Designing EvoRoom: An Immersive Simulation Environment for Collective Inquiry in Secondary Science

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
Curriculum, Teaching and Learning
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Abstract

This dissertation investigates the design of complex inquiry for co-located students to work as a knowledge community within a mixed-reality learning environment. It presents the design of an immersive simulation called EvoRoom and corresponding collective inquiry activities that allow students to explore concepts around topics of evolution and biodiversity in a Grade 11 Biology course. EvoRoom is a room-sized simulation of a rainforest, modeled after Borneo in Southeast Asia, where several projected displays are stitched together to form a large, animated simulation on each opposing wall of the room. This serves to create an immersive environment in which students work collaboratively as individuals, in small groups and a collective community to investigate science topics using the simulations as an evidentiary base.

Researchers and a secondary science teacher co-designed a multi-week curriculum that prepared students with preliminary ideas and expertise, then provided them with guided activities within EvoRoom, supported by tablet-based software as well as larger visualizations of their collective progress. Designs encompassed the broader curriculum, as well as all EvoRoom materials (e.g., projected displays, student tablet interfaces, collective visualizations) and activity sequences. This thesis describes a series of three designs that were developed and enacted
iteratively over two and a half years, presenting key features that enhanced students’ experiences within the immersive environment, their interactions with peers, and their inquiry outcomes. Primary research questions are concerned with the nature of effective design for such activities and environments, and the kinds of interactions that are seen at the individual, collaborative and whole-class levels. The findings fall under one of three themes: 1) the physicality of the room, 2) the pedagogical script for student observation and reflection and collaboration, and 3) ways of including collective visualizations in the activity. Discrete findings demonstrate how the above variables, through their design as inquiry components (i.e., activity, room, scripts and scaffolds on devices, collective visualizations), can mediate the students’ interactions with one another, with their teacher, and impact the outcomes of their inquiry. A set of design recommendations is drawn from the results of this research to guide future design or research efforts.
Acknowledgments

I would like to start by dedicating this work to my almost-two-year-old son, Brandon – may your curiosity about the world never cease and your sense of wonder continue to inspire. It is my hope that by the time Brandon reaches secondary school, it is not out of the ordinary for science classes to nurture students’ creativity, exploration, and collaboration with peers through memorable collective experiences.

In many ways, the work presented in this dissertation is inspired by the power of the collective and working as a knowledge community. It is no accident then that this work leverages a knowledge community in its own right. Without the input, guidance, and support provided by the members from my own community, the people acknowledged below and many more, the thesis project would not be in its current form. At the center of this community is Professor Jim Slotta, my doctoral supervisor, who spent countless hours on this work in discussion, in design meetings, in edits, and in sharing his vision and encouragement to me in pursuing innovative and transformative educational research. I would like to offer my sincere gratitude to Jim for many years of mentorship, advice, and support that many students could only dream of being the recipient of. You’ve helped me to become a better writer, thinker, researcher, and designer. I am grateful to members of my committee, Professor Jim Hewitt, for providing instrumental feedback that guided me throughout the process; Professor Earl Woodruff, who always inspired me to broaden my thinking about the research with respect to the future of education and social impact of technology; Professors Peter Trifonas and Rob Simon, who provided valuable comments and suggestions for thinking about this line of research moving forward; and Professor Sara Price, my external examiner, for her detailed reading of the thesis and in elucidating contributions and criticisms that helped me to further develop the ideas presented in this thesis.

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Chapter 1

1 Introduction

Digitally augmented physical spaces (e.g., smart classrooms) offer opportunities to engage students in novel and potentially transformative learning experiences. This dissertation explores an immersive classroom space and technology-enhanced inquiry activities where students collect observational data from the environment and explore their peers’ data through large visualization displays and personal mobile devices, all situated within a broader high school science curriculum. Students work within multiple social planes (i.e., individually, collaborating in small groups, and as a collective or a knowledge community) and across time scales – exploring a simulation of the Borneo rainforest in its history through two hundred million years for understanding biodiversity and evolution topics. In this chapter, I present the motivations for the study, describing the research questions that guide the study, and provide a list of frequently used glossary terms. This chapter concludes with a description of the organization of the thesis.

1.1 Motivations for the Study

The educational research community is recognizing that traditional didactic pedagogy is ill suited to prepare students for the complex, evolving global challenges of the 21st century (Collins & Halverson, 2009). This realization rings especially true in science disciplines, where students are tasked with more than simply developing an understanding of concepts, but also with important inquiry skills such as working with data and visualizations, collaborating in teams, thinking critically about problems, and evaluating arguments based on evidence. Designing instruction that helps students achieve on all of these levels means adopting new modes of inquiry where students are engaged in scientific practices during relevant activities where they develop their own understandings about conceptual content as well as inquiry processes (Linn & Eylon, 2006; Quintana et al., 2004).

In order to design inquiry activities that are meaningful and engaging to students, a number of scholars have suggested transforming classrooms into “knowledge communities” (e.g. Brown & Campione, 1996; Scardamalia & Bereiter, 2003). In a knowledge community approach, members are given the responsibility to generate and build upon each other’s ideas,
developing their own knowledge base while jointly negotiating problems and working towards a common goal, much like a team of research scientists would (Bereiter & Scardamalia, 2003; Brown & Campione, 1996). A challenge to using this approach in science instruction is allowing students enough autonomy for their ideas to flow and build upon peer contributions, yet still retain enough control to ensure that curriculum expectations are met. The pedagogical processes within a knowledge community approach are more complex than those of lecture and lab-based instruction, and are often unwieldy for teachers, particularly in the context of a secondary school science class (Slotta and Peters, 2008).

Technology environments can help by scaffolding students and teachers in complex new forms of learning (Slotta and Linn, 2009). One role for technology is to help orchestrate the “script” that guides the flow of people, materials, and activities (Slotta, 2010; Kollar, Fischer, & Slotta, 2007). With the advent of sophisticated collaboration technologies, it is now possible to develop applications that support the design and enactment of such instruction. Thus, technology enhanced learning environments offer a means of supporting research of knowledge community models, as well as the adoption of such approaches by teachers.

In recent years, researchers have begun to reconsider the role of the physical learning environment and to experiment with learning activities in digitally augmented physical spaces, such as mixed reality environments. These spaces offer new ways of engaging students with science concepts that have traditionally been taught or addressed through more passive forms of instruction. By coupling digital content with more familiar forms of physical and embodied engagement, students are prompted into active learning, which encourages students to think, reflect, and drive their own understanding (Price and Rogers, 2004). Moreover, digitally augmented physical spaces provide opportunities for promoting socially mediated learning through collaboration (Price, Roussos, Falcao, & Sheridan, 2009). Early efforts of such learning spaces have shown positive outcomes in facilitating creativity and reflection (e.g., Bell, Chalmers and Barkhuus, 2006; Facer et al, 2004; Rogers and Muller, 2006). It has been suggested that coupling digital augmentation with physical spaces promotes active learning by increasing the students’ awareness of the activities and information presented, provides a richer experience by bridging various perspectives between the physical and digital worlds, and engages students through a juxtaposition of familiar actions with unexpected digitally augmented results (Price and Rogers, 2004).
Building on prior research on digitally augmented physical spaces, Slotta and his colleagues (e.g., Slotta, 2010; Lui, Tissenbaum, & Slotta, 2011) have advanced the notion of a “smart classroom,” where the physical environment (e.g., walls, furniture, etc.) is integrated with a set of digital tools and materials to support student interactions across multiple social planes, providing access to dynamic materials, and encouraging adoption of different roles and responsibilities. Combining digital content with physical spaces can elicit new forms of collaboration, including models where student are engaged in scientific inquiry as a whole class (i.e., “collective inquiry”). Other scholars have pursued approaches such as participatory simulations (Colella, 2000), where students themselves serve as the elements of a simulation, embedded phenomena, where a scientific phenomenon is embedded within the walls or floor of the classroom (Moher, 2008), or mixed reality environments, where students interact through full body 3D movements and gestures within a collaborative, digitally mediated space (Birchfield et al., 2009).

To date, however, there has been little research that investigates mixed reality environments as a setting where students engage in collective inquiry – that is, collaborative inquiry carried out as part of a knowledge community. This is partly because the required technology has only recently become accessible, but also because such models are intrinsically challenging to design, and even more challenging to enact. Thus, any such research project will require close collaboration between the researchers and teachers, including substantive development of technology and physical classroom environments, requiring several iterative cycles of development, classroom enactments and design revisions.

Responding to the need for understanding how mixed reality learning environments can contribute to collective approaches in classroom learning, this research explores a new form of digitally mediated “smart classroom.” Inspired by the research tradition in immersive virtual worlds, such as River City (Dede, 2009), we are investigating a possible new educative role for immersive simulations, where the room itself is converted into a rich simulation, and conceptual content is embedded within ubiquitous technology to support students in their inquiry activities. We are concerned with how students work together in such a space, how they capture knowledge as it emerges in real-time, including aggregate or summative aspects (i.e., “wisdom of the crowd”) as well as discrete knowledge elements—all the while carefully balancing face-to-face
interactions within inquiry activities, and how they may lead to patterns of interactions that support productive knowledge co-construction.

1.2 Research Goals

Knowledge communities offer a powerful new way of leveraging the collective intelligence of a classroom by aggregating the insights and contributions of its members, but this approach is difficult to achieve and is often too open-ended to ensure that students achieve the requisite learning goals in secondary science. Slotta and his colleagues (e.g., Slotta, 2007; Slotta and Peters, 2008) developed the Knowledge Community and Inquiry (KCI) model in response to the challenges of transforming classrooms into knowledge communities, with an emphasis on the use of Web 2.0 technologies and orchestration. Previous studies suggest that the pedagogical model offers promising recommendations for students to achieve a knowledge community, while integrating purposeful inquiry activities.

By coupling a collective approach, as inspired by the KCI model, with immersive mixed reality environments, dramatic new forms of inquiry may be envisioned. This research explores one such form of collective inquiry, investigating how immersive learning experiences can scaffold a classroom (or multiple classrooms) as a learning community. The perspective of orchestration (Dillenbourg and Jermann, 2010) considers the notion of “scripts” that shape how students engage with materials, tools, and their peers, working individually, in small groups and as a class, to define the overall activity design. Scripts developed for collective inquiry that specify individual, collaborative, and collective activities (Slotta, Tissenbaum & Lui, 2013) provide a useful framework for design and – in turn – for analysis. Dillenbourg and Jermann (2010) observe that, although the three dimensions represent “an arbitrary segmentation of a social scale continuum…most classroom activities occur along these three levels: solo, class or in between” (Dillenbourg and Jermann, 2010, p. 530). This is especially true of collective inquiry activities where community knowledge and sense of collective epistemology are central to the theoretical aims of KCI, but are typically contributed by students who work as individuals, pairs, or small groups. This thesis study addresses questions of how to design collective inquiry activities along the three dimensions, including the use of immersive simulations.

To design and develop the immersive simulations and collective inquiry, this design-based research study employed KCI as an underlying model. By examining how students interact
with various people and components in the room through a pilot study and two years of design iterations, I explore how mixed reality spaces, specifically immersive simulations, support collective approaches to inquiry across various social planes and what roles various components play in student learning.

1.3 Research Questions

1. How can immersive simulations be designed to support three epistemological and interactional dimensions of collective inquiry: Individual (i.e., individual student), Collaborative (i.e., small group), and Collective (i.e., whole class)?

2. What roles do the teacher, peers, and interactive materials play in student learning with immersive simulations?

1.4 Researcher Background

Prior to my doctoral studies, I completed an undergraduate degree in Pharmacology and pursued a Master of Science in Biomedical Communications (BMC), the study of creating visuals for communicating science, medicine and health topics – a discipline that allowed me to combine a strong interest in both arts and science. It was within the context of the BMC program that I first became interested in interactive media. After completing the degree with a specialization in Biomedical Media Design, I had the opportunity to work in industry, at an interactive and animation studio for healthcare communication, first as a medical illustrator and later managing the interactive department as a Junior Art Director. As I gained fluency in designing interactive products, I became increasingly interested in programming and enrolled in further coursework at a local college. This coincided with the studio’s emerging interest in educational games, and served to broaden my experience with innovative interactive technology. Recognizing the connection between communication and education, I was inspired to bridge this gap through doctoral studies in Education, with a particular interest in Knowledge Media Design.

For my dissertation, I became interested in designing interactive experiences that helped students to learn complex science concepts, with particular interests in immersive environments and collective inquiry. As part of this dissertation project, I was deeply engaged in a co-design process, where the teacher of the classroom innovation was a core participant (Penuel, Roschelle, & Shechtman, 2007). EvoRoom (as presented in this thesis) emerged out of a two-and-a-half
year co-design effort, a long-term design process by any standard, and is very much a product of the design process itself, encompassing a number of knowledge domains within the co-design team: the teacher’s years of experience and practical pedagogical knowledge, as well as her strong scientific background (with a Ph.D. in the biological sciences, experience as a former veterinarian); my research supervisor’s (Jim Slotta) decades of experience designing technology-enhanced learning environments, materials and activities; and my own background in the life sciences as well as art and design, in combination with industry experience in illustration, design, interactive media development and art direction.

Because of my scientific background (i.e., undergraduate studies in life sciences, experience in scientific and clinical research), combined with the doctoral training in the Learning Sciences, my approach to this research may be seen as somewhat positivistic or empirical in nature, treating the classroom and even the teacher as elements of the inquiry. However, I wish to note here at the outset that the teacher, while definitely an object of inquiry in her own right (i.e., as an integral player within the EvoRoom context) was also a principal designer and equal member of the team. She was highly cognizant that – at the end of our design efforts, when the materials and activities were all ready to run – she would step into a practitioner role that would be part of the system under scrutiny. Yet most importantly, she was a voice of innovation and thoughtful reflection about pedagogy and practice, disciplinary content and how students come to learn within that discipline.

As well, it is appropriate to note that the students of this particular school setting (described in detail in Chapter 2) were not a “normal” sample, in regard to their motivations, capability or behavior. This research was conducted in a school setting that should be seen as being well-suited to this form of innovative technology-oriented research, with a unique population of talented students who gained admission to the school based on their performance on entry examinations, and have a strong reputation as one of the leading science academies in Canada. At the same time, this raised the standard for our work: it was unacceptable for EvoRoom to be anything but highly engaging and effective, and the teacher remained engaged throughout the design, partly to ensure this high standard. Hence, the context of research was a highly selective, exceptional environment where all participants were seen as highly supportive and valued members of the research community.
1.5 Glossary of Terms

- Co-location – The placing of two or more participants in close proximity (i.e., in the same room)

- Collective Inquiry – A pedagogical method where students investigate a phenomenon and draw conclusions about it through collaborative exploration, carried out as part of a knowledge community

- Digitally augmented physical spaces - Pervasive environments that include handheld devices and wireless networking. These environments may be indoors or outdoors, and to interact in these spaces, students use a variety of tools and body movements (Price & Rogers, 2004).

- EvoRoom – An immersive simulation of a Southeast Asian rainforest designed for co-located students to engage with their peers and teacher on topics of evolution and biodiversity through collective inquiry activities, set within a broader curriculum.
  
  o For purposes of clarity, within the present thesis, the technology environment is known as the “EvoRoom Immersive Simulation.”

  o The collective inquiry activities, designed in parallel of the environment, is known as the “EvoRoom Collective Inquiry Activities (with Immersive Simulations)” – of which there are two, an Evolution Activity, and a Biodiversity Activity.

  o The broader “EvoRoom Curriculum” incorporates the evolution and biodiversity activities into a rich curricular context, which includes in-class activities, homework assignments, and a field trip activity.

- Immersive simulations – Room-sized simulations of a phenomenon achieved with large displays stitched together, with accompanying audio track for a full multi-modal experience. Immersive simulations facilitate face-to-face interactions of groups of students collaborating with one another and as a collective group.
• Knowledge community - A learning community that emphasizes identity, shared interests and goals, and more importantly, production of collective knowledge and collective understanding (Kling & Courtright, 2003; Scardamalia & Bereiter, 2003).

• Mixed reality environments – Environments in which the physical world is merged in some proportion with the digital (Drascic and Milgram, 1996).

• Smart classroom – A physical classroom environment infused with digital tools and materials to support student interactions, scaffolding seamless and dynamic collaboration, enhancing real-time face-to-face interactions, and capturing the collective wisdom of the entire class (Slotta, 2010; Slotta, Tissenbaum and Lui, 2013).

1.6 Organization of the Thesis

This thesis consists of six chapters. Chapter 2 reviews the relevant literature related to knowledge community learning approaches, digitally augmented physical spaces for learning including smart classroom research, and previous immersive and embodied learning studies. I describe the research setting, participants and methodology in Chapter 3. Chapter 4 describes the design and implementation of the pilot study, while Chapters 5 and 6 provide information about the design and implementation of the first and second design research iterations, respectively. Each of the design and implementation chapters conclude with a set of design insights based on the results of the enactments. Chapter 7 is a general discussion on design decisions made across study iterations and the study as whole, concluding with a discussion on creating other collective inquiry activities with immersive simulations, including other mixed reality learning environments.
Chapter 2

2 Literature Review

This chapter reviews the body of literature related to this study beginning with a review of the theoretical foundations in social constructivism. The social constructivist perspective asserts that learning is an active process of constructing knowledge within the context of shared activities (Palinscar, 1998). Several conceptual frameworks that are relevant to the present research have grown out of a social constructivist perspective, including: (a) inquiry-based learning, (b) knowledge communities, and (c) embodied learning approaches. The chapter describes research from each of the above frameworks, and concludes with how the present research builds upon this prior work.

2.1 Theoretical Foundations

Dating to the 1930’s, constructivism advanced a vision of students building upon their existing ideas and taking ownership of their own learning. The chief premise is that a person constructs an understanding of the world by reflecting on his or her experiences, and can only connect those experiences to ideas that they already possess. Learning is thus seen as a process of sorting out the resulting cognitive mix of ideas, perceptions and experiences. Often contrasted with didactic forms of instruction such as lecture or textbooks, constructivism offers students an active role beyond that of a knowledge receptacle. Direct instruction is argued to be fundamentally limited in its ability to help students develop higher order thinking skills, such as reasoning and problem-solving skills (Palinscar, 1998).

Jean Piaget (1896-1980) advanced the notions of constructivism through his theory of cognitive development from an individual perspective. Piaget believed that a close association exists between an individual’s biological and intellectual development, which progresses through rich interactions with the world. He proposed four stages of intellectual development that occur between infancy and adolescence, through which the developing child actively and adaptively builds cognitive structures (or mental organizations) known as schemes (Piaget, 1936).

Where Piaget’s theory focused on the individual’s cognitive development, Vygotsky took into account social and cultural influences in his social development theory. Vygotsky’s work
advanced a “social constructivist” perspective that recognizes that knowledge acquisition is essentially a deeply social process, rooted in linguistic, historical and cultural contexts. Vygotsky asserts that children are socialized into learning, using cognitive and communicative tools that have been passed down to them from past generations. Through socialization, children learn the accumulated ways of thinking and doing that are relevant in their cultures (Vygotsky, 1978). Thought, learning and knowledge are more than just influenced by social interactions; they are social phenomena in and of themselves whereby cognition is developed through a collaborative process (Palincar, 1998).

