basic. An example of an observation that focused on behavior was, *"There are two tapirs, one walking really slowly and one drinking from a shallow pool."* Observations that focused on physical characteristics were also superficial, e.g., "*The fig wasp has purple wings, long antenna, and a striped body.*" To help promote deeper explanations, we designed scaffolding for iteration 2, in the form of more structured observations. For example, students to answer simply *yes* or *no* to the question, "*Is the organism present here?*" and then reflect more deeply on the larger patterns. Since they only observed their own assigned species, students relied on the work of their peers to understand the complete picture of how all the organisms evolved over time. Their answers were aggregated to the interactive white board at the front of the room (Figure 6) and reviewed in teams of four to six. With students providing structured observations, we were able to assess more easily whether they were paying attention to the correct pieces and seemed to yield positive results (with over 80% accuracy).

Increased Variation of Evolutionary Topics

At first glance, the student explanations from iteration one do not differ significantly from the explanations written from iteration two, given their comparable KI scores. However, improvements to the activity in iteration two may be demonstrated in the increased variation in the types of evolutionary concepts that students addressed. Figure 7 demonstrates the nature of explanations with a visual representation (i.e., Wordle - http://www.wordle.net/), where words with the highest frequency are given greater prominence. The nature of the explanations in iteration one tended to be about surface features of the species observed, while the explanations in iteration two focused more so on the processes of evolution.

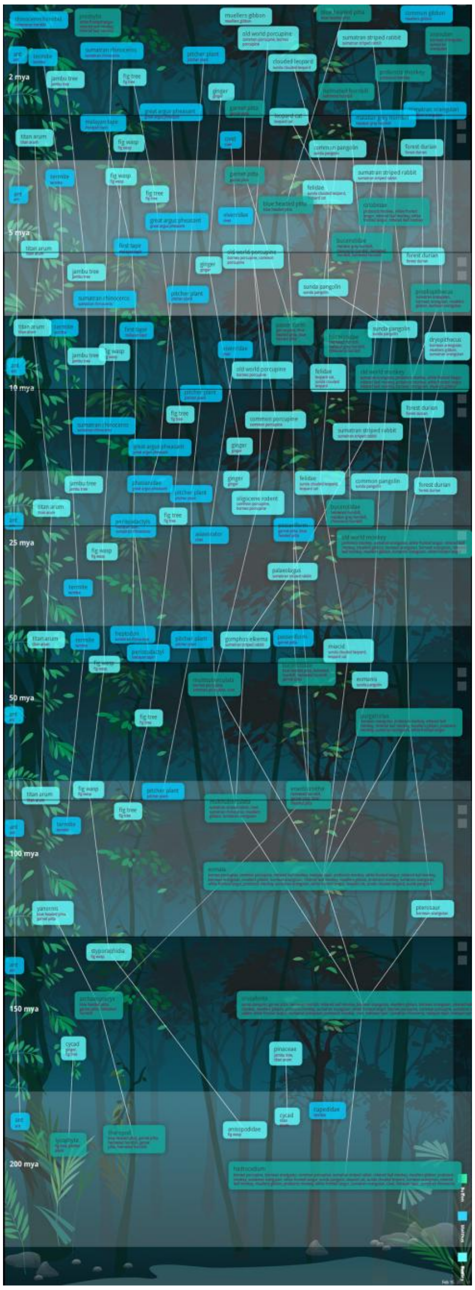

Figure 6. Interactive cladogram created from the collective inputs of 16 students' structured observations.

Figure 7. Wordle of student explanations from iteration (left). Words, such as camouflage (6x), curtain figs (6x), different (5x), and wasps (4x), were most frequently encountered. Wordle of student explanations from iteration two (right). Words such as evolved (19x), selection (14x), adapted (12x), species (11x) appeared most.

Current Progress & Future Directions

At the time of writing, audio and video analysis of student interactions are in progress. We expect that results will glean important insights about students' thinking behind their written explanations. We will continue to analyze students' biological understanding by coding the various elements, particularly from our second iteration, which was embedded within a much larger curricular sequence. From the early results presented here, we are already making progress in designing our next iteration. We understand the need to better address students' preconceptions about evolution, as well as the need to encourage increased complexity of student thinking. We will look for opportunities to incorporate these ideas into our designs in a more seamless and meaningful manner.

References

Alters, B. J., & Nelson, C. E. (2002). Teaching evolution in higher education. *Evolution*, *56*(10), 1891–1901.

Anderson, R. D. (2007). Teaching the theory of evolution in social, intellectual, and pedagogical context. *Science Education*, *91*(4), 664–677.

Brown, A.L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141-178.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences, 6*: 271-315.

Chinn, C. A., & Buckland, L. A. (2012). Model-based instruction: Fostering change in evolutionary conceptions and in epistemic practices. In K. S. Rosengren, S. K. Brem, E. M. Evans, & G. M. Sinatra (Eds.), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning About Evolution.* Oxford University Press.

Colella, V. (2000) Participatory simulations: Building collaborative understanding through immersive dynamic modeling, *Journal of the Learning Sciences, 9*(4), 471-500.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, *323*, 66–69.

Demastes, S., Good, R., & Peebles, P. (1995). Students' conceptual ecologies and the process of conceptual change in evolution. *Science Education*, *79*(6), 637–666.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8.

National Academies Press, 1998

Kampourakis, K., & Zogza, V. (2008). Preliminary evolutionary explanations: A basic framework for conceptual change and explanatory coherence in evolution. *Science & Education*, *18*(10), 1313–1340.

Linn, M., & Eylon, B. (2011). Science learning and instruction: Taking advantage of technology to promote knowledge integration. New York: Routledge.

Mayr, E. (2002), What Evolution Is. New York: Basic Books.

Moher, T. (2008). Learning and participation in a persistent whole-classroom seismology simulation. Proceedings of the International Conference of the Learning Sciences (ICLS) – Volume 2, 82-90.

Passmore, C., & Stewart, J. (2002). A modeling approach to teaching evolutionary biology in high schools. *Journal of Research in Science Teaching*, *39*(3), 185–204.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning, 2*(1), 51-74.

Reiser, B. J., Tabak, I., Sandoval, W. A., Smith, B. K., Steinmuller, F., & Leone, A. J. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry in biology classrooms. In S. M. Carver, & D. Klahr (Eds). *Cognition and Instruction: Twenty-Five Years of Progress*, (pp. 263–305). Mahwah, NJ: Erlbaum.

Resnick, M. (1996). Beyond the Centralized Mindset. *Journal of the Learning Sciences, 5*(1), 1-22.

Rudolph, J. & Stewart, J. (1998). Evolution and the nature of science: On the historical discord and its implications for education. *Journal of Research in Science Teaching*, *35*(10), 1069-1089.

Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *The Journal of the Learning Sciences, 12*(1), 5-51.

Slotta, J. D. (2010). Evolving the classrooms of the future: The interplay of pedagogy, technology and community. In K. Mäkitalo-Siegl, F. Kaplan, J. Zottmann, & F. Fischer (Eds.), *Classroom of the Future: Orchestrating collaborative spaces* (pp. 215-242). Rotterdam: Sense.

Wilensky, U., & Stroup, W. (1999). Learning through participatory simulations: Network-based design for systems learning in classrooms. Proceedings of the conference on Computer Support for Collaborative Learning, Palo Alto, California.