At its core, the social constructivist perspective believes that learning is an active process of constructing knowledge within the context of shared activities (Palinscar, 1998). Below I review several conceptual frameworks that are relevant to the present research based on the social constructivist perspective: (a) inquiry-based learning, (b) knowledge communities, and (c) immersive learning approaches.

2.2 Inquiry-based Learning

Deeply rooted in a constructivist approach to learning, inquiry-based learning is based on an idea advocated by John Dewey (1964a, 1964b) that science learning should be authentic to science practice. He reacted against traditional instructional methods of his time – memorization and recitation – and argued for restructuring education to meet the changing needs of the Industrial Age in America (Kliebard, 1986). Dewey’s view (1916) suggested that experience is the cornerstone from which new knowledge is created, promoting authentic, meaningful experiences that foster new knowledge growth.

Building on the work by Dewey, Piaget, Bruner, Schwab and others, inquiry-based learning was incorporated into science curriculum as part of American educational reform efforts in the 1960’s (Olson & Loucks-Horsley, 2000; Linn, Songer, & Eylon, 1996). Instead of mastering disconnected facts, students were encouraged to develop a deep understanding of scientific concepts, critical reasoning, and problem-solving skills (White, 1988; Bruner, 1990). In inquiry-based science instruction, students typically investigate a phenomenon and draw conclusions about it. The approach places a heavy emphasis on posing questions, gathering and analyzing data, and constructing evidence-based arguments. Students work autonomously, but may be prompted to formulate questions, plan activities, and draw and justify conclusions about
what they have learned (e.g., de Jong and van Joolingen, 1998; Kuhn, Black, Keselman, & Kaplan, 2000; Krajcik & Blumenfeld, 2006). The learning is organized around relevant, authentic problems or questions, and a heavy emphasis is placed on collaborative activities. The teacher plays the role of a facilitator, and may provide content knowledge on a just-in-time, or targeted basis (Hmelo-Silver et al., 2007).

Critical to the success of inquiry learning is the timing of the availability of information. Providing information at the moment it is needed by the learner is more effective than providing all necessary information before inquiry or interaction with a simulation begins (Berry and Broadbent, 1987; de Jong and van Joolingen, 1998). Other challenging aspects of inquiry are hypothesis generation, design of experiments, interpretation of data, and regulation of learning (de Jong and van Joolingen, 1998). In response to these substantive task demands, researchers have often proposed various technological “scaffolds” to support students and teachers in working with complex material or instructional designs.

2.2.1 Scaffolded inquiry

Scaffolding, in the form of learning materials or coaching by a teacher, is derived from Vygotsky’s concept of Zone of Proximal Development (ZPD), which draws on learners’ receptivity to reach beyond their current competency with the help of others (Wood, Bruner, & Ross, 1976; Vygotsky, 1978; Kozulin, 2003). Scaffolding is often used to guide students in the complex inquiry process by structuring problematic tasks in ways that allow the learner to focus on relevant learning goals, thus decreasing the cognitive load necessary to complete the process (Quintana et al., 2004; Hmelo-Silver, 2006; Salomon, Perkins, & Globerson, 1991). Leveraging new available information technologies, researchers have developed a number of promising pedagogical approaches, described below, to support students as they conduct an inquiry-based learning curriculum (e.g., Linn & Hsi, 2000; Songer, 2006).

2.2.1.1 Supporting constructing explanations

Technology-enhanced learning environments can support students in constructing empirically supported explanations by providing templates for them to follow. Sandoval and Reiser (2004) developed the Biology Guided Inquiry Learning Environments (BGuILE) project to guide students in constructing and supporting explanations based on a rich set of data. In the
“Struggle for Survival”, a middle school unit on evolution, students were presented with a crisis in a Galapagos island ecosystem using a BGuILE software component. They were tasked with finding out what was killing some of the finches on the island. The ExplanationConstructor tool in BGuILE prompted students to complete an evidence-based argument, helping them articulate questions and support their explanations with data (Reiser et al. 2001). The study 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 attention to epistemic practices directed students to focus on evidence (Sandoval, 2003).

2.2.1.2 Modeling the inquiry process

Another method to support students in the inquiry process is through modeling. The Inquiry Island (White, Shimoda & Frederiksen, 1999) modeled the inquiry process in six main steps: Question, Hypothesize, Investigate, Analyze, Model and Evaluate. At each stage of the intervention, software “advisors” guided students, presented advice, and suggested goals and strategies to students. For example, Quentin Questionner asked students whether they wanted help learning about how to make alternative hypotheses. Studies conducted with 10- to 11-year olds suggested that students who used the intervention improved in their ability to design and understand an inquiry-based science project (Eslinger et al., 2008).

2.2.1.3 Supporting argumentation

The Knowledge Integration Environment (KIE) offers another example of scaffolding for science inquiry, providing software scaffolds such as Mildred, the Cow Guide and SenseMaker (Bell, Davis & Linn, 1995; Linn, Davis, & Bell, 2004). These scaffolds guided students as they investigated complex problems like “how to keep your soup hot and your soft drink cold”, critiqued Internet evidence, and produced scientific explanations and arguments. Mildred provided cognitive guidance for any part of the process, giving “hints” in the form of questions that helped students focus on science topics. SenseMaker was a visual argument-building tool where students sorted “Evidence” icons into boxes (or “frames”) as a way of structuring their arguments. A total of 172 middle school students worked in pairs on the “How far does light go?” project, spending approximately six days reviewing evidence and constructing arguments. As a result of this intervention, over half of the students were found to have acquired the full
instructed model at the end of the project, compared to less than 10% of students in the pre-test (Bell & Linn, 2000).

2.2.1.4 Breaking down activities into manageable steps

Often technology-enhanced learning environments break activities down into clear sequences of “steps” represented in an inquiry map. The Web-based Inquiry Science Environment (WISE), a descendent of KIE, presented students with an “Inquiry Map”, which consisted of a sequence of activity steps that comprised a WISE project (Slotta, 2004). Typical projects engaged students as they designed solutions (e.g., design a desert house that stays cool during the day and warm at night), debated scientific controversies, or critiqued scientific claims. In the WISE environment, students navigated through “steps” which may involve writing notes, engaging online discussion or working with a visualization component.

2.2.1.5 Making thinking visible

Visualizations and simulations are another way to scaffold students with technology, helping to make the ideas within science content more visible, and allowing students to make their own thinking more visible. Model-It is a learning environment that allowed students to study natural phenomena (such as a stream ecosystem) for building dynamic qualitatively and quantitatively models (e.g., visualizing relationships between phosphate on stream quality) in planning, building, and testing modes (Jackson et al., 1996). Also known as STELLA (a commercial version of Model-It) this software allowed students to dynamically visualize complex systems, as well as provided numerical readouts, tables, and graphs as output (Mandinach & Cline, 1996). Positive effects on students’ cognitive and motivational processes were demonstrated in a study that involved approximately 5,000 students across eight middle and high schools. More recent research studies on visualizations have elucidated design principles for the design of simulations, and their integration into curriculum (see for example, Chiu, 2010 and Kali & Linn, 2009).

The research reviewed above is representative of an extensive body of research conducted over the past decade in the role of scaffolding technologies within inquiry-oriented science instruction. Several major reviews have synthesized this body of work, most recently by Linn and Eylon (2006) who organized their review according to pedagogical patterns, and by
Quintana et al (2004) who offered a design framework for scaffolded inquiry. Taken together, this substantive effort has offered compelling evidence that students can be supported in complex inquiry processes through the use of carefully designed technology-enhanced learning environments.

2.2.1.6 Designing advanced technological scaffolds

Researchers are now investigating more advanced forms of scaffolding, where computer software automatically analyzes the content materials created by students, detecting patterns of learner actions that can be used to provide contextualized feedback (van Joolingen & Zacharia, 2009). Such “data mining” techniques can also be employed to allow teachers to monitor learners’ progress during the activity and provide timely support or locate those students who may need further assistance (Azevedo & Jacobson, 2007). In general, technology-based scaffolds raise the challenging questions of how much support to provide, and at what time during instruction.

Another challenge confronted by technological advances is the difficulty in effectively engaging the whole class in inquiry investigations. Typically, students work in scaffolded environments as individuals, pairs or, at most, small groups. However, computer and networked communications can also enable more complex forms of collaborative inquiry. For example, materials may be served up dynamically to individual students by a central server, based on pre-designated variables captured by the networked system such that students may interact with a mix of materials and group members across carefully designed activities to achieve a common inquiry goal. This idea will be explored further in the section below.

2.2.2 Collaborative inquiry

In the early 1990’s, in response to the recognized benefits of collaboration for learning, the field of computer-supported collaborative learning (CSCL) emerged to promote productive collaborative discourse with the help of the computer and other communications technologies (Dillenbourg, Jarvela, & Fischer, 2009; Kollar, et al., 2007). One common approach to the design and orchestration of collaborative learning activities is that of the “collaboration script” (e.g., De Wever, et al., 2009; Kollar, et al., 2007; Rummel & Spada, 2005; Schellens, et al., 2007; Stegmann, et al., 2007; Weinberger, et al. 2005; Weinberger, et al 2010) where students
and teachers are guided through a sequence of interaction moves via designated activities and roles – defining participants, roles, and groups, and specifying how tasks and materials are distributed, how groups are formed and the sequence of activity flow (Kobbe, et al., 2007). Collaboration scripts add structure to activities and distribute responsibility, ensuring that all members actively participate.

In an inquiry-based learning environment, scripts may take the form of a structured template. Kollar, Fischer and Slotta (2007) scaffolded dyads working in a collaboration script using a German version of the WISE project “The deformed frog mystery.” In the task, students investigated competing hypotheses and discussed why many frogs with physical deformities were found in North American waterways in the late 1990’s. To provide structure for the discussions, scaffolds were incorporated into pages using pre-structured blank text boxes that asked students to fill in the requested argument components (i.e., data, claim, reason). One learner would be responsible for constructing the page for one side of the argument, and his or her partner would construct the page for the counter argument. In the last step, the pair would construct an integrative argument collaboratively. In a study of 90 students in grades eight to ten, the scripts were found to foster domain-general knowledge about argumentation (Kollar, Fischer, & Slotta, 2007).

In recent years, the notion of collaboration scripts has evolved from one of specific scaffolding elements situated within computer-supported learning environments to a more holistic and adaptive notion of orchestrating collaborative activities within the broader learning environment (Dillenbourg, Jarvela, & Fischer, 2009). This view recognizes that complex collaborations occur “at various social levels (e.g., individual, group, class), across different contexts (classroom, home, laboratory, field trips) and media (with or without computers, video, etc.)” (Dillenbourg, Jarvela, & Fischer, 2009, p. 12).

In order to orchestrate or manage multiple classroom activities and various learning processes, advanced technologies are called upon to capture real-time data, give instruction to students, and relay pertinent information to classroom teachers. The I-MINDS project (Soh, et al., 2008) investigated the use of software agents for teacher, students, and groups, working in parallel to coordinate a pedagogical script. For example, the teacher agent disseminated information streams to student agents, assessed the progress and participation of students, ranked
and filtered the questions asked by students, and monitored the progress of a classroom session. This work serves as a promising example of research in an area that is still in its infancy. Yet, scholars are looking ahead, envisioning educational data-mining, pedagogical agents and other advanced technological developments to add a layer of intelligence to future inquiry learning environments (Slotta, 2010).

The advent of data-mining techniques and Web 2.0 technologies (e.g., wikis, social tagging, etc.) makes it possible for participants to jointly exchange information and materials in an accessible manner, ultimately allowing a community knowledge base to emerge. The next section discusses an exciting research tradition that is gaining renewed interest in recent years.

2.3 Knowledge Communities

Bearing social constructivist roots, the notion of knowledge communities for learning can be considered a distinct thread from inquiry-based learning approaches in the research literature. Learning in a community emphasizes identity, shared interests and goals, and more importantly, production of collective knowledge and collective understanding (Kling & Courtright, 2003; Scardamalia & Bereiter, 2003). Knowledge communities are created through collaboration, where members generate and build upon each other’s ideas, ultimately resulting in the development of a collective knowledge base (Bereiter & Scardamalia, 2003). Having access to their collective knowledge base not only allows for ideas to be further developed, but it also provides a shared artifact to be discussed and explored that binds students together as a community of learners.

2.3.1 Fostering Communities of Learners (FCL)

Brown and Campione (1990, 1996) first offered an interpretation of science classrooms as knowledge communities in their Fostering Communities of Learners (FCL) research program, where students engaged in research activities, shared findings, and used their collective expertise to develop a shared understanding. FCL curriculum features depth over breadth of coverage, with a few recurring themes (e.g., animal defense mechanisms, endangered species, changing populations, food chains, etc.) with curriculum and assessment focused on students’ ability to discover and use knowledge, while the technology environment encourages intentional learning, reflection and communication. Each theme is divided into five subtopics (e.g., for changing
populations: extinct, endangered, artificial, assisted, and urbanized populations). In a complex “jigsaw” script (Aronson et al., 1978), students form five ‘research’ groups, each responsible of one of the subtopics, then regroup into ‘learning’ groups in which each student is an expert in one subtopic. In the ‘learning’ groups, students prepare for participation in a “consequential task” (e.g., design an animal of the future) that requires students to achieve a deeper understanding of the scientific domain. In a study comparing sixth grade students in the research classroom to those in a traditional classroom, the students taught with FCL outperformed their peers in the number of biologically appropriate mechanisms included in their designs (Brown, 1992).

The FCL research program builds on Vygotsky’s zone of proximal development by demonstrating how individual students can help each other learn. Encouraging students to specialize in one aspect of a problem means students have to rely on one another to help each other make sense of complex situations. In addition, peers help learners monitor progress, critique accounts, and provide alternative thinking (Linn & Eylon, 2006). Four crucial ideas underlying FCL are agency, reflection, collaboration and culture. Individual students take charge of their own learning, given strategies that lead to transfer, and appropriate and creative use of knowledge (Brown, 1992, 1997). Working together in a carefully scripted set of activities, the influence of common knowledge, beliefs and expectations allow an identity of a community of learners to develop (Brown, 1997).

2.3.2 Knowledge Building (KB)

A related approach called Knowledge Building (KB) emphasizes the advancement of knowledge, or creative work performed as a community, rather than as individual effort (Scardamalia & Bereiter, 2006). In this perspective, students are explicitly involved in the process of building upon one another’s ideas, with the goal of developing a knowledge community in the classroom (Scardamalia and Bereiter, 1994; 1996). Through developing common goals, engaging in group discussions, and synthesizing ideas, KB advances the understanding of individuals (Scardamalia & Bereiter, 2003). By continually reinforcing the standard of knowledge advancement, students are encouraged to persistently improve their ideas rather than search for a certain truth or a recognized end point (Scardamalia and Bereiter, 2006).
Scardamalia and Bereiter (2006) created a computer-supported learning environment called Knowledge Forum (“KF”) in order to support knowledge building practices. Using student-generated notes and threaded discussions, KF acts as a knowledge base for a community of learners. Student notes record the ideas in a primarily text-based format, although images, animations and links may also be added. KF was built as a flexible environment whose main goal is to support the progression of idea improvement within a community. Students collaborate by sharing ideas, discovering dissonance, negotiating, and co-constructing knowledge from these ideas.

An important implementation challenge for any knowledge community approach lies in meeting curriculum expectations, particularly for secondary science, where teachers are accountable to a heavy load of content expectations. In general, it is quite challenging for teachers or researchers to coordinate a knowledge community approach in any classroom. As Kling and Courtright (2003) observe, “developing a group into a community is a major accomplishment that requires special processes and practices, and the experience is often both frustrating and satisfying for many of the participants” (p. 221). Moreover, any knowledge community approach will emphasize depth of understanding over breadth of coverage; teachers may rightfully feel that even if they could achieve such a model, it would not satisfy their basic content requirements. Thus, while this research tradition has earned great respect among scholars, it has been difficult to extend into K-12 classrooms.

2.3.3 Knowledge Community and Inquiry (KCI)

In an effort to make knowledge community approach more accessible to K-12 classrooms, Slotta and his colleagues (e.g., Slotta, 2007; Slotta and Peters, 2008) have developed the Knowledge Community and Inquiry (KCI) model, which integrates scripted inquiry activities into a knowledge community to facilitate a culture of collective inquiry in classrooms while still targeting specific curriculum objectives. Central to the KCI model are collaborative knowledge construction activities where students explore and investigate their own ideas as a community of learners and create knowledge artifacts that are aggregated into a knowledge base. The community knowledge base then serves as a resource for subsequent inquiry activities, where students are engaged in collaboration and reflection. Common themes, ideas or interests that emerge are incorporated into the design of learning activities (Peters & Slotta, 2010).
Technology plays an essential role for aggregating information in the knowledge base, for visualizing collective knowledge, promoting student contribution and allowing common interests and themes to emerge (Najafi & Slotta, 2010; Peters & Slotta, 2010). To ensure that the activities meet curriculum expectations, KCI specifies a co-design process with classroom teachers, as such activities must be designed concurrently with the curriculum, to respond to community interests while emphasizing learning objectives (Peters & Slotta, 2010).

In the first implementation of KCI, 104 Grade 10 biology students from four class sections worked as a community, collaboratively editing wiki pages describing human diseases from one of three different body systems (i.e., respiratory, digestive, circulatory). Students became an expert in one of the systems, then worked in groups to create “challenge cases” (involving fictitious characters exhibiting physical symptoms that required diagnosis) from their system that peers from the other systems were required to solve. Students’ final exam scores in physiology were found to be significantly higher than scores from the same teachers’ Grade 10 students in the previous year (Slotta & Peters, 2008).

A more recent KCI curriculum on climate change had 42 Grade 10 students from two class sections working on an initial knowledge construction activity. Students then formed groups based on Canadian regions where they were assigned a specialist role (i.e., primary industries; secondary industries; environmental activism, or tourism). For their final project, specialists from each region formed advisory groups to deliver proposals for national guidelines to remediate adverse effects of climate change. The initial success of this curriculum (including a positive correlation between students’ level of contribution and their achievements on post-assessments) has led to another design iteration, with 5 sections of the course and 108 participants (Najafi & Slotta, 2010). The efforts to develop KCI and related curriculum are ongoing.

2.3.4 New technologies for building knowledge communities

Web 2.0 technologies (e.g., Wikipedia, YouTube, Facebook) have enabled new ways to leverage social networks and user-generated content in support of emerging knowledge and online communities, which in turn bring new opportunities for the research of collaborative inquiry (Ullrich, et al., 2008). The knowledge communities in early KCI studies employed wikis, which are websites that allow pages to be written, edited and maintained by a group of authors,
relying on the “Wisdom of Crowds” for its content (Surowiecki, 2004). Students working in a wiki cannot predict how their contributions will be received, nor can they know how the co-authored document will evolve. Negotiating the content for a collaborative document can prompt the type of peer exchange that has been shown to foster student learning (e.g., Webb & Palincsar, 1996; Palincsar, 1998).

2.3.5 Smart classrooms for knowledge communities

New interactive technologies (e.g., Smart boards, Nintendo Wii, Microsoft Kinect) and real-time computational platforms (e.g., context-aware applications or instant messaging) have made it possible to develop applications that allow for more seamless collaboration, supporting new forms of collaborative inquiry in classrooms. With the parallel emergence of mobile and ubiquitous technologies, more complex and participatory forms of scientific inquiry may be envisioned. Slotta and his colleagues (Slotta, Tissenbaum & Lui, 2013) have begun to re-focus their understanding of KCI, with renewed emphasis on the learning environment, including the physical space, as well as distributed forms of learning (i.e., where students might contribute their own observations or found content from their mobile phones, collected in various contexts).

Slotta and his colleagues have begun to re-focus their understanding of KCI, with renewed emphasis on the learning environment, including the physical space, as well as distributed forms of learning (i.e., where students might contribute their own observations or found content from their mobile phones, collected in various contexts).

The concept of a “smart classroom” was advanced to support such activities where the physical environment is infused with carefully designed digital tools and materials to support student interactions across multiple social planes, scaffolding seamless and dynamic collaboration, enhancing real-time face-to-face interactions, and capturing the collective wisdom of the entire class. The current technology framework (“SAIL Smart Space”) consists of a portal that allows students to register and log in, intelligent agents that allows tracking of student interactions, a central database that houses curriculum materials and the products of student interactions, and a visualization layer that controls the information presented to students (Slotta, 2010). This work has challenged the notion of technology-enhanced learning, moving the learning content from the computer screen onto walls and furniture, into students’ hands, and distributing it strategically around the physical space of the classroom. Several preliminary studies have employed combinations of laptops, projectors, spatial arrangement of topic areas, and small group tagging activities to study new approaches to the instruction of problem solving in math and physics (Lui, Tissenbaum and Slotta, 2011; Tissenbaum, Lui and Slotta, 2012).
Further research is needed to understand how such technologies, including immersive or embedded environments (described below) may be used to support the formation of knowledge communities and – more importantly – how they contribute to the learning process. This thesis study investigates a possible new educative role for immersive simulations, where the smart classroom itself is converted into a rich simulation, employing large-scale shared displays that depict visually rich, interactive media, allowing students to immerse themselves in carefully designed curriculum activities. Conceptual content is embedded within ubiquitous technology to support students in their inquiry activities. In the next section, we describe some of the relevant research that has informed our own efforts.

2.4 Embodied Interactions for Learning

Another line of research founded on constructivist principles is embodied learning. Though not as well established in the research literature (i.e., in comparison to inquiry-based learning and knowledge community models) there have been significant contributions made in recent years. Concurrent theoretical work in the fields of education and Human-Computer Interaction (HCI) finds important connections between physicality and cognition (Dourish, 2001). Several researchers have developed interesting approaches to engaging students as a whole class, such as participatory simulations and digitally augmented physical spaces. These examples extend our notion of a "smart classroom" to one that can support the interactions of students, their access to materials, their adoption of different roles, and completion of interdependent sub-scripts. They also raise the notion that the physicality of the environment has an impact on the interactions amongst peers and how they may construct shared meaning, suggesting that mixed reality learning environments could be an important means of engaging students in inquiry within a knowledge community approach.

2.4.1 Ubiquitous computing and participatory simulations

Recent technological advances have brought the goal of developing integrated classroom applications within reach, to scaffold seamless and dynamic collaboration and real-time face-to-face interactions while capturing the collective wisdom of the entire class. One such development is seen in the move from the “personal” computer to the “interpersonal computer”, exemplified by computers with multiple input devices, tangible objects, and roomware (Dillenbourg et al., 2009). First put forth by Weiser (1993), the notion of “ubiquitous computing”
represents a departure from people interacting with “boxes on desks”, but instead interacting with objects that have computation embedded within them. Wilensky and Resnick argued for the use of pervasive, non-desktop technologies that engage learners with the physical environment (Wilensky and Resnick, 1999).

Several investigators have developed “participatory simulations,” where students act out individual roles of a system so that the emergent behavior may be directly observed or experienced (Wilensky & Stroup, 1999). Such participatory role-playing is augmented with networked technologies, such as wearable computers (e.g. “Thinking Tags”) to help collect information for the participant during the simulation (Colella, 2000). In SimVirus, the Thinking Tags were used to transform high-school students into potential virus carriers in a simulation of disease propagation, where students tried to greet as many people as they could without getting “sick” – knowing that one of the participants carried the virus (Colella, 2000). This approach draws upon the notion of ‘experiential learning’ where knowledge is created through a transformation of direct experience (Dewey, 1916; Kolb, 1984). In actualizing a simulated experience, learners can form personally relevant connections, enabling them to bring previous experience to bear and potentially draw upon the experience in future learning (Colella, 2000).

More recently, the notion of collective simulations builds on the earlier participatory simulations by incorporating a set of networked computers that run distributed simulations. In the “Mr. Vetro” Collective Simulation, different organ systems are simulated on wirelessly connected computers (Ioannidou et al., 2010). A central computer manages Mr. Vetro’s vital signs based on the aggregated information from the distributed client machines. High school students work in groups to vary parameters based on specific goals (e.g., the lung group needs to provide more oxygen if Mr. Vetro engages in intense exercise). The first implementation of this collective simulation demonstrated a positive impact on learning outcomes and increased interest in health issues. An interesting outcome was a pattern of mostly positive responses from regular biology students but more mixed responses from the advanced/AP groups. Certainly, more research is needed to understand the pedagogical, curricular and motivational issues surrounding new forms of simulations.
2.4.2 Digitally augmented physical spaces

Several researchers have extended ideas of participatory simulations and other simulation systems that enable students to serve roles as embodied participants by embedding ubiquitous computing media in the physical learning environment for science education. The Hunting of the Snark (Rogers and Muller, 2006) combines the use of mobile technology with the physicality of the classroom environment. Young children (ages 6-10) investigate a virtual creature by exploring a variety of physical spaces the creature might be located (e.g., cave where it sleeps). Location tracking devices, pressure pads, and other sensor technology is used to engage pairs of children in interacting with the creature (which responds with sounds) and exploring its characteristics. The children in the study generated theories about the Snark (i.e., describing its emotional state), and were found to engage in various forms of collaboration to creatively experiment and explore ways of interacting with the Snark (Price et al., 2003).

The Embedded Phenomena (EP) framework leverages the physicality of the classroom, carefully “mapping” a persistent scientific simulation onto the walls or floor of the room in the form of location-specific computer “portals” (Moher, 2006). Students monitor and manipulate the simulation and gather evidence to solve a problem or answer a question. The use of EP was associated with greater learning gains compared to students who experienced an analogous “non-embedded” curriculum (i.e., the simulation activity was replaced with an exercise on desktop computers) in a quasi-experimental, within-teacher study (Moher et al., 2010).

Another example of digitally augmented learning spaces is that of the Situated Multimedia Arts Learning Lab (SMALLab), which consists of an interactive floor display measuring 15-by-15 feet that supports a number of different simulations and learning modules (Lindgren & Johnson-Glenberg, 2013), including science education. In one module, high school students studied geologic evolution by collaboratively constructing and monitoring the earth’s crust, investigating 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 (Birchfield & Megowan-Romanowicz, 2009).

2.4.3 Embodiment & immersive experiences

The above examples may be also be identified as mixed-reality environments—in which the physical world is merged in some proportion with the digital (Drascic and Milgram, 1996), and in many such cases it is believed that embodiment plays a role in student learning (Lindgren & Johnson-Glenberg, 2013). According to Varela, Thompson and Rosch (1991), cognition “depends upon the kinds of experience that comes from having a body with various sensorimotor capacities, and...these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, and cultural context” (p. 173). Understood as being present and participating in the world, in real-time and in real-spaces (Dourish, 2001) and as the “the enactment of knowledge and concepts through the activity of our bodies” (Lindgren & Johnson-Glenberg, 2013, p. 445), embodiment offers a lens from which activity in the mixed reality world may be understood, since the kinds of interactions experienced in mixed reality environments are similar to the way we interact with the everyday world (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002).

Embodiment may be achieved through different means. Multiuser online immersive virtual worlds aim for a sense of embodiment by representing the movement of “avatars” that have location within a space, clear roles, and a variety of possible interactions within that space (Birchfield et al., 2008). In the River City environment, for example, students are immersed in a 19th century city, where they collaborate in teams of three or four to discover why people are getting sick and how they can resolve disease transmission issues (Dede, 2009). Using River City, students show improved learning of science concepts and scientific inquiry skills compared to those taught with conventional instruction or with a board game (Ketelhut, 2006; Nelson, 2007).

Unlike the avatars in online immersive environments, participatory simulations allow students to be actually embodied in particular roles – perhaps as a discreet element within a complex system – so that the properties or behaviour of the system is directly affected by their motions within the room or interactions with peers, objects or digital elements (Wilensky & Stroup, 1999). Other examples that incorporate immersion and embodiment include the Cave
Automated Visualization Environment (CAVE; Cruz-Neira, Sandin, & DeFanti, 1993). The CAVE is a small surround-screen projection space in which audio and visual media are projected in order to present users with a walk-in feeling, as if they were in a certain geographical or historical space (Cruz-Neira et al., 1993). Such immersive environments have been developed for purposes of professional training in a number of disciplines, such as submarine operation (Hill, Gratch & Johnson, 2001), medical preparedness (von Lubitz et al., 2001), rehabilitation (Tarr & Warren, 2002), mining (Kenyon et al., 1995), and flight simulation (Simpson et al., 2004).

Within the learning sciences, themes about embodiment and learning are relatively new and the spectrum of research broad (e.g., across formal and informal settings, varying time scales, and levels of social interaction). While successful application of mixed reality environments in various learning contexts has been demonstrated (including the examples above), our explicit understanding of the relationship between technologies and embodiment for learning is limited, with minimal concrete findings about learning gains (Price et al., 2008). One challenge for building on this body of research is developing effective methodologies for understanding the relationship between embodied interactions and real-time meaning making (Price & Jewitt, 2013). Compounding this issue is the increasing complexity of mixed reality environments for learning. Researchers are recognizing that environments that support co-located participants offer opportunities for promoting socially mediated learning through collaboration (Price, Roussos, Falcao, & Sheridan, 2009). To make progress on our understanding of the relationship between embodiment and learning, more investigations are needed to understand how environments taking advantage of embodied modes of interaction can contribute to classroom learning.

2.5 Summary

This chapter reviewed the body of literature related to this study, which began with a review of the theoretical foundations in social constructivism, followed by several relevant conceptual frameworks based on this perspective, including inquiry-based learning, knowledge communities, and embodied learning approaches. The KCI model, which combines traditions of inquiry learning with knowledge communities, offers educators an accessible means for integrating classrooms into a knowledge community through scripted inquiry activities,
facilitating a culture of collective inquiry in classrooms while still targeting specific curriculum objectives. While previous studies about KCI relied on wiki and other distributed technologies, the research program on smart classrooms was conceived as a means to support blended collective inquiry activities to encourage transforming classrooms into knowledge communities. The work presented in this thesis extends the smart classroom framework with a layer of immersion, building on prior work from on participatory simulations, mixed reality environments, and immersive environments to encourage embodied interactions for learning.

While a considerable amount of research has addressed the design of digitally augmented physical spaces, few projects have investigated rich, immersive experiences for inquiry-based learning, and none have investigated collective inquiry in digitally augmented physical spaces. Building on the literature on participatory means of engaging the whole class, such as Colella’s thinking tags (Colella, 2000) for how students could be engaged as pieces of the collective whole for supporting inquiry discussions (as individual agents in a disease simulation); building on a large corpus of scholarly work on scaffolded inquiry, scripting, and orchestration, and prior work on embedding content in physical space, such as Moher’s work on Embedded Phenomena that situates the investigational context in the physical classroom, motivating students’ inquiry (Moher, 2006); this thesis explores how the physical space of a room can serve to mediate students working as a knowledge community to collect data, support the visualization of the community’s aggregate data, and facilitate inquiry activities, including discussions of data. Prior to EvoRoom, we (the co-design team) did not know how students should be scaffolded within an immersive context – what they should see, how they should talk, how they could be supported in their discrete inquiry tasks (i.e., via their tablets). We did not know how students’ collective knowledge could be made to be a part of their inquiry in an immersive, whole-experience context – where should the collective knowledge reside, what the representation should be, how to include it in the pedagogical script. In the following chapters, I describe the methodology and present a pilot study and two iterations of a KCI curriculum designed around two collective inquiry activities with immersive simulations. To the extent that the findings relate specifically to the design of EvoRoom itself, they are later discussed in relation a set of broader design recommendations that may guide future design or research efforts.
Chapter 3

3 Methodology

This chapter presents the overall research methodology that guided the design-based research thesis study. Beginning with a description of design-based research, I discuss how this approach matches the goals of this study. I then describe the co-design process used to create the intervention materials and activity design. This is followed by descriptions of the participants and research setting, data sources and general analyses methods. This chapter concludes with a discussion on the limitations of the research.

3.1 Design-Based Research

This research employs a design-oriented methodology with the goal of developing and refining a new form of collective learning based on the KCI model that takes place in technology-augmented spaces. Design-based research was chosen as the research methodology for this project, as technological and pedagogical innovations is co-designed in close collaboration with teachers, and studied within the context of high school biology classroom.

Design-based research is characterized by iterative cycles of design, development and evaluation (Brown, 1992; Bannan-Ritland, 2003), and is well suited to studies involving the development of technology-enhanced learning environments, primarily due to its commitment to advance design, research and practice concurrently (Design-based research collective, 2003; Wang & Hannafin, 2005). The method embodies “the commitment to using theory-driven design to generate complex interventions that can be improved through empirical study and that can contribute to more basic understanding of the underlying theory” (DBRC, 2003, p.7). Through iterative cycles of design, enactment and evaluation, this method leads to an effective design, as well as temporal comparisons that can provide empirical findings. Importantly, it allows researchers to understand a learning phenomenon in the context in which the innovation is enacted. Because it emphasizes the study of a design within authentic situations, this method allows research within the complex and messy context of a classroom environment, as opposed to carefully controlled laboratory settings. Even so, adoption of a design-based research paradigm and the use of experimental research methods are not mutually exclusive. Evaluation
methods may be in the form of formative evaluation, usability studies, as well as empirical comparisons between groups or across successive iterations.

3.2 Co-design

It is not an easy task to develop a successful educational innovation that ultimately informs a theory for learning. Once designed, a number of factors will affect how a designed curriculum may be enacted, including the amount of support that teachers receive when implementing new innovations (Cohen & Hill, 2001), and how the new innovation complements the teacher’s current practice (Cuban, 2001). Co-design offers a method that involves researchers, teachers and technology developers throughout the design process (Penuel, Roschelle, & Shechtman, 2007). Working together, the co-design team attempts to understand each other’s values and perspectives while creating all the materials that address the research questions as well as the teacher’s learning goals (Peters & Slotta, 2008; Slotta & Peters, 2010). Through iterations of design and evaluation, teachers develop a close affinity with the project, understand the theoretical framework underlying important design decisions, and hence more faithfully enact the designed curriculum. By anticipating and managing tensions (e.g., by establishing realistic expectations, working towards a common goal), this method can allow teachers to develop increased agency, reflect on their practice and develop a sense of ownership of the innovation (Penuel, Roschelle, & Shechtman, 2007). A key rationale for using the co-design method is that it ensures ecologically validity: since all materials will be designed specifically for the participating teacher’s curriculum, the teacher will likely be able to enact the design without assistance from researchers.

3.3 Participants

3.3.1 Co-design team

The core design team, consisting of two researchers (Ph.D. supervisor and myself) and a high school biology teacher collaborated using a co-design methodology to create the simulation, inquiry activity and interactive materials. Our co-design partnership began six months prior to the pilot study, ending two and a half years later. Meeting approximately once per week during the academic school year, we considered important design elements and outlined our overall strategy. In the months leading up to the enactments, design meetings widened to include two
technology developers, and (in the Year 2) three additional researchers who occasionally joined the co-design meetings.

### 3.3.2 Students

The pilot study was conducted with eight high-school student volunteers who completed Grade 11 Biology. Participants from the first curricular year included 45 students (ages 14-16) from four class sections of Grade 11 Biology taught by the co-design teacher. The second trial occurred in the following academic year and included 56 new students. All of the participants (109 students) entered the study with no prior experience of the immersive simulation. Two students in Year 2 of the study dropped the Biology course midway for unrelated reasons. Due to variable completion rates for different components within the curricula, the sample size for each activity will be reported in detail in the relevant sections (in Chapters 4-6).

### 3.4 Research Setting

The research setting is an independent secondary school affiliated with the University of Toronto that offers a specialized curriculum for Grades 7 through 12. Students are high achieving and are admitted based on a competitive application process, which includes a Secondary School Admission Test (SSAT). Located on the downtown campus of the university, the school’s administrators and teachers are supportive of collaborations with researchers from Ontario Institute for Studies in Education of the University of Toronto (OISE/UT). It is also a training site for OISE/UT teacher candidates. Students are encouraged to balance academic work with a variety of extracurricular activities, which present many leadership opportunities as well as achievements in various competitions. As part of the specialized academic program in this school, students typically take on course work a year ahead of the local school board’s curricular expectations. As a result, many Grade 10 students are enrolled in the Grade 11 Biology course. Classes are age and gender balanced, which are determined by administrators at the beginning of the academic school year.

### 3.5 Materials

The product of our co-design effort is a curriculum for teaching biodiversity and evolution topics known as EvoRoom, which evolved over the course of our two and a half year collaboration. EvoRoom began as a 75-minute inquiry activity for students to explore evolution
concepts in the context of an immersive simulation of a rainforest in Southeast Asia, modeled after Borneo and Sumatra. This was evaluated in the pilot study in June 2011. In the two subsequent design iterations, the immersive simulation was embedded in a longer curriculum that included in-class activities, homework, a field trip to the zoo, and another collective inquiry activity with an immersive simulation on biodiversity topics. Year 1 was evaluated between November 2011 and February 2012, and the second design iteration of the curriculum was evaluated between February and June of 2013, lasting 12 and 16 weeks respectively, which included breaks in the regular school year calendar (e.g., Winter holiday, March break).

The many materials of EvoRoom fall into one of two wider categories: 1) those associated with the immersive simulation – “immersive simulation materials” and, 2) those associated with the curricular activities (e.g., in-class, homework activities) – “non-immersive materials.” Much of the latter set of materials was developed and delivered within a Drupal website (www.drupal.org) created by the co-design team, called the Learning Portfolio (Figure 1). Students used this website for a variety of course work both directly and peripherally related to the EvoRoom curriculum (i.e., throughout the Biology course) such as writing blog posts about unit topics (shared across classes within the same academic year) and writing personal reflections on each unit, viewable only by the student author, the teacher, and the research team. Details of materials specific to each design iteration will be discussed in the following relevant chapters.
Figure 1. Learning Portfolio class website from Year 2 of the study (student names blurred).
The collective inquiry activities with immersive simulations were designed for implementation within the smart classroom research environment (details described in the previous chapter). The following components make up the general set of materials for these activities:

- Collective inquiry activity script
- Immersive walls
- Collective visualizations (i.e., displays of aggregated information)
- Student device application
- Teacher control application

The collective inquiry activity script (Figure 2) specifies the instructional narrative of the activity, defining the roles of the students, their tasks and their groups, how materials are distributed, and the sequence of activity flow. The immersive walls situate students in the simulated rainforest through two sets of large projected displays (achieved by stitching together three displays) that students examine during collective inquiry activities (Figure 3).

Collective visualizations serve to capture and aggregate student observations in real-time for purposes of knowledge building and discourse. Custom EvoRoom tablet applications were developed to navigate student through the activities, providing instructions and supporting the collection of student observations. The simulation files shown on immersive walls are networked and controlled with a custom application that allows the teacher to manage the time spent in each portion of the activity, controlling the pedagogical flow within the room.
Figure 2. (Top) Activity script for the EvoRoom biodiversity version in Year 1, (Bottom) close-up.
3.5.1 Activity design

Two collective inquiry activities with immersive simulations were ultimately designed. One of the collective inquiry activities focuses on the topic of evolution. The general premise is that 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. Details of each activity and their materials are presented in the following chapters.

3.6 Design and Analyses

This thesis study employs a mixed methods research design to complement its design-based methodology. Both qualitative and quantitative evaluations are necessary to adequately represent a complex curriculum with numerous components, particularly since the enactments were done in the context of an authentic science classroom with few available experimental controls. Quantitative measures were primarily used to determine learning outcomes and student attitudes towards the intervention. Several sets of qualitative data were coded into quantitative data (Chi, 1997) and statistically analyzed (e.g., Student’s t-test, ANOVA). Student artifacts produced during the EvoRoom curriculum were evaluated with such a method. Qualitative
evaluations were primarily used to analyze long passages of text, such as video transcripts, to explore emergent content themes and embodied interactions.

### 3.6.1 Data sources

In the pilot study, students completed pre-/post activity questionnaires about their experience and attitudes towards the activity, while in Years 1 and 2 students completed pre-/post-tests for evaluating their scientific knowledge in addition to the questionnaires. During the activities, video recordings captured student interactions, while knowledge artifacts created by students (e.g., notes) were collected as measures of the quality of student ideas. For in-class activities, field trips, and homework assignments, student artifacts were collected. Many of these artifacts were gathered via the Learning Portfolio class website, which logged student activity. At the end of the school year, interviews with a randomly selected set of students were conducted to better understand student perceptions of the activities. A full list of data sources organized along each of the three dimensions of collective inquiry is included in Table 1.

In order to support the analysis of how EvoRoom enabled the three dimensions of collective inquiry, all data sources have been aligned with the dimensions in Table 1, below. Note that some data sources provide evidence for two or more of the levels.

**Table 1.** Data sources organized along three dimensions of collective inquiry

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Collective inquiry activities with immersive simulations</th>
<th>Curricular activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>• Activity logs of individual work</td>
<td>• Activity logs of individual work</td>
</tr>
<tr>
<td></td>
<td>• Artifacts of individual work</td>
<td>• Artifacts of individual work</td>
</tr>
<tr>
<td></td>
<td>• Post-activity questionnaires</td>
<td>• Post-curriculum questionnaires (i.e., student attitudes items)</td>
</tr>
<tr>
<td></td>
<td>• Student interviews</td>
<td>• Pre/post-tests</td>
</tr>
<tr>
<td></td>
<td>• Student reflections</td>
<td>• Student interviews</td>
</tr>
<tr>
<td></td>
<td>• Video data</td>
<td>• Student reflections</td>
</tr>
<tr>
<td>Collaborative</td>
<td>• Activity logs of collaborative work</td>
<td>• Activity logs of collaborative work</td>
</tr>
<tr>
<td></td>
<td>• Artifacts of collaborative work</td>
<td>• Artifacts of collaborative work</td>
</tr>
<tr>
<td></td>
<td>• Video data</td>
<td>• Post-curriculum questionnaires on collaboration items</td>
</tr>
<tr>
<td>Collective</td>
<td>• Activity logs of collective work</td>
<td>• Activity logs of collective work</td>
</tr>
<tr>
<td></td>
<td>• Artifacts of collective work</td>
<td>• Artifacts of collective work</td>
</tr>
</tbody>
</table>
3.6.2 General analytical approach

In general, the same basic analytical approach is applied to all design iterations, which will be described in this section. A detailed description of the specific analyses and coding schemes used for each iteration is provided in Chapters 4 through 6. In order to address how to design immersive simulations to support collective inquiry, and to understand the roles of the teacher, peers, and materials in student learning through the design iterations, findings are presented in terms of: 1) design issues, 2) design changes, and 3) outcomes of the change. A set of design recommendations based on the findings is presented in Chapters 4 through 6, while generalized design principles are presented in Chapter 7.

Although the pilot study was not designed as closely embedded within the broader curriculum, it was our first experience in creating such an environment and revealed a number of important design issues around engaging co-located students in an immersive simulation – including ideas for the broader curriculum itself. I thus begin with a description and discussion of the pilot study in Chapter 4, which sets the stage for the iterative design of EvoRoom.

In the two full implementations of the EvoRoom curriculum (i.e., Years 1 and 2) there were two distinct EvoRoom immersive simulations: one for biodiversity and one for evolution. For each Year, both collective inquiry activities within each EvoRoom curriculum are discussed along the three dimensions of collective inquiry. There are a total of five enactments of collective inquiry within the EvoRoom immersive environment: a pilot study (of the evolution activity), two enactments in Year 1 (i.e., biodiversity and evolution), and two enactments in Year 2 (i.e. evolution and biodiversity). The order of presentation of the two activities was reversed from Year 1 to Year 2; as a result of design revisions where the team felt that biodiversity might be best delivered after evolution. For the purposes of framing comparative analyses between activity enactments, there are interacting levels, as the notion of an “iteration” not only spans the pilot study, Year 1 and Year 2 (i.e., successive school years of iterative design and enactment), but also spans the revision of each specific topical activity (i.e., biodiversity and evolution activity). Hence, I examine all three levels of iterations, but with particular focus on the collective inquiry activities:
Iterations of EvoRoom Curriculum: Pilot → Year 1 → Year 2

Iterations of EvoRoom Evolution Activity: Pilot → Year 1 → Year 2

Iterations of EvoRoom Biodiversity Activity: Year 1 → Year 2

For each enactment of the EvoRoom curriculum (i.e., pilot, Year 1, Year 2), analyses and findings are organized according the three dimensions of collective inquiry (Table 2), presented in terms of design issues, changes that responded to these issues, and outcomes or results of the changes. Comparative analyses (i.e., between successive enactments) are presented to highlight the qualitative effects of the design changes implemented.

Table 2. General analyses organized along three dimensions of collective inquiry

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Collective inquiry activities with immersive simulations</th>
<th>Curricular activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>• Statistical analysis of student performance (i.e., from coding artifacts of individual work) &lt;br&gt; • Statistical analysis of participation from activity logs (for individual work) &lt;br&gt; • Statistical analysis of student attitudes of EvoRoom environment and inquiry activities &lt;br&gt; • Qualitative analysis of student attitudes of EvoRoom environment and inquiry activities &lt;br&gt; • Interaction analysis of video data</td>
<td>• Analysis of participation (i.e., from activity logs of individual work) &lt;br&gt; • Statistical analysis of pre/post-tests &lt;br&gt; • Qualitative analysis of student attitudes of EvoRoom curriculum</td>
</tr>
<tr>
<td>Collaborative</td>
<td>• Statistical analysis of group performance &lt;br&gt; • Multimodal interaction analysis of video data</td>
<td>• Analysis of participation from activity logs (for group work) &lt;br&gt; • Descriptive statistics and/or assessment of collaborative work &lt;br&gt; • Statistical analysis of post-curriculum questionnaires on collaboration items</td>
</tr>
<tr>
<td>Collective</td>
<td>• Analysis of participation from activity logs (for collective work) &lt;br&gt; • Analysis of performance from artifacts of collective work</td>
<td>• Analysis of participation from activity logs (for collective work) &lt;br&gt; • Analysis of performance from artifacts of collective work &lt;br&gt; • Statistical analysis of post-curriculum questionnaires on collective epistemological items</td>
</tr>
</tbody>
</table>
3.6.2.1 Interaction analysis

To categorize the interactions observed (e.g., student-to-student, student-to-tablet, student-to-visualization, student-to-teacher) in videos recordings of the EvoRoom collective inquiry activities, I developed a method of content analysis (Chi, 1997) to examine larger patterns of interactions combined with deeper qualitative multimodal interaction analyses for investigating the role of embodiment in the collaborative learning process within mixed reality learning environments. As with analyzing small group interactions and video-based interactional data, one challenge of solely utilizing multimodal methods of analysis is that they are often nuanced and specific to the context being examined. With the high levels of complexity designed into our mixed reality learning environment—including different forms of digital representations coupled to physical space, as well as capabilities for collaboration and collective knowledge work—detailed scrutiny of each and every student’s mode of communication for the entire duration of the intervention may not be possible. Content analysis of qualitative data may be used in such cases to interpret wider patterns of activity, as exemplified by CORTRA diagrams (Hemlo Silver et al., 2010) and Wilkerson-Jerde, Gravel and Macrander’s (2014) coding representations.

Recent work by Price and Jewitt (2013), offers a methodological approach to examine embodiment and learning with case study analysis, drawing on multimodal methods of analysis. Multimodal analysis approaches are based on the premise that human communication involves both spoken and written language as well as non-verbal behavior, such as body movement and gaze (Norris, 2004). That is, our interaction with the material world is characterized by communicative modes. By breaking down enactments of complex learning environments into units of action—mediated or otherwise, multimodality offers a way to explore concepts of embodiment in the knowledge construction process. For mixed reality learning environments and other complex learning environments, quantitative data analysis offer broad brush sketches of embodied interactions in situ, while deeper analyses of small group interaction and discourse data allow us to understand how observed patterns translate into student actions, and how knowledge construction and collaboration is mediated.

To explore student interactions with various components of EvoRoom, this thesis uses multimodality as a lens to explore how the mixed reality environment can serve to support
students’ collaborative and collective inquiry patterns. Specifically, I consider the role of embodied interactions in mediating their collective inquiry. For each collective inquiry activity (with immersive simulations), I first examine larger patterns of changes in communications modes over time, then present a deeper multimodal interaction analysis (Norris, 2004) of a representative small-group interaction, guided by the preceding broader analysis.

Table 3 describes the multimodal interaction analysis employed in this research. First, I used this framework to determine the relevance of different communicative modes for representation and meaning making (Norris, 2004) in our mixed reality environment. Next, a list of codes for examining gaze and interactions was generated, as they apply to the environment. The specifics of this set of analysis are described in Chapters 5 and 6.

**Table 3.** Multimodality communicative modes relevant to the analysis of mixed reality learning environments

<table>
<thead>
<tr>
<th>Communicative mode</th>
<th>Analysis in mixed reality environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken language</td>
<td>Indicative of interaction between people (e.g., student, teacher). May be seen (i.e., mouths moving) or heard in video. Salient mode particularly for collaborative learning environments. A conversation between two or more students may be considered a student-to-student interaction. One between a student and teacher maybe further broken down as student-to-teacher or teacher-to-student interaction, depending on who initiated contact. Often transcribed, content of discourse may be coded and quantified (Chi, 1997).</td>
</tr>
<tr>
<td>Proxemics</td>
<td>How people utilize space and arrange themselves in space. May be important to understand pair-wise or small group interactions, particularly environments involving manipulation of tangible technology. Distance between participants may be considered (e.g., indicating formality, intimacy).</td>
</tr>
<tr>
<td>Posture</td>
<td>How people position their own bodies (e.g., open, close positions) may have implications in understanding group dynamics or studies on engagement.</td>
</tr>
<tr>
<td>Gesture</td>
<td>Considered an important mode of non-verbal communication, primarily because it occurs temporally with speech but conveys idiosyncratic and imagistic information (McNeill, 1992).</td>
</tr>
<tr>
<td>Head movement</td>
<td>How people positions their heads may signal shifts in a number of different modes, including gaze and posture.</td>
</tr>
<tr>
<td>Gaze</td>
<td>Direction, duration, and intensity may provide information about attention and awareness.</td>
</tr>
</tbody>
</table>
This study is one from a series of smart classroom studies that investigate new ways of teaching and learning in technology-enhanced classrooms led by my Ph.D. supervisor, Professor James Slotta. University of Toronto’s Research Ethics Board (REB) approved this research in April 2010 and extended until the completion of this research in 2015 (University of Toronto Protocol Reference #25178).

3.7.1 Confidentiality, privacy and anonymity

Every effort has been made to ensure confidentiality and anonymity of all participants involved in the study. All names were replaced with codes and will only be accessible by the immediate co-design research team. Any references to a specific school or other identifying information were removed from the data. Images with students’ names were blurred for privacy.

3.7.2 Conflicts of interest

There are no conflicts of interest associated with the research associated with this thesis. The researchers, members of the researcher team, and/or their immediate family have not received any personal benefits, nor is there any pre-existing relationship between the researchers and the researched.

3.7.3 Informed consent process

At the beginning of each school year a detailed Information Letter was provided to the students of our co-design teacher (Appendix A). This letter outlined the goals of the study, described how the researchers would analyze student work in the curriculum, and explained how confidentiality would be protected. Students were instructed to show this letter to their parents, who were encouraged to contact the researcher or the school officials if they would like more
details. All students in the classrooms of participating teacher took part in the co-designed curriculum activities, which constituted part of their normal curriculum.

Students who participated in a photographed/videotaped classroom session received a letter of permission well in advance of any such activity (Appendix B). Any students who did not return signed letters of permission were not videotaped. Students selected to participate in an interview also were also required to return a letter of permission from their parents (Appendix C). Finally, letters of permission were obtained from school administrators and teachers affected by the study (Appendices D & E).

3.8 Limitations of Study

This thesis study represents the first effort to employ a mixed-reality, immersive environment to encourage collective approaches to learning. Due to the complexity of activities and interaction scripts to be designed, a number of limitations were involved. First, within my own limits as a researcher, I may only be able to attend to certain aspects of these designs in addressing the research questions. Also since the study was conducted in a unique high school setting, it will be difficult to draw any conclusions about the extensibility of this approach to other settings (i.e., in relation to external validity). Indeed, the technology would be difficult to implement in other classrooms but that is not the aim of the research. The main goal for the study, rather than informing educational change, is to investigate the theoretical implications of immersive learning within the collective inquiry framework provided by the KCI model. Findings were abstracted in terms of design guidelines for educational research to be presented as part of the general discussion in Chapter 7.
Chapter 4: Pilot Study

4 Pilot Study

The pilot study of this research was conducted in June 2011 after six months of regular co-design meetings with a high school biology teacher. Our goal was to design an immersive simulation that built upon ideas from the research literature, incorporating aspects of participatory simulations and full-body immersion to deeply engage students in conducting embodied scientific inquiry about their immediate surroundings. This study is an exploratory study of students’ experience in our first design of such a space.

To begin, we decided not to try to evoke any sense of belonging in the immersive rainforest. In other words, we were not trying to suspend students’ disbelief to make them feel as if they were in an actual forest where they would be able to interact with insects and animals and manipulate the environment. Rather, the intent was that they be collectively immersed in observing a rainforest, carefully situated in space and time. While this is a hybrid form of immersivity, it allows us to define our interaction space, and not adopt direct modes of interaction and focus on conceptual connections and peer exchange.

4.1 Participants

The pilot study was conducted with eight high school student volunteers who had completed a Grade 11 Biology course.

4.2 Procedure

The study was conducted as a single two-hour session, which took part in the EvoRoom immersive simulation environment one week after the end of the academic school year, and provided important insight into formative aspects of the design, including the collaborative activities, media elements and interactions.

4.3 Data Sources

Students completed pre-/post-activity questionnaires (Appendix F). During the activity, video recordings captured student interactions, providing a data source for qualitative analysis,
while knowledge artifacts created by students (e.g., notes) were also collected as measures of the quality of student ideas.

4.4 Activity Design

The first version of EvoRoom was quite basic, with students entering the room (Figure 4) to find large projected animations of the rainforest ecosystem on the left- and right- hand walls, with the rainforest scenery, plants and animals rendered as computer animations. Using the smart classroom’s integrated audio system, we played ambient background recordings of rainforest insects, hung mosquito nets from the ceiling and included large potted palm plants in the corners of the room. The result was an immersive experience of Sundaland, a region in Southeast Asia predating Borneo and Sumatra, about two Million Years Ago (MYA). After the premise of the activity was introduced, and the historical context of the rainforest environment explained, students were scaffolded by their tablets to record field observations about various species within the EvoRoom (Figure 5). This employed a custom software application that was integrated within the broader smart classroom infrastructure (Figure 6).

Figure 4. Room layout of EvoRoom, pilot version
Figure 5. Image of students collecting observations in the EvoRoom pilot. Three projectors make up one of two "immersive walls" and the projection at the front of the room provides geographical context for the environment.
Figure 6. Selected screens of the tablet application, pilot version. Top left: Home screen of observation tab, featured tag clouds of observations made. Top middle: View all screen of observation tab, allowed students to filter observations made by the associated location (i.e., Sundaland - “SUD”, Borneo - “BOR”, Sumatra - “SUM”). Top right: View observation screen. Bottom left: Field guide home screen. Bottom middle: Screen for selecting specific species to access detailed information. Bottom right: Detailed information screen of a species.
The teacher also had a tablet computer that provided her with controls for the various elements of the room. For example, using a tablet screen controller, she could advance the room through time, revealing a sequence of geologic events that affected the Sundaland landscape over the span of two million years. On the projected display 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, one side of the room showed Borneo’s ecosystem, while the other side showed Sumatra’s (Figure 7). Observable differences between the two sides of the room reflected evolutionary separation that resulted when they became separated by ocean. Students spent 15 minutes making observations of the two sides of the room in this context. Next, they 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?*). These observations were projected on the walls and the teacher led a discussion.
In the final step, the two teams came together to review their collective observations about the process of evolution over this two million year span (as captured by the emerging differences between the two sides of the room). Students were encouraged to discuss their ideas with others and to post ideas about evolution concepts. The posts were aggregated to the interactive whiteboard, visibly representing the collective knowledge base of the students at the end of the activity (Figure 8). The teacher was able to use the content of this display to lead a synthesis discussion to close the activity.

**Figure 7.** "Immersive wall" content in EvoRoom, pilot version. Top: Sundaland image shown on both side walls of the room during the first observation period. Middle: Sumatra rainforest shown on the right side wall during the second observation phase. Bottom: Borneo rainforest shown on the left side wall during the second observation phase.
Figure 8. Collective visualization of aggregated notes from the final step where students brainstormed about the processes of evolution over the two million year span were shown on the interactive whiteboard.

4.5 Results and Discussion

4.5.1 Overview

Analysis of student performance and perceptions in EvoRoom indicates that students were able to effectively allocate their attention between the immersive simulation and the various technologies supporting their tasks (e.g., tablets, laptops). Although content analysis of observation notes indicated that more scaffolds are needed to support higher-level thinking about evolutionary mechanisms, most students found that they had better grasps of evolution after the activity. The most cited reason was that the activity helped to reveal the interconnectedness between organisms in an ecosystem as well as the connections between evolutionary concepts. The students also believed that the environment supported their engagement (as a group) in the activity. Sections below review the outcomes of the pilot in terms of individual, collaborative,
and collective dimensions of collective inquiry. Each section ends with a design recommendation for the further development of EvoRoom.

4.5.2 Individual level

Finding: Student attitudes were positive, highly rating their immersive experience

Students and the teacher were excited and engaged by this experience, which had been their first, in terms of experiencing large format displays and immersive simulations in a school setting. Of the specific components of the activity, the most highly rated by students was the use of tablets for accessing information ($M = 9.00$, $SD = 0.58$), on a scale of 1 to 10 (with 1 being unsuccessful and 10 being very successful; Table 4). One student mentioned that it was “Really useful, especially when researching biological relationships between animals.” The use of the immersive environment was also rated highly ($M = 8.86$, $SD = 0.95$), eliciting comments such as “Very nice, interactive environment”, “Creative and fun”, and “The use of the [smart classroom] really helped to immerse the group in the activity and prompted us to get more involved in the activity.”

Table 4. Student attitudes on EvoRoom, evolution activity, pilot version

<table>
<thead>
<tr>
<th>Items</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall activity</td>
<td>7.64</td>
<td>0.85</td>
</tr>
<tr>
<td>Activity's learning potential</td>
<td>8.21</td>
<td>1.15</td>
</tr>
<tr>
<td>Visualizing the integration of evolutionary concepts</td>
<td>7.36</td>
<td>1.11</td>
</tr>
<tr>
<td>Role of discussions</td>
<td>7.36</td>
<td>0.75</td>
</tr>
<tr>
<td>Flow of information</td>
<td>7.50</td>
<td>0.65</td>
</tr>
<tr>
<td>Use of tablets for adding observations</td>
<td>7.71</td>
<td>1.35</td>
</tr>
<tr>
<td>Use of laptops for group work portion of this activity</td>
<td>6.93</td>
<td>0.35</td>
</tr>
<tr>
<td>Use of tablets of accessing additional information (e.g., field guide)</td>
<td>9.00</td>
<td>0.58</td>
</tr>
<tr>
<td>Use of the &quot;smart classroom&quot; (e.g., large screen projectors, immersive environment, etc.)</td>
<td>8.86</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Finding: Limited interactions amongst stationary students characterized the enactment

The evolution activity enactment was completed in 96 minutes, which was 36 minutes over the time allotted for the activity. When students first walked into the room, they moved around in the space, looking around the room until they were asked to take a seat on one of the stools provided in the center of the room. The intent was for students to sit there while the teacher introduced them to the activity, which they did. However, to our surprise, they remained
seated there, looking around the room but did not leave their stools throughout the observation phase. Despite the teacher’s suggestion that they could see more if they went up closer to the displays, students remained in their seats, occasionally turning to switch views between the left and right immersive walls. One student stood up briefly to look at one of the walls and promptly sat down again. It was not until the group reflection phase, when students were explicitly asked to move to their designated group workspace, that they moved to the “research stations.” Students remained seated in their static positions throughout other phases of the room as well, as indicated in Table 5.

**Table 5.** Patterns of interactions and students’ spatial positions within EvoRoom during phases of the evolution activity, pilot version

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Interactions (between students and teacher)</th>
<th>Student positions</th>
<th>Duration (h:m:s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Teacher introduces premise of the activity</td>
<td>Teacher-class interaction (i.e., plenary)&lt;br&gt;1 Student-teacher interaction, fact-based question (“How do you decide if it’s an organic structure?”)</td>
<td>Students moved from the door to the center of the room, looking around</td>
<td>0:03:43</td>
</tr>
<tr>
<td>Observation</td>
<td>Students individually make observations about Sundaland</td>
<td>12 student-to-student interactions&lt;br&gt;11 teacher-to-class interactions, over half of the statements concerned class management and student performance.&lt;br&gt;7 student-teacher interactions, fact questions</td>
<td></td>
<td>0:17:30</td>
</tr>
<tr>
<td>Transition</td>
<td>Teacher reveals a sequence of geologic events that broke Sundaland into a peninsula and several islands (e.g., Borneo and Sumatra)</td>
<td>Teacher-class interaction</td>
<td></td>
<td>0:01:52</td>
</tr>
<tr>
<td>Observation II</td>
<td>Students individually make observations about Borneo and Sumatra</td>
<td>1 student-teacher interaction (about the technology – “Is there a way to edit stuff?”) 5 teacher-class interactions (most statements were related to classroom management, particularly time)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group reflection phase</td>
<td>Students work in groups to answer a set of questions about their observations. The teacher leads a discussion on their answers</td>
<td>Student-student interactions  Teacher-group interactions  Teacher-class interaction (Students spent approximately 34 mins discussing with their team members as well as their teacher, results were projected and discussed for 7 mins)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td>Students write notes about processes of evolution that might have occurred in this environment</td>
<td>Some students worked on their final explanations together, while others submitted their own explanations. Specific student interactions were not mapped out due to the quality of video recorded</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total | 1:36:10 |

Relatively few student interactions were observed (with the exception of the group reflection phase, where students were instructed to complete a collaborative task). Of the two observation phases, all of the student-initiated interactions occurred during the first phase (12 student-to-student, 7 student-to-teacher interactions / fact questions asked; Table 5). None of the students were observed to initiate any interaction during the second observation phase. This is likely due in part to the students remaining stationary throughout the observation phases, with access only to their immediate neighbours. One idea to explore further is compelling students to move around the room, encouraging more natural face-to-face interactions among peers. It was one of our initial suppositions for such a space – that face-to-face interactions situated in an embodied physical space foster knowledge co-construction, thereby improving scientific reasoning and understanding.
Design recommendation: Encourage student movement around the physical space of the immersive simulation by designing activities and prompts that required student localization.

Finding: Only some student observations were focused on the intended pedagogical target

Using a note-taking form on their tablet computers, students made free-form observations about the organisms 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. Student wrote an average of 19.6 \((SD = 8.8)\) observations per person (ranging from 7 to 28 observations per person), with an average of 11 words per observation \((SD=12.2)\). The notes were analyzed, following Chi’s (1997) method for content analysis. Using each observation as a unit of analysis, they were coded for content type and nature of the content (Table 6). An inter-rater reliability (IRR) 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 (38%) or about the animal’s behavior (55%) – Figure 9 shows the complete breakdown of the nature of content in students’ observation notes.

<table>
<thead>
<tr>
<th>Content Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence</td>
<td>Discusses the presence or lack of presence of a species, e.g., <em>There are two kinds of figs, strangler fig and curtain fig.</em></td>
</tr>
<tr>
<td>Physical Characteristics</td>
<td>Describes a physical characteristics of a species, e.g., <em>The fig wasp has purple wings, long antenna, and a striped body.</em></td>
</tr>
<tr>
<td>Behavior</td>
<td>Describes the behavior of a species, such as movement, e.g., <em>There are two tapirs, one walking really slowly and one drinking from a shallow pool.</em></td>
</tr>
</tbody>
</table>
Students showed considerable focus in their interactions with the materials (e.g., tablets, walls), but were only able to make superficial evolutionary connections. Examining the students’ observation notes more closely, we noticed that there was a wide range in the quality of the observations. For example, the word count ranged between 1 and 104 words per observation note. Many observations were rather basic and did not reveal information pertaining to evolutionary change. Moreover, over half of the observations made focused on the behavior of the organisms, which was not intended as a productive line of reasoning in the design (i.e., the behaviours of species were not designed so as to provide any productive evidence about evolution). For example, an observation that focused on behaviour was, “There are two tapirs, one walking really slowly and one drinking from a shallow pool.” An observation that focused on physical characteristics was, “The fig wasp has purple wings, long antenna, and a striped body.” The nature of the explanations also tended to be about surface features of the species observed. We recognized that asking students to make general observation notes was not conducive to the goal of the activity itself. It became clear that more scaffolds were needed to support students in higher-level thinking about evolutionary mechanisms.

**Figure 9.** Pie chart of observation notes categorized by coded content type
**Design recommendation**: Support higher-level thinking about evolutionary mechanisms by including more structured and scaffolded tasks that help students make connections to the relevant features of the simulations.

**Finding**: Quality of explanations was lower than desired

At the end of the activity, students were asked individually, to address 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 (e.g., adaption, bottleneck, coevolution…etc.) and to explain their answers with sufficient evidence. 14 explanations were collected, with an average word count of 24 words per explanation (*SD=14.58*).

Students tagged the explanations as adaptation in 36% of the notes, with the remaining explanations tagged as: coevolution (21%), sexual selection (21%), and reproductive isolation (14%). However when a content analysis similar to that of the previous section (for observation notes) was performed to characterize the content type, only 36% of the explanations were coded as being about evolution (Figure 10). This meant that 64% of these explanation notes were not relevant to the discussion on evolution.

**Figure 10.** Pie chart of explanation notes categorized by coded content type.
The explanations were scored using a 0-5 Knowledge Integration scale that rewards valid scientific connections between concepts (Table 7; Linn & Elyon, 2011). The explanations scored an average of 2.36 ($SD=0.75$) out of a possible score of 5, which reflected the nature of the explanations, many were about surface features of the species observed. The results echo the finding on student observations, suggesting that more support is needed to foster higher-level thinking about evolutionary mechanisms.

**Table 7.** Knowledge Integration rubric used to score student explanations (Linn & Elyon, 2011).

<table>
<thead>
<tr>
<th>Score</th>
<th>KI Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No answer</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Off task</td>
<td>· Response is irrelevant or “I don’t know”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>· Student writes some text, but it does not answer the question being asked</td>
</tr>
<tr>
<td>2</td>
<td>Irrelevant/Incorrect</td>
<td>· Have relevant ideas but fail to recognize links between them</td>
</tr>
<tr>
<td></td>
<td></td>
<td>· Make links between relevant and irrelevant ideas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>· Have incorrect/irrelevant ideas</td>
</tr>
<tr>
<td>3</td>
<td>Partial</td>
<td>Have relevant ideas but do not fully elaborate links between them in a given context</td>
</tr>
<tr>
<td>4</td>
<td>Basic</td>
<td>Elaborate a scientifically valid link between two ideas relevant to a given context</td>
</tr>
<tr>
<td>5</td>
<td>Complex</td>
<td>Elaborate two or more scientifically valid links among ideas relevant to a given context</td>
</tr>
</tbody>
</table>

*Design recommendation (same as above): Support higher-level thinking about evolutionary mechanisms by including more structured and scaffolded tasks that help students make connections to the relevant features of the simulations.*

### 4.5.3 Collaborative level

**Finding:** Students believe that discussions allowed them to share ideas and highlighted items they did not individually notice, but are in favor of more challenging collaborative tasks

The group reflection phase was the only point during the activity when students were explicitly asked to work together. Despite some technical issues that arose during this phase, disrupting the flow of the activity, students were able to complete the tasks, answering the summative questions as a group without very much facilitation from the teacher. The following transcript is an example of a typical interaction between group members:

S1: Ok Borneo, what other species are there in Borneo?
S2: That's it.
S3: No there's one thing. There’s a specific [organism].
S2: There’s the orangutan. If it’s the same species...(student referring to tablet)
S1: No [inaudible] species
S2: It's the Bornean orangutan. Ummm…
S1: Anything else?
S1: (Reading question aloud) What common species are found in both Sundaland and Borneo?
S2: Uh. Fig wasps? Hornbill.
S3: Proboscis monkey.
S1: Orangutan.
S2: And then plants, there’s that…
S3: Fig?
S1: Let’s say corpse flower.
S2: Strangler fig. And apparently there’s the Tetrastigma but I didn't see it.

All group members in this example contributed to the discussion and the answers reflected the input of those involved.

Two students suggested, in their post-activity questionnaire, that their small group discussions helped them share ideas and highlighted items that they did not individually notice. One person noted that using the collaborative time to solve problems, rather than to compare notes about their individual observations, would have been a more productive use of their time – suggesting that the activity needed to be more challenging. From this, we found that one opportunity for improvement in the next iteration was to raise the standard for collaborative work, supporting further advancement with an additional level of scripting for collaboration.

**Design recommendation:** Add a level of scripting to support student small groups, giving them more explicit opportunities to share and exchange in the advancement of their inquiry tasks.

### 4.5.4 Collective level

**Finding:** Students had limited access to collective levels of knowledge

Throughout the activity, students were engaged on the collective level primarily through the teacher’s interactions with the class, with the dominant mode of interaction for the teacher being one of initiating plenary exchanges (i.e. teacher-to-class). Many of the teacher’s statements performance statements (i.e., 23 classroom management and student performance made; Table 5) during the activity, with most of these statements related to time management (e.g., “Are you
ready to move on? Are you satisfied with your observations?”). At one point during the transition phase, the teacher attempted to engage students in discussion, but generally allowed students to work individually and in their groups. Collective levels of knowledge were mostly found in the discussion phases (i.e., in group reflection and explanation phases) where all of the students’ work were projected and discussed. The teacher led students through this information and asked a series of open-ended and closed-ended questions to engage students in discussion. Over the course of the entire activity, the teacher asked a total of 3 open-ended questions and 7 more closed-ended questions (i.e., with well-defined answers). In the explanation phase, she ended the activity with a summative statement about natural selection as an important unifying principle that connects other evolutionary mechanisms – an idea she had been trying to elicit from students during the earlier questioning. Below is an excerpt:

Ok so natural selection is actually the one that encompasses them all. It makes sense that it gets all the tags and it doesn’t matter which species... they're not isolated, they are all working together and that was kind of the idea of trying to do this exercise, because in the end it's going to show that when you tag the notes, the [term with the] most number of tags IS the umbrella term. The one that is going to bring them all together, and you're going to have details about them [from the notes].

- Mallory, 11th EvoRoom classroom teacher

One of the outcomes of this pilot study was that most students found that they had better grasps of evolution after the activity, with the most cited reason being how the activity helped revealed the interconnectedness between organisms in an ecosystem as well as the connections between evolutionary concepts. Several students identified the collective explanation step as having been important to their insight. This was an encouraging outcome, as the explanation step was explicitly designed for students to make ties between their observations and the underlying evolutionary concepts. However, students had limited opportunity to take advantage of the group’s collective knowledge during the activity. The visualization that showed aggregated notes (Figure 8) was shown at only at the end of the activity, and only the teacher actually manipulated the interactive white board display.

**Design recommendation:** Make students’ collective inquiry products visible and accessible during the activity, and allow students as well as the teacher to interact with the display.
4.5.5 Design Implications

The pilot study provided our first glimpse – and one of the first ever – into the use of an immersive simulation for collective inquiry, allowing us to see and experience EvoRoom in action. We were in new territory, as (to our knowledge) few if any such environments had ever been created – particularly those designed to emphasize group-level curricular interactions. This concern with group interactions was a central concern in our design of the high school biology curriculum, in which the EvoRoom immersive simulations would play an important role. The pilot study provided a wealth of experience and insight in all aspects of the research, including the development of immersive wall content, the design of tablet-based collaborative software, the representations of community knowledge (on interactive whiteboards), and the underlying infrastructure (i.e., for collecting and disseminating collective visualizations). This initial version of EvoRoom also reinforced many positive aspects of our designs, and provided a valuable source of reference in our subsequent design efforts. Table 8 summarizes the design recommendations that came out of this pilot trial.
**Table 8.** Summary of findings and design recommendations from the EvoRoom pilot study

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Pilot study findings</th>
<th>Pilot design recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>1. Limited interactions amongst stationary students characterized the enactment</td>
<td>• Encourage student movement around the physical space of the immersive simulation by designing activities and prompts that required student localization (<em>to address finding 1</em>)</td>
</tr>
<tr>
<td></td>
<td>2. Only some student observations were focused on the intended pedagogical target</td>
<td>• Support higher-level thinking about evolutionary mechanisms by including more structured and scaffolded tasks that help students make connections to the relevant features of the simulations (<em>to address findings 2 and 3</em>)</td>
</tr>
<tr>
<td></td>
<td>3. Quality of explanations was lower than desired</td>
<td></td>
</tr>
<tr>
<td>Collaborative</td>
<td>4. Students believe that discussions allowed them to share ideas and highlighted items they did not individually notice, but are in favor of more challenging collaborative tasks</td>
<td>• Add a level of scripting to support student small groups, giving them more explicit opportunities to share and exchange in the advancement of their inquiry tasks (<em>to support finding 4</em>)</td>
</tr>
<tr>
<td>Collective</td>
<td>5. Students had limited access to collective levels of knowledge</td>
<td>• Make students’ collective inquiry products visible and accessible during the activity, and allow students as well as the teacher to interact with the display (<em>to address finding 5</em>)</td>
</tr>
</tbody>
</table>
Chapter 5

5 Year 1 Design Iteration

The first full iteration of this research was conducted between November 2011 and February 2012 during the academic school year, for use by students in our co-design teacher’s classes. It had been a well-settled element of our design that we would embed the immersive simulation activity within a series of in-class and homework activities and package (i.e., as part of a longer curriculum). After the pilot study, we continued meeting over the summer to design these activities. All curriculum activities – those to occur in the regular classroom, as homework, and in the EvoRoom immersive simulation environment – were designed to guide the development of student ideas and promote a sense of knowledge community within the class.

One of our insights from enacting the pilot study was our understanding that biodiversity and evolution are interrelated, and that students may benefit from understanding the organisms and their roles in the ecosystem before they could reflect more deeply about their evolution. As a result, we added a biodiversity activity in the immersive space as part of the curriculum, to be completed before the evolution activity. Hence, Year 1 (as well as Year 2) included two distinct EvoRoom immersive simulations, one for biodiversity and one for evolution.

5.1 Participants

Participants of the trials in Year 1 were 45 students from two class sections of Grade 11 biology (taught by our co-design teacher).

5.2 Procedure

The Year 1 iteration was embedded within a broader 12-week curriculum design, and included two EvoRoom collective inquiry activities, designed in close connection with in-class and homework activities.

5.3 Data Sources

Students completed a pre-/post-test administered to determine students’ understanding of evolution concepts. The Concept Inventory of Natural Selection (CINS; Anderson, Fischer, &
Norman, 2002) was used as a source of the conceptual elements on the pre-/post-assessments. Students also completed pre-/post-activity questionnaires (Appendix F) that asked about their experiences with the collective inquiry activity and to rate the various components of the immersive simulation. During the EvoRoom collective inquiry activities, video recordings captured student interactions, and all knowledge artifacts created by students (e.g., notes) were collected, providing measures of student ideas and collaborative exchange.

5.4 Curriculum Design

The collective inquiry activities with immersive simulations were designed as tightly integrated elements within a broader 12-week curriculum evolutionary biology and biodiversity. It was a priority to ensure that the immersive simulation activities were connected with other activities in such a way that they provided real learning advantage for students. Hence, we designed “pre” activities for students to complete in class or as homework that would ensure they were prepared for our designed experiences within the room. We also designed “post” activities that promoted reflection and application of ideas, with the general aim of integrating the overall curriculum. Using a combination of in-class activities, a field trip to the zoo, and homework activities, students engaged with several forms of instructional media, including paper and pencil (e.g., for zoo worksheets), a class website (e.g., for supporting group work, personal reflections, and homework), as well as tablets computers, large-screen displays, and interactive white boards during the immersive simulation activities. This section describes the various elements of the curriculum, detailing the EvoRoom activities as they occurred within the curriculum sequence (
Table 9).
Table 9. Summary of the Year 1’s curriculum design: in-class (I), homework (H), and smart classroom (S).

<table>
<thead>
<tr>
<th>Week</th>
<th>Description</th>
<th>Curricular Goals</th>
</tr>
</thead>
</table>
| 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 instruction: The origin of life and the theory of evolution | • Prepare students with background knowledge |
| 5    | • Traditional instruction: Molecular evidence for evolution and micro-evolution | • Prepare students with background knowledge |
| 6    | • Traditional instruction: Variation, selective advantage, natural selection | • Prepare students with background knowledge |
| 7    | • Traditional instruction: Mechanisms of evolution, including sexual selection, gene flow, genetic drift | • Prepare students with background knowledge |
| 8    | • Understanding of evolution survey (H) | • Reflect on personal understanding of evolution |
| 9    | • Relatedness of species in Borneo and Sumatran assignment (H) | • Understand concept of “relatedness” and how assigned species are related to each other |
| 10   | • EvoRoom: Evolution activity – 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 activity – Day 2 (S) | • Investigate evolutionary processes in rainforest ecology |
| 12   | • Personal reflection (H) | • Reflect on personal understandings |
Figure 11. Image of digital field guide on a class website, designed as part of this research (names of students blurred).

The goal of the curricular activities in weeks 1 and 2 was to help students to develop some preliminary understandings of complex interrelationships within an ecosystem and think about the implications of environmental effects on the biodiversity of the species in the ecosystem. Each class was divided into two cohorts (i.e., since only groups of 12 would work...
well within the EvoRoom environment), each of which was further divided into four specialist
groups: plants & insects, birds, primates, and other mammals. Hence, there were eight groups per
class, consisting of two or three students (i.e., there are two “bird” specialty groups in each class
– one for each cohort). Students were presented with information about each of their species via
a digital field guide that was accessed through their class website (Figure 11).

As part of a field trip to the Toronto zoo, students completed a 7-page worksheet that
asked them to find different species and describe their physical appearance, including
information about their diet, reproduction, and predators for each of the following phyla or
classes of organisms: invertebrates, plants, bony fish, amphibians, reptiles, birds, and mammals.
Students were to find four organisms per category, noting the common features for each of these
categories (e.g., endoskeleton, exoskeleton, warm blooded, cold blooded). For the category that
matched their specialty (e.g., primates), students were asked to choose either their specialty
species (if it was found at the zoo) or its closest relative.

The collaborative food web activity was designed to familiarize students with the
relationships between the different species of Borneo. For this activity, each student had access
to an online food web file, shared amongst all the students from the class. Students were
instructed to divide and conquer within their specialty groups to add their specialty species to the
food web and create connections between their own species and those belong to other specialties.
To scaffold students in completing the food web in an efficient manner, students filled out a
worksheet in their class website describing the predators and prey of their assigned species.

5.4.1 EvoRoom Biodiversity activity

For homework in the days preceding the collective inquiry activity, students worked as a
group to create “scenarios” about how various environmental conditions could affect the
biodiversity of a rainforest ecosystem over a five-year time span. The factors included: high
rainfall, low rainfall, high sunlight, low sunlight, high temperature, low temperature, earthquake,
and tsunami. Each of the eight groups in each class was assigned one of these factors.

Students then visited EvoRoom as cohorts such that four groups with different specialties
would be in the room together. Once in the room, they were presented with four different
versions of the Borneo rainforest ecosystem (Figure 12). We designed a tablet-based interface
that challenged students to explore the differences between these four rainforests and to locate the rainforest that resulted from the variable they had explored in their homework (Figure 13).

**Figure 12.** Image of room setup of EvoRoom, Year 1 biodiversity activity version. Four scenarios of the rainforest ecosystems were designated Station A, B, C and D.
Figure 13. Selected screens of the EvoRoom biodiversity tablet application for Year 1. Top left: Observation screen. Top right: Note-taker screen for the scribe during the rainforest rotation phase. Bottom left: Information look-up screen for group members not acting as the scribe during the rainforest rotation phase. Bottom right: Rainforest ranking screen during the final phase.
The biodiversity activity was designed for a 75-minute class period, with five main steps. *Observation (individual) phase* - Students logged into a tablet as they entered the room, which assigned to them two organisms to look for at each of the four rainforest stations (Figure 14). For each rainforest station, students were prompted to record whether their assigned organisms were present. All responses were aggregated on the interactive white board at the front of the room, presenting a tally for reference by teachers and students alike (Figure 15).

**Figure 14.** Immersive wall content in EvoRoom biodiversity activity in Year 1. Top left: Earthquake. Top right: Low rainfall. Middle left: Tsunami. Middle right: Low sunlight. Bottom left: Low temperature. Bottom right: High rainfall.
**Figure 15.** Collective visualizations displayed on interactive white boards during different phases of the EvoRoom biodiversity activity in Year 1. Top left: Observation phase. Top right: Rotation phase. Bottom left: Ranking phase (left display). Bottom right: Ranking phase (right display showing student explanations of their ranking choices).

**Observation (collaboration) phase** – Students were instructed to meet with their specialization group members at a designated rainforest station provided via their tablets to begin eliminating rainforest stations that likely did not result from their factor. Groups had 5 minutes at each station to make notes. One person was designated to be the scribe, while the other group members were instructed to look up information from the field guide and/or their prediction from their class website (accessed as a link on the tablet). All of the group's decisions and notes were collected on the collective visualizations on the interactive white boards at the front of the room.

**Interview phase** – Students interviewed two other people in the room who were not part of their group. The smart classroom technology infrastructure coordinated the interview assignments,
which were sent to student tablets. Once students entered their interviewee’s group climatic scenario / group variable, they were given suggested questions and a field for entering notes. Once the interviews were completed students shared their notes with group members.

Explanation phase – Working as a group, students ranked the different rainforest stations from 1 to 4, with 1 being the rainforest most likely influenced by their environmental condition. Each student explained their group’s choice by answering one of three questions (e.g., what is your strategy in ranking the rainforests? Describe your process). The aggregated ranking results were all shown on the interactive white boards for the final step of the activity.

Summative discussion – The teacher used the information gathered on the interactive white boards to lead a discussion on the various variables and how they might affect the flora and fauna of Borneo.

As a post-EvoRoom biodiversity activity, students were asked to reflect on their experience by answering questions on a form in their class website, such as “Was there anything that you didn't expect that showed up in the rainforest? Support your answer” and “What do you think may happen with your scenario in a 300 years?”

5.4.2 Evolution activity

The EvoRoom evolution activity was preceded by several weeks of instruction on evolution, taught by the biology teacher using her normal instructional method (i.e., lecture, small groups, and homework activities). Topics covered included: theories on the origin of life, evidence of evolution (e.g., fossil records, anatomy, embryology, molecular biology), mechanisms of evolution (e.g., adaption, natural selection, genetic variation, mutations, sexual selection, gene flow, genetic drift), and divergent and convergent evolution. We introduced a lab activity on island biogeography and evolution served as a precursor to the EvoRoom evolution activity. The lab (developed by R. P. Filson, n.d.) explored the evolution of three species of lizards on the Canary Islands. It introduced the concept of island biogeography with respect to molecular genetics. Later, in the EvoRoom evolution activity, students delved deeper into the issues around biogeography.

As homework in the days preceding the EvoRoom evolution activity, students were asked to review the field guide, which had been prepared by the co-design team to describe the species
of Sumatra and Borneo. Students maintained their specialty groups throughout the unit, and were asked to write a note (posted on their course website) about how closely related the species are within their specialty, between Borneo and Sumatra (e.g., if their specialty was the primates, they would describe how closely related orangutans vs. gibbons are, across the two ecosystems).

The evolution activity was split into two half-period sessions (i.e., two 38-minute sessions) that were enacted on different days. For the first session, we greatly extended and enhanced the timeline of the activity, such that students examined the Borneo rainforest as it may have appeared at nine different historical time periods: 200, 150, 100, 50, 25, 10, 5, 2 Million Years Ago (MYA) and present day (i.e., expanding on the 2 million year span that was used in the pilot activity). Students were assigned to jigsaw teams, based on a strategy of maximizing specializations in each team (e.g. ideally, a group would include one student from each of the four specializations).

On Day 1 of the EvoRoom evolution activity, students used tablets to collectively construct a cladogram (a diagram showing descendancy relations amongst species over time) of their species as a way to survey the immersive environment and to contribute to the collective knowledge base. Day 1 consisted of five main steps:

Introduction – The teacher introduced the time periods (i.e., 200, 150, 100, 50, 25, 10, 5, 2 MYA) that students were to examine (Figure 16). Using a custom-designed control tablet, the teacher stepped through each time period in sequence, giving an overview of important historical geological events through time.

Observation I – The teacher used the Control tablet to start the phase, resulting in four projection stations showing the Borneo rainforest as it may have appeared at 200, 150, 100 and 50 MYA (i.e., the four oldest time periods). Students were asked to go to each station and look for their assigned specialty species. If the species were not present, they were asked to identify their predecessors from a short list on their tablets that popped up (Figure 17). Their answers were recorded, resulting in the emergence of an aggregated, interactive cladogram on the interactive whiteboards at the front of the room (Figure 18).
Figure 16. Immersive wall content in EvoRoom evolution activity in Year 1.
Figure 17. Selected screens of the EvoRoom evolution activity tablet application in Year 1, for Day 1. Top row: Screens from the observation phase. Bottom row (left and middle): Screens from the observation phase, continued. Bottom row (right): Screen from group reflection phase.
Figure 18. Cladogram that one cohort of students created during Day 1 of the EvoRoom evolution activity in Year 1.
Group reflection I – Students were instructed to assemble with their team members at an assigned location (delivered via their tablets), where they were tasked with reviewing their work thus far. Each student was asked to review the cladogram at the front of the room and discuss a specific question with his or her team and record the answer on the tablet. An example of a question that a primate specialist received was: Primates differentiated at 50 MYA. What did you see happen in 100 MYA in other categories that could explain this differentiation? The students’ answers were shown on the interactive whiteboards.

Observation II and Group reflection II – were identical to steps 2 and 3 respectively, except students examined the remaining time periods (i.e., 25, 10, 5 and 2 MYA). The result of this activity was an elaborate cladogram that expressed the historical emergence of the various species of interest across a 200 million year window.

As homework following Day 1 of the activity, students were assigned three organisms for which they were required to identify the main evolutionary mechanisms influencing the organism’s evolution between 200 and 2 MYA. All homework activities were implemented in the class website. The community-generated cladogram and student reflection notes were provided as a resource to inform their homework.

Day 2 of the EvoRoom evolution activity was similar in nature and goals to those of the pilot evolution activity, but with more structured tasks, scaffolded by the custom EvoRoom tablet application. Day 2 consisted of five main steps:

Review – The room was ‘set’ at 2 MYA, with the same rainforest version occupying both large screens on opposite walls of the room. Students were prompted by their tablet computers to write a brief note describing a specific feature (e.g., long limbs) for each of their assigned organisms, and to reflect on what evolutionary mechanisms might be responsible for that feature (Figure 19). This step was designed to integrate the information from Day 1 of the activity and their homework.
Figure 19. Selected screens of the tablet application for Day 2 of the EvoRoom evolution activity in Year 1. Top row: Screens from the group reflection phase. Bottom row (left): Screen from observation III phase. Bottom row (right): Screen from the explanation phase.
Transition – Using the control tablet, the teacher transitioned the room from 2 million years ago to present day, by launching an animation sequence. During the animation, the teacher described how climate changes had caused water levels to rise and fall, and noted that the Sumatran mainland eventually became a peninsula and several islands, which included Borneo and Sumatra. Animals on the two islands had evolved along separate trajectories, particularly once the connecting land bridge had disappeared for the last time.

Observation III – Students were presented with the Borneo rainforest on one side of the room and the Sumatran rainforest on the other side. The students’ task was to take notes about their assigned organisms on both sides.

Explanations – Using the aggregated information from the previous step (presented on the interactive whiteboards) as well as the cladogram they had created on Day 1, students worked with their team members to articulate the evolutionary mechanisms, contributing notes about the mechanism and the species involved. Each student was responsible for making notes about his or her assigned organisms.

Summative discussion – The notes from step 4 were sent to the interactive whiteboards (Figure 20), which the teacher used to facilitate a class discussion about evolution. As homework after the evolution activity, students were asked to write a reflection of their experience in EvoRoom.
Figure 20. Collective visualization of aggregated notes from the final step of the EvoRoom evolution activity in Year 1 where students’ brainstorm about the processes of evolution over a two hundred million year span were shown on the interactive whiteboard.

5.5 Results and Discussion

5.5.1 Overview

This first full iteration of EvoRoom (i.e., that embedded the collective inquiry activities with immersive simulations within a longer curriculum) demonstrated positive learning gains in pre/post assessments. Student attitudes towards the intervention were also positive, rating the immersive environment highly (detailed below). In the biodiversity activity, few students were able to accurately identify their climatic scenario. However, for those who did, the quality of their explanations was significantly better than those written by students who did not accurately identify their scenario. Throughout the activity, students’ movement through the room was observed and captured by video recording, including their interactions with tablets, collective visualizations and their peers. Students engaged with their tablets the most, followed by
interactions with other students. Over half of the student-to-student interactions occurred simultaneously with students interacting with tablets (i.e., within the same unit of video analysis). In the evolution activity, student observations were over 80% correct and student explanations scored higher than those from an analogous task in the pilot study. Student-teacher interactions were the third most frequent type of interactions. Collective visualizations were observed to be an important mediating object in student-teacher interactions – individual student-teacher interactions, teacher-small group interactions, as well as teacher-class interactions.

In sections below, findings are detailed according to the three levels of interaction defined in previous chapters: Individual, Collaborative and Collective. The goal is to examine the efficacy of the specific Year 1 designs, and to reveal insight into the nature of immersive simulations for collaborative and collective inquiry. Throughout all three of these sections, attention is given to (1) findings: outcomes that were relevant to the specific interaction level; (2) issues: aspects of the design that raise attention to matters for consideration in future designs or analysis; and (3) design recommendations: specific goals for future iterations that follow from analysis of the present Year 1 versions.

5.5.2 Individual level

Finding: Significantly pre-post gains on a test of conceptual understanding

In evaluating the curriculum, one question is concerned with whether it supported students in understanding the challenging scientific concepts associated with biological evolution. 45 students completed the pre-test and 32 students completed the post-test (13 students did not complete the post-test due to logistical challenges at the end of the school year). An independent-samples t test was conducted on the pre- and post-CINS questions to evaluate whether the curriculum supported students in understanding evolution concepts. The mean score on the post-test ($M = 78.75, SD = 16.16$) was significantly greater than that on the pre-test for CINS items ($M = 59.40, SD = 19.00$), with $t(75) = 4.68, p < 0.001$. Because these items have been developed and validated by assessment researchers as a measure of the evolutionary processes concerned with natural selection (Anderson, Fischer, & Norman, 2002), we are satisfied that this overall curriculum did help students to learn within this notoriously challenging domain.
**Finding:** Student attitudes were positive, with high ratings of their immersive experience

39 students responded to the post-activity questionnaires after their experience with the biodiversity activity (Table 10). Students rated the use of personal tablets in the smart classroom with an average of 7 ($SD = 2.76$). Similar to the results from the pilot study, the immersivity of EvoRoom was rated highly, at an average of 9 out of 10 ($SD = 1.48$).

**Table 10.** Student attitudes on EvoRoom, Year 1 version

<table>
<thead>
<tr>
<th>Items</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall activity</td>
<td>7.74</td>
<td>1.27</td>
</tr>
<tr>
<td>Visualizing rainforest scenarios</td>
<td>8.21</td>
<td>1.00</td>
</tr>
<tr>
<td>Role of discussions</td>
<td>6.82</td>
<td>1.76</td>
</tr>
<tr>
<td>Flow of information</td>
<td>7.03</td>
<td>1.33</td>
</tr>
<tr>
<td>Use of tablets of accessing additional information (e.g., field guide)</td>
<td>7.05</td>
<td>2.76</td>
</tr>
<tr>
<td>Use of the &quot;smart classroom&quot; (e.g., large screen projectors, immersive environment, etc.)</td>
<td>8.82</td>
<td>1.48</td>
</tr>
</tbody>
</table>

**Finding:** Students moved around the room throughout activities

In the pilot study, an important finding was that students were largely stationary and mostly kept to themselves as they recorded their observations. This was contrary to our intended pattern of students moving about the room, interacting with peers and discussing the specific elements of the simulations and tablet materials. Hence, one of the design recommendations from the pilot study, aimed at improving student engagement, was to encourage student movement around the physical space by designing activities and prompts that required student localization. In the Year 1 evolution and biodiversity activities, we addressed this recommendation by creating four distinct “stations” from which students could examine various forms of the rainforest, necessitating their movement between stations to access different immersive simulation content. In the pilot study, content had been indexed only to the two different sides of the room, (i.e., two walls depicting Borneo and Sumatra), both of which could be accessed from a stationary vantage point at the center of the room (Figure 21). In Year 1 designs, students were instructed (via their tablets) to move to specific stations, where they had to scan a QR code to sign in and confirm their location before receiving further instruction.
Figure 21. Room layout in EvoRoom, pilot study (top) and Year 1 (bottom). In the pilot study, students were able to view both Rainforest A and B screens from the middle of the room and did not walk around the room to observe more closely. In Year 1’s iteration, students used the QR scanning functionality to receive instructions on each task and moved around, working at different locations around the room.

Student movement throughout collective inquiry activities was confirmed by the QR scan, and also captured as part of the video analysis, examining student interactions. Videos collected from one of the biodiversity sessions, and one of the evolution sessions were coded. The video data from various camera recordings were composited into one file (Figure 22), and then split into 2-minute segments (Wilkerson-Jerde, Gravel & Macrander, 2014). The first 10-seconds of each segment was analyzed, yielding a total of 33 clips for the biodiversity activity, and 57 clips for the evolution activity. Each student’s position(s) in the room during each clip were coded according to his or her placement in designated areas of the room (Figure 22). Movement is detected when the student’s position changed between clips.
Figure 22. EvoRoom room set up, indicating video camera positions (A-E) during the biodiversity activity (left) and evolution activity (right) in Year 1. Students’ positions in the room were assigned to one of six locations: 1) Rainforest A, 2) Rainforest B, 3) Rainforest C, 4) Rainforest D, 5) Front boards, 6) Table, according to the designated areas indicated inside dotted lines.

In both activities, movement was detected throughout, particularly in the observation phase, where students moved between areas and frequently interacted with one another (Figure 23 and Figure 24).
Figure 23. Average student movement (between video clips, across six locations) in each phase of the EvoRoom biodiversity activity in Year 1.

Figure 24. Average student movement (between video clips, across six locations) in each phase of the EvoRoom evolution activity in Year 1.
**Finding:** High incidences of student-device, student-student, and student-teacher interactions were observed

Not only was student movement across locations was observed in all video recordings analyzed in both biodiversity and evolution activities, moreover the frequency of student-to-student and student-to-teacher interactions was also much higher in the Year 1 activities. The same clips from the previous “movement analysis” were used for the “patterns of interactions” analysis. I began by determining the different communicative modes based on the multimodal interaction analysis framework (see Table 3; Norris, 2004), generating a list of codes for examining gaze and interactions as applied to the EvoRoom environment (Table 11). For each video clip, the presence of the interactions designated in Table 11 was noted for each student. While this allowed some analysis of the kinds of interactions that occurred throughout the activity, the method of splitting video data into 2-minute segments and sampling only the first 10-seconds likely introduced a risk of over representation for short-duration interactions. Nevertheless, this approach did allow some unbiased inspection of basic forms of interactions that occurred at various phases during the activities, which is useful for comparison between activities (and iterations), and allows identification of interesting patterns of interactions for deeper analysis (i.e., using a multimodal interaction analysis method – Norris, 2004; Price and Jewitt 2013).

**Table 11.** Multimodality communicative modes relevant to analysis of the patterns of interactions present in EvoRoom’s collective inquiry activities with immersive simulations

<table>
<thead>
<tr>
<th>Communicative mode</th>
<th>Analyzed in EvoRoom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken language</td>
<td>Yes, coded as:</td>
</tr>
<tr>
<td></td>
<td>student-student interaction,</td>
</tr>
<tr>
<td></td>
<td>student-teacher interaction,</td>
</tr>
<tr>
<td></td>
<td>teacher-student interaction,</td>
</tr>
<tr>
<td></td>
<td>teacher-small-group interaction, and</td>
</tr>
<tr>
<td></td>
<td>teacher-whole-group interaction</td>
</tr>
<tr>
<td>Proxemics</td>
<td>Not coded, but examined in detailed qualitative case analysis</td>
</tr>
<tr>
<td>Posture</td>
<td>Not coded, but examined in detailed qualitative case analysis</td>
</tr>
<tr>
<td>Gesture</td>
<td>Yes, coded as one of four types  (McNeill, 1992):</td>
</tr>
<tr>
<td></td>
<td>iconic gestures (e.g., mimicking action),</td>
</tr>
<tr>
<td></td>
<td>metaphoric gestures (e.g., expression of abstract idea),</td>
</tr>
<tr>
<td></td>
<td>deictic gestures (e.g., pointing),</td>
</tr>
<tr>
<td></td>
<td>beat gestures (e.g., rhythm in speech)</td>
</tr>
</tbody>
</table>
In the biodiversity activity, the interaction patterns analysis revealed that a student was observed interacting with peers in 88% of the segments analyzed (Figure 25). At the same time, the analysis also showed that students were interacting (e.g., touching screen or typing) with their tablets in 76% of the video clips, and frequently gazing towards the immersive wall content and their devices. This led us to question how often students interacted with their tablets simultaneously as they interact with their peers. Of 35 total occurrences of student-student interaction, 65% of them were observed in combination with student-device interactions. An example of this pattern of interaction occurred when one person was typing on their tablet with their head down as their partner was talking. Usually this was an attempt to capture what their partner was saying, typing their partner’s thoughts on the tablet. Another commonly seen interaction involved small group members staring at the immersive wall during their discussions about the rainforest ecosystem shown on the immersive, with intermittent gesturing.

In 55% of the video segments, student-student or student-teacher interactions were supported by deictic gestures (e.g., pointing) toward the immersive wall or the collective visualization, which happened throughout the activity (Figure 26). During student-teacher interactions, she engaged them in discussion about their progress (e.g., “You all have to move on”) as well as initial student ideas (e.g., “What was your prediction?”). The teacher also interacted with students individually or in small groups (48%) more so than with the class as whole (6%; Figure 27). When not engaging in discussing with students, the teacher used the collective visualizations at the interactive whiteboard to review and organize student work, using the displays to monitor student progress.

<table>
<thead>
<tr>
<th>Head movement</th>
<th>Not coded, but examined in detailed qualitative case analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaze</td>
<td>Yes, coded in terms of potential gaze targets:</td>
</tr>
<tr>
<td></td>
<td>device</td>
</tr>
<tr>
<td></td>
<td>immersive wall display</td>
</tr>
<tr>
<td></td>
<td>visualization</td>
</tr>
<tr>
<td></td>
<td>student</td>
</tr>
<tr>
<td></td>
<td>teacher</td>
</tr>
<tr>
<td>Music</td>
<td>No</td>
</tr>
<tr>
<td>Print</td>
<td>Yes, coded as:</td>
</tr>
<tr>
<td></td>
<td>student-device interaction</td>
</tr>
<tr>
<td></td>
<td>student-visualization interaction</td>
</tr>
<tr>
<td></td>
<td>teacher-device interaction</td>
</tr>
<tr>
<td></td>
<td>teacher-visualization interaction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Head movement</th>
<th>Not coded, but examined in detailed qualitative case analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaze</td>
<td>Yes, coded in terms of potential gaze targets:</td>
</tr>
<tr>
<td></td>
<td>device</td>
</tr>
<tr>
<td></td>
<td>immersive wall display</td>
</tr>
<tr>
<td></td>
<td>visualization</td>
</tr>
<tr>
<td></td>
<td>student</td>
</tr>
<tr>
<td></td>
<td>teacher</td>
</tr>
<tr>
<td>Music</td>
<td>No</td>
</tr>
<tr>
<td>Print</td>
<td>Yes, coded as:</td>
</tr>
<tr>
<td></td>
<td>student-device interaction</td>
</tr>
<tr>
<td></td>
<td>student-visualization interaction</td>
</tr>
<tr>
<td></td>
<td>teacher-device interaction</td>
</tr>
<tr>
<td></td>
<td>teacher-visualization interaction</td>
</tr>
</tbody>
</table>
Figure 25. Student interaction patterns of the EvoRoom biodiversity activity in Year 1.

Figure 26. Gestures observed over duration of EvoRoom biodiversity activity in Year 1.
In the evolution activity, a pattern of frequent student-device, student-student, and student-teacher interactions, was observed. In all 57 10-second video clips analyzed from across the 2-day session, at least one student was looking at their device (Figure 28). In 63% of the video segments, a student was observed to be looking at a fellow student, followed by gazes aimed at the collective visualizations (54%) and at the teacher (35%). Students interacted with devices the most (84% of video clips), followed by the student-student (63%) and student-student-teacher interactions (61%).
While the enactments in Year 1 showed students interacting within EvoRoom as the design team had envisioned – moving around, and talking to one another and referring to walls and tablets – a number of specific findings (discussed below) suggested that more focus needed to be paid to improving the quality of student-to-student interactions. The most prevalent interactions were those where students were looking at or typing on their tablets, or looking at the immersive walls during conversations. In the biodiversity activity, many of the student-student interactions occurred while their attention was directed at either the tablet or the wall, which may have negatively affected the quality of those exchanges. Moreover, in both the biodiversity and evolution activities, individual observation phases did not optimize benefits of co-located peers. Students were seen to move around, following instructions, performing straightforward tasks, such as noting the presence or absence of a species, rather than taking advantage of opportunities for collaborative discussions about these observations. The following design recommendation responds to these observed limitations, aiming to encourage deeper student-student interactions, where students must collaborate with peers in direct relation to their interactions with media elements in the room.

**Figure 28.** Interaction patterns of the EvoRoom evolution activity in Year 1.
**Design recommendation:** Offer more opportunities for student-student interactions, including more reflective group tasks, prompting engagement with other students where the media content serves as a source of discussion or cognitive support.

**Finding:** Structured observations resulted in accurate outcomes

The pilot study resulted in a design recommendation to support higher-level thinking about evolutionary mechanisms by including more structured and scaffolded tasks. In the Year 1 evolution activity, we designed structured observations, where students were scaffolded by the tablet application to decide whether their assigned organism was present at different time points, and if not, which ancient organism was most likely its predecessor. These observations were scored for accuracy. Of 1112 answers collected by the student tablets, 78% were correct, with an upward trend of accuracy compared to time period (Figure 29). 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 they were indeed paying attention to the task at hand and engaging with the media appropriately.

**Figure 29.** Observation accuracy of the EvoRoom evolution activity in Year 1.
In the biodiversity activity in Year 1, a similarly structured task supported students in making observations of assigned organisms within the various stations. 80% of the individual observations were found to be correct, again indicating that structured observations tasks supported accuracy of student outcomes.

**Finding: Improved evolution explanations compared to pilot study**

At the conclusion of both the pilot study and the Year 1 evolution activity, students reflected on the following question: *What evolutionary forces do you think were at play in this environment?* They were asked to choose an evolution concept from a predefined list (e.g. adaptation, natural selection, sexual selection etc.) and explain their answers with sufficient evidence. 43 explanations were collected, each note had an average word count of 33.28 ($SD = 29.51$) and average KI score of 2.72 ($SD = 1.05$). Figure 30 shows the distribution of evolutionary concepts that the explanations attempted to address. Explanations from the pilot study were predominately about adaptation (36%), with topics from the ‘Other’ category comprising of: co-evolution (21%), sexual selection (21%) and reproductive isolation (14%). In contrast, explanations from Year 2 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 included: sexual selection (12%), co-evolution (7%), reproductive isolation (7%), gene flow (5%) and miscellaneous topics (12%).

**Figure 30.** Distribution of evolutionary concepts that the explanations from the pilot (left) and Year 1 (right) iterations attempted to address
The explanations were scored using the same KI scale that was used to score explanations in the pilot study. While the explanations from Year 1 were scored higher, on average ($M = 2.72$, $SD = 1.05$) than those from the pilot ($M = 2.36$, $SD = 0.75$), this difference was not significant. In general, there was an increase in the complexity and sophistication of explanations from the pilot (34%) to those in Year 1 (43%). Figure 31 displays the distribution of explanations based on their KI scores.

**Figure 31.** Distribution of KI scores for student explanations

Support for individual student reflections was implemented in the Year 1 designs, through several approaches. In both biodiversity and evolution activities, just-in-time instructions were delivered to students via their tablets at each step throughout the activities, which served to scaffold students in various tasks. For the evolution activity, the observation task was changed from making open-ended observations about any species to a more specific task that asked students to note the presence of their assigned species (from their species’ specialties) or their potential predecessors through various time periods. Although it is difficult to determine the degree to which the structured scaffolded tasks supported higher-level thinking about evolutionary mechanisms, the impact of these design changes was demonstrated through individual students’ performance during the activity, which in the evolution activity included the combination of an accuracy rate of 78% with improved explanation scores over the pilot study.
**Finding:** *Explanations in biodiversity activity were limited in their accuracy and reasoning*

In the biodiversity activity, 6 out of the 16 total groups correctly identified the rainforest stations that were associated with their assigned environmental factor. In one session, all four groups correctly identified their climatic scenario. Generally, students who made the correct match used a specific strategy, such as process of elimination or identifying a set of characteristics that matched their predictions. The quality of students’ final explanations were analyzed using the Claim-Evidence-Reasoning (CER) grading rubric (McNeill & Krajcik, 2011), which was modified slightly to fit the context (Table 12). The explanations for the groups’ final choices were scored an average of 6.0 of 8 (SD = 1.4). IRR was performed on 20% of data, where 100% agreement was achieved. A one-way ANOVA was conducted to evaluate the relationship between the groups’ CER scores and their identification accuracy, which found that students who correctly identified rainforest stations received significantly higher CER scores than groups who incorrectly identified the rainforest stations, $F(1, 14) = 7.30, p < 0.02$.

<table>
<thead>
<tr>
<th>Claim</th>
<th>Evidence</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0: Nothing/not a claim</td>
<td>0: No evidence</td>
<td>0: Reasoning absent, non-sensible, or fails to connect evidence to claim</td>
</tr>
<tr>
<td>1: Claim is incomplete or not related to the question</td>
<td>1: Does not provide relevant evidence</td>
<td>1: Provides reasoning that links the claim and the evidence by repeating the evidence</td>
</tr>
<tr>
<td>2: Makes a complete claim related to the question</td>
<td>2: One relevant piece of evidence</td>
<td>2: Explains why evidence supports the claim, but does not address all aspects of evidence</td>
</tr>
<tr>
<td></td>
<td>3: Multiple relevant evidence</td>
<td>3: Explains how the evidence supports the claim and addresses all aspects of evidence</td>
</tr>
</tbody>
</table>

While students were engaged in their tasks, as indicated by their performance in the observation phase (i.e. 80% accuracy), low accuracy of rainforest identification and low explanations scores indicated that students might benefit from additional scaffolds in identifying their climatic scenario and in writing explanations. Additionally, the simulations themselves may have contained fundamental ambiguities rendering this task intrinsically challenging. For the next iteration of the biodiversity activity, one goal is to improve scaffolds for making observations and writing explanations.

*Design recommendation: Scaffold students’ data collection and explanation writing.*
5.5.3 Collaborative level

Finding: Specialty assignments and jigsaw collaboration groups allowed students to transfer curricular expertise to their work in collective inquiry activities with immersive simulations

From the beginning of the EvoRoom curriculum, students collaborated in small groups. Content specializations (i.e., species, climatic scenario) were given to each student in part to focus their attention in a relatively complex learning context. They worked in specialist groups of two to three in their collaborative food web activity, during the zoo trip assignment and during the evolution activity. One idea for dividing students into different specialties was to support their eventual collaboration in the biodiversity and evolution activities. Since students can bring their specialty knowledge to collaborations with students of different specialties, it would make their exchanges more meaningful. As hoped, we observed students working well within their specialty groups throughout the curriculum as well as paying attention to other students’ specialties.

In the biodiversity activity, students worked in their specialist group to identify the rainforest that best matched their climatic group variable, but were able to participate in an exchange of information with members from other groups during the interview phase. Several students identified this phase as being productive. One student wrote: I felt that this was a very effective way to learn about the species that we were not assigned. I was able to discuss my own findings and see whether or not other classmates agreed with me. Another student wrote the following about the interview phase: This taught me different variables and how they apply to rainforest situations, and not just my variable. It also taught me about the impacts of the variables on various peoples' animals groups.

Finding: Students did not engage in discussion with all of their team members during evolution group reflection

In the final evolution activity, although prompted to do so, students did not work with their entire jigsawed team of four to six, preferring to interact with smaller groups of one to three students. This may be due to the large size of the group or to the collaborative task itself, which asked students to discuss with group members and then answer their own question. How various
specialists were supposed to contribute to the discussion was left open to the students themselves. Although students were asked to get together with their team members during the collaborative phases, video analysis showed some discussion with a few of their group members but not as a cohesive team. Group members were scattered in different areas of the room during the group reflection phase (Figure 32).

**Figure 32.** Position mapping of Team 1 (top) and Team 2 (bottom) members during group reflection I phase. Numbers radiating out represents percentage of time student spent in location during the phase.
Finding: Rotation of functional roles supported collaboration in biodiversity activity

One effective design pattern for small group collaboration was to provide a separate task for each member of the group. This was first used in the biodiversity activity in the collaborative observation phase, when groups were asked whether the rainforest in front of them could have resulted from their climatic scenario. One student was assigned to be the scribe, another to look up their original prediction, and another to look up information from the field guide. One small group interaction from this phase was the subject of a deeper analysis using the multimodal interaction analysis method, conducted to better understand how students engaged with both the materials of the room as well as their peers at the same time (Figure 32). In the interaction, students discussed whether the rainforest ecosystem shown on the wall in front of them could have resulted from the group’s environmental variable: tsunami. In the beginning, talk was limited as all three students were looking at the wall display (“Rainforest D”) with their bodies facing inward but all looking directly at the wall. After one of the students (Mark) gestured towards the wall content (at the start of this clip), it was followed by a number of subsequent gestures (by all group members). They also started looking at each other while speaking and became more engaged in the discussion itself, as noted by the change in rhythm of their talk. One member of the group, Alexis, was not as active in the discussion in the beginning of the transcript, but after a postural change, she began to engage more actively, as noted by increased talk and gestures. More frequent occurrences of socially positive body postures (e.g., looking at each other, moving toward one another) accompanied the productive advancement of their discussion.
The analysis above reveals an interesting interaction between three students that were able to successfully identify the rainforest affected by their environmental variable. The interaction began with all three focused on the immersive wall, but as their focus shifted towards one another, their gazes followed, with more gesturing to the wall (topic of discussion) by all three students. At the same time, the group made progress in knowledge co-construction. Could interactions like this one be improved upon? How can we support other groups of students in
such interactions? In the evolution activity, most students did not discuss with all members of their group, even when instructed by their tablets, choosing to work individually.

Design recommendation: Scaffold collaborations by providing functional roles to ensure participation, including prompts to use media as cognitive supports.

5.5.4 Collective level

Finding: Ambient displays of collective knowledge encouraged ad-hoc discussions between students and with their teacher

In the pilot study, the collective visualization was shown only at the end of the activity, which meant that the potential benefits of displaying collective knowledge was difficult to assess. In the current iteration, collective knowledge was made visible and accessible during the activities (pilot design recommendation), and how the students and the teacher made use of the collective visualizations was analyzed. In both activities, the collective visualizations served as ambient displays of collective progress throughout.

In the biodiversity activity, 85% of students referred to the collective visualizations and elicited many small group discussions. In the evolution activity, all of the students referred to the displays, which can be attributed to the instruction to do so on student tablets during the group reflection phase. In both Year 1 biodiversity and evolution activities, the teacher was the main user, in terms of frequency of gaze and interaction with collective visualizations. In the evolution activity, the teacher used the visualizations to support a class discussion at the end of the activity. This allowed all students to review the collective knowledge, but the activity ended at this point with no further opportunity to build upon one another’s work. In subsequent iterations, a goal is to ensure that all students review the collective work, especially during the activity rather than near the end.
Figure 34. Proportion of teacher gaze targets during one EvoRoom session of the biodiversity activity in Year 1.

An additional analysis was performed to determine the frequency of student and teacher interactions with the collective visualization. This was performed across all four sessions for the biodiversity activity. 85% of students were found to have referred to the collective visualizations through gaze. A few students interacted with the whiteboard to obtain further details of the data being displayed, which was done by one student in three of four sessions and four students in one session. The teacher interacted with the interactive whiteboard the most, with an average of 8.3 interactions per session ($SD = 2.9$). Additionally, ad hoc discussions were observed between the teacher and students near the interactive whiteboards. When the teacher was located at the boards, students would approach, either curious about the display, or wanting to consult with the teacher. They would engage in discussion, with the teacher often gesturing towards the boards and using them as an aid to answer the students’ questions. When students independently walked up to the displays without the teacher’s presence, their group members often joined them and engaged in their own discussion. In most such cases, the teacher then joined the group discussion.

As an important part of the evolution activity, students collectively created a cladogram by entering information about their assigned organisms into their tablets. Because students could not directly create entries in the cladogram, we did not experience the same issues as creating the
collaborative food web. Rather, using their tablets, students noted organism presence or choosing a predecessor organism, which resulted in the automatic generation of cladogram entries, and ultimately in the emergence of the cladogram itself, with entries color-coded according to team contribution (see Figure 18).

The teacher was seen and/or heard in 54 of the clips of 57 video clips analyzed in the evolution activity, and her gaze was split between the collective visualization and her students (Figure 35). She was located in front of the collective visualizations in 35 of the video clips, and spent 77% of the time in some kind of interaction with her students (i.e., teacher-student, teacher group, teacher-class). Her interactions with the students tended to be individual or small group interactions (61%; Figure 28), whereas teacher-class interactions occurred as part of her teacher script (i.e., “As you can see, it’s different time periods…”), or to move students along (i.e., “Ok we need to get going”). 11% of the time the teacher’s interaction with her students was supported by her interaction with the collective visualization (Figure 36).

In both the Year 1 biodiversity and evolution activities, the teacher was the main user, in terms of frequency looking at and interacting with the collective visualizations. In the evolution activity, the teacher used the collective visualizations to support a class discussion at the end of the activity. This allowed all students to review the collective knowledge, but the activity ended at this point with no further opportunity to build upon one another’s work. In subsequent iterations, a goal is to ensure that all students review the collective work, especially during the activity rather than near the end.

**Design recommendation:** Give collective work a larger role within the activity design, and improve its “visibility” to encourage more students to review the collective products.
Figure 35. Proportion of teacher gaze targets during an EvoRoom session of the evolution activity in Year 1.

Figure 36. Teacher interactions located at the collective visualizations during the EvoRoom evolution activity in Year 1. She was located there in 35 of 57 analyzed video clips.

5.5.5 Design Implications

Our analysis of student outcomes and perceptions in the Year 1 EvoRoom activities uncovered several findings about individual, collaborative and collective dimensions within collective
inquiry activities in immersive environments, and how to design effective learning activities for such a context. In the pilot study, we were careful not to over-script collaborative activities, so as to encourage organic rather than forced discussions. However, these early trials suggested that certain activities needed an increased level of scaffolding, and that a rich curriculum context needed sufficient time to facilitate more productive face-to-face interactions amongst students. Design principles for augmenting collaborative knowledge co-construction were suggested by Year 1 findings (}
Table 14) to inform new designs that harness the potential of immersive simulations for supporting students to learn as a knowledge community.
Table 13. Summary of findings and design recommendations from Year 1

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Year 1 findings</th>
<th>Year 1 design recommendations</th>
</tr>
</thead>
</table>
| Individual| 1. Significantly pre-post gains on a test of conceptual understanding  
2. Student attitudes were positive, with high ratings of their immersive experience  
3. Students moved around the room throughout activities  
4. High incidences of student-device, student-student, and student-teacher interactions were observed  
5. Structured observations resulted in accurate outcomes  
6. Improved evolution explanations compared to pilot study  
7. Explanations in biodiversity activity were limited in their accuracy and reasoning | • Offer more opportunities for student-student interactions, including more reflective group tasks, prompting engagement with other students where the media content serves as a source of discussion or cognitive support (to address finding 4)  
• Scaffold students’ data collection and explanation writing (to address finding 7)                                                                                     |
| Collaborative| 8. Specialty assignments and jigsaw collaboration groups allowed students to transfer curricular expertise to their work in collective inquiry activities with immersive simulations  
9. Students did not engage in discussion with all of their team members during evolution group reflection  
10. Rotation of functional roles supported collaboration in biodiversity activity | • Scaffold collaborations by providing functional roles to ensure participation, including prompts to use media as cognitive supports (to address findings 9 and 10)                                                                                   |
| Collective | 11. Ambient displays of collective knowledge encouraged ad-hoc discussions between students and with their teacher | • Give collective work a larger role within the activity design, and improve its “visibility” to encourage more students to review the collective products (to address finding 11)                                                             |
Chapter 6

6 Year 2 Design Iteration

The second full iteration of this research was conducted between February and June of 2013 during the academic school year, with students in our co-design teacher’s classes. After the enactment of the Year 1 iteration, the design team resumed regular weekly meetings at the end of August 2012 to revisit Year 1 outcomes and redesign the EvoRoom activities. One of our important recognitions was that understandings about evolution could be important precursors to understanding how ecosystems functioned over time. Thus, we decided to reverse the order of presentation of the biodiversity and evolution activities, which entailed substantive revisions to the overall course curriculum as well. We also felt that our prior effort had not sufficiently established a sense of collective epistemology amongst the students, such that they would appreciate the importance of one another’s work during immersive activities. Therefore, an instructional treatment of collective epistemology was added to the beginning of the course, in order to help students understand the collective nature of their inquiry. We also revised the curriculum activities within the broader course, such that students would research the Borneo rainforest environment through two hundred million years, creating their own field guide, collectively. Thus, encouraging a sense of collective epistemology became a common theme that ran through many of our design decisions in the Year 2.

6.1 Participants

Participants of the second iteration of the EvoRoom curriculum were 56 students from two class sections of Grade 11 Biology (taught by our co-design teacher).

6.2 Procedure

The collective inquiry activities in Year 2 were embedded within a broader 16-week curriculum design, and included two visits to the EvoRoom immersive environment – one for the evolution activity and one for biodiversity.
6.3 Data Sources

Students completed a pre-/post-test, administered to determine their understanding of evolution concepts. Since pre/post assessments from Year 1 using CINS items were not sufficiently sensitive to the impact of the EvoRoom activities, we revised the test items to include deeper conceptual questions targeted to the pedagogical goals of the activities (Appendix G). During both EvoRoom activities, video recordings captured student interactions, while knowledge artifacts created by students (e.g., notes) were collected automatically by the system, as measures of student reasoning and interactions.

6.4 Curriculum Design

The immersive simulation activities were designed to fit within an integrated a 16-week curriculum on biodiversity and evolution topics.

Table 14 shows elements of the curriculum that were relevant to the EvoRoom study. Weeks omitted were focused on conventional treatment of topics, similar to those employed within the Year 1 iteration of the curriculum.
Table 14. Summary of the activity sequence for Year 2: in-class (I), homework (H), and smart classroom (S).

<table>
<thead>
<tr>
<th>Week</th>
<th>Description</th>
<th>Curricular Goals</th>
</tr>
</thead>
</table>
| 1    | Introduction (I) | • Research assigned organisms and Borneo at various time periods  
|      | • Collective epistemological treatment (I) | • Understand scientific connections (e.g. taxonomy and phylogeny) between related species  
|      | • Assign groups and specialty categories (i.e., plants & insects, birds, primates, and other mammals; I) |  
|      | • Assign field guide assignment (H) |  
|      | • Assign timeline assignment (H) |  |
| 4    | • Progress check on field guide and timeline assignments (I) |  |
| 5    | • Progress check on field guide and timeline assignments (I) |  |
| 8    | • EvoRoom: Evolution activity (S) | • Make connections between evolutionary mechanisms (learned in class) to the organisms in a specific ecosystem  
|      | • Collaborative food web activity (H) | • Improve understanding of different organisms' lineages with respect to evolutionary forces over millions of years  
|      | • Assign environmental impact variable (I) |  
|      | • Prediction analysis group assignment (H) |  
|      | • Introduction to Zydeco (I) |  
|      | • Zoo field trip group assignment (I) |  |
| 9    | • EvoRoom debrief discussion (I) | • Improve understanding about evolutionary mechanisms  
|      | • Personal reflection (H) |  |
| 14   | • Collaborative food web activity (H) | • Understand relationships among a set of species (e.g., in the Borneo rainforest)  
|      | • Assign environmental impact variable (I) | • Understand how environmental factors (e.g., high/low rainfall, tsunami, earthquake) affect ecosystems  
|      | • Prediction analysis group assignment (H) | • Learn to use a mobile inquiry application for the Zoo trip  
|      | • Introduction to Zydeco (I) |  
|      | • Zoo field trip group assignment (I) |  |
| 15   | • EvoRoom: Biodiversity activity (S) | • Improve understanding of complex interrelationships within an ecosystem and implications of environmental factors on biodiversity  
| 16   | • EvoRoom: Biodiversity activity (S) |  
|      | • Personal reflection (H) |  |

The goal for adding a preliminary instructional treatment of collective epistemology, and designing collective activities like the construction of the field guide was to engender a sense of collective epistemology and to encourage a sense of student ownership of the activities. The initial treatment consisted of a short lecture on “Science 2.0” delivered by members of the co-design team. This began with a class discussion of “Web 2.0” and web applications such as Wikipedia, Flickr, and YouTube, positioning these websites as content communities that
demonstrate the power of the collective. The talk extended to the domain of science, introducing large-scale, collaborative projects such as the Human Genome Project as “Science 2.0” – where science itself is more socially driven, and scientists work as active collaborators across distances and on large data sets, rather than as lone scientists in isolated labs. Students were told that they would be experiencing Science 2.0 as part of the evolution and biodiversity activities and that they would be learning as a classroom community, such that they would all move ahead further together than if they were working independently (i.e., competing with one another). After the EvoRoom construct was introduced, students were given their field guide assignment. Students were assigned to one of four specialist categories (i.e., plants & insects, birds, primates, and other mammals), where they would serve as experts in certain species. They would research specific topics about an assigned organism from their specialty as well as a specialty time period (between 2 and 200 MYA). Students would collaborate across both class sections to complete a single field guide. By doing so, they would be contributors within a “Science 2.0” community, since the field guide would be used by their peers in subsequent activities, and their research about the various time periods would contribute to the rendering of designs in the EvoRoom immersive simulations. Students were informed that they would also be contributors to “Science 2.0” beyond their classroom community since their species research would be submitted to a website called Encyclopedia of Life (EOL) – an online collaborative encyclopedia cataloguing information about all species on Earth (http://eol.org/). Students worked on their assignments using special wiki pages developed for their class website (Figure 37).
Blue-headed pitta

LETHBRIDGE

J.D. Hammon

http://d01.tiltshift.com/d01_bluehead.jpg

The Blue-headed Pitta is a small passerine bird. It is found in the forests of Southeast Asia, particularly in Indonesia, Myanmar, Thailand, and Bangladesh. It is a small black bird with a blue head and wings.

HABITAT

The Blue-headed Pitta is found in dense forests, particularly in the understory of moist deciduous forests. They are generally solitary and do not form flocks.

DIET

The Blue-headed Pitta feeds on a variety of insects, such as beetles, ants, and termites. They also feed on fruits and seeds.

REPRODUCTION

The Blue-headed Pitta is a monogamous bird. It builds a nest on the ground, usually in a forst. The nest is made of leaves and plant material.

DISTRIBUTION

The Blue-headed Pitta is found in the forests of Southeast Asia, particularly in Indonesia, Myanmar, Thailand, and Bangladesh.

REFERENCES


http://d01.tiltshift.com/d01_bluehead.jpg
The collaborative food web activity was changed from an in-class activity to homework due to available class time, and also since we used EOL’s ecosystem explorer tool (http://education.eol.org/eco/), which supports multiple users making connections between species. Each class section completed a food web and this was discussed during class.

### 6.4.1 Evolution activity

The EvoRoom evolution activity was followed by several weeks of instruction on evolution taught by the biology teacher similar to those in Year 1. Each class was divided into two sessions, with 13-14 students participating in each. Students were further divided into three groups of four to five students with varied species and time period specialties. The evolution activity was designed as a 75-minute activity, consisting of the following steps:

**Introduction** – The teacher introduced the activity and used the control tablet to start the next phase.

**Observation I** – Four projection stations showed the Borneo rainforest as it may have appeared at 200, 150, 100 and 50 MYA (Figure 38). Students were asked to go to each station and look for their assigned specialty species. If the species were not present, they were asked to identify their predecessors from a short list on their tablets that popped up (Figure 39). Their answers were recorded, resulting in the emergence of an aggregated, interactive cladogram on the interactive whiteboards at the front of the room (Figure 40). A new feature of this phase is that an individual student was chosen to serve as a guide at each station (acting like a docent at a museum), to help his or her peers with the observation task, and to encourage interactions between students with their peers and media elements.
Figure 38. Immersive wall content in the EvoRoom evolution activity in Year 2. The top four panels were used in Observation I phase, and the second four were used in Observation II phase.
Figure 39. Selected screens of the tablet application, Year 2 evolution activity version. Top row: Screens from the observation phase. Bottom row (left and middle): Screens from the comparison phase. Bottom row (right): Screen from explanation phase.
**Figure 40.** Cladogram that one cohort of students created during the EvoRoom, Year 2 evolution activity version.

*Group reflection I* – Teams of different species specialists actively compared adjacent time periods (e.g., 200 vs. 150 MYA) with reflective question prompts. One person from each group was assigned to be the scribe. Others were provided with additional information about the time periods, with information appearing on their tablets that served to augment the rainforest simulations.

*Observation II and Group reflection II* – The two steps were identical to Observation I and Comparison I respectively, with the exception that students examined the remaining time periods (i.e., 25, 10, 5 and 2 MYA). The result of this activity was a complete cladogram created collectively by the students over the observation steps.

*Explanation* – The final step where students discussed and posted ideas about evolutionary processes was analogous to the question from Year 1, but 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 40) as part of their reflective process.

During the Year 2 evolution activity, two of four sessions used paper handouts instead of tablet computers, due to technical difficulties, and one session was prevented from receiving the intervention at all (again as a result of technical difficulties and very tight scheduling constraints). In the one successful tablet session, students were unable to complete the final step
of discussing and posting ideas about evolutionary processes due to time constraints. To help capture some comparable measure of student understanding, we gave students a post-activity homework assignment: *Choose an organism from the Borneo ecosystem and discuss the evolutionary forces you think are at play through 200 million years?*

### 6.4.2 Zoo activity

Rather than asking students to complete a 7-page worksheet as part of a field trip to the Metro Toronto Zoo, as we had done in Year 1, we chose to use Zydeco, a mobile app created by researchers from the University of Michigan (Cahill et al., 2010; Kuhn et al., 2010; Quintana, 2012) to support students in collecting data from the field. We collaborated with the researchers and both teachers of the biology course to design relevant questions about biodiversity. These items asked students to take a position on the following three issues: 1) Unifying principles underlying biodiversity, 2) human impact on biodiversity, and 3) What makes an effective educational exhibit.

In the class section immediately prior the field trip, students received 75-minutes of training on how to use the Zydeco application, where researchers demonstrated how to collect and review observations, as well as how to create claims in Zydeco. Students practiced using the application with a sample investigation within the classroom and immediate surrounding areas.

When they arrived at the zoo, students split into pre-assigned groups of three to four, each of which were given particular species and pavilions (i.e., habitats within the zoo) to observe. Each group was given two devices: an iPod touch and an iPad or iPad mini. In Zydeco, observations can be made in the form of text notes, images, video, audio or any combination thereof, and are annotated with tags/labels (e.g., species names, pavilion, helper question) for ease of retrieval. Students used the following four “helper questions” to guide their observations to be shared with their peers through the application:

1. What are the traits of the organism you’re looking at right now?
2. How does the structure of the exhibit (e.g. format, information available) affect your thinking about the organism?
3. What human activities are affecting these species?
4. What type of information is present in this exhibit?
After the zoo trip, students returned to the school in time for the last period of the day, where they were provided with the collective pool of data (i.e., drawn from all Zydeco observations) to make claims about the three issues as individuals. Their respective teachers assessed the students’ claims, which made up 5.6% of their overall grade. It should be noted that no other aspect of the EvoRoom curriculum was explicitly graded by their teacher.

### 6.4.3 Biodiversity activity

This activity was preceded by traditional instruction on biodiversity topics as well as the trip (described above) to the zoo, where students used the Zydeco application to complete their assignment. As in the first iteration, students were presented with four different scenarios, which they had to observe, in order to distinguish which scenario corresponded with a particular variable. In a homework assignment the previous day, they had been asked to predict how changes in various environmental conditions (i.e., high rainfall, low rainfall, high sunlight, low sunlight, high temperature, low temperature, earthquake, and tsunami) could affect the biodiversity of the rainforest over five years.

Students visited EvoRoom in cohorts of 13 to 14, and were again split into four groups of three or four members, with each student in a particular group drawn from different species specializations. In the room, they were presented with four different versions of the Borneo rainforest ecosystem, with the baseline rainforest ecosystem shown on the front interactive whiteboards (Figure 41). We asked students to use Zydeco to collect observations in a variety of media formats (e.g., images, audio, written notes). Zydeco thus scaffolded data collection and analysis of observational data, helping to link student observations and explanations (Figure 42). An extension of Zydeco to visualize student-collected data on the interactive whiteboards was designed and developed for the second iteration (Figure 43). A trade-off from this was that separate tablets were needed to drive the interactivity of the boards (limiting access to those handling the tablets).
**Figure 41.** Image of room setup of the EvoRoom biodiversity activity in Year 2. Each version of the four rainforest ecosystems was designated Station A, B, C or D. Interactive front boards show the baseline rainforest ecosystem (without effects from any climatic scenario).
Figure 42. Selected screens of the Zydecò, used in the EvoRoom biodiversity activity in Year 2. Top: Review screen showing everyone’s observations. Middle: Completed observation. Bottom: Explanation / Claim screen.
Figure 43. Collective visualizations displayed on the interactive white boards at data review step of the EvoRoom biodiversity activity in Year 2.
The biodiversity activity was designed for a 75-minute class period, with four main steps.

- **Observation phase** – Students used a handheld computer to collect evidence concerning which rainforest station showed the effects of their group's assigned environmental factor.
- **Data review** – The teacher facilitated a data review session that revealed students’ initial ideas.
- **Explanation phase** – Students constructed explanations about their final decision
- **Discussion** – Each group displayed their work and presented their findings. At the end of the session, the teacher revealed the correct answers (i.e., which station resulted from which environmental factor) and held a deeper discussion about environmental impacts and biodiversity.

### 6.5 Results and Discussion

#### 6.5.1 Overview

The second iteration of EvoRoom once again resulted in significant pre-post gains in both evolution and biodiversity topics. Student attitudes towards the intervention, revealed by the questionnaire, were also quite favorable, as they had been in Year 1. For example, the immersivity of the environment was again rated highly (average 8 of a possible 10) than other aspects of the activities. The questionnaire responses for the biodiversity activity were comparable or even slightly higher than those in the evolution activity, in all dimensions except for one (i.e., use of tablets), suggesting that novelty effect may not be a significant issue.

In the evolution activity, only students in one of four planned sessions were able to use the custom tablet application in support of the activity. Students from two sessions used paper supports and one session did not participate in the activity, due to technology issues. For the one tablet session, we were able to examine the accuracy of student observations with the aid of a guide. Approximately 84% of answers were accurate with an upward trend as the historical time periods examined reached closer to present day. Moreover, students were able to attain over 90% accuracy between 100 and 2 MYA. Both tablet and paper sessions successfully completed the comparison phase of the evolution activity, we found that the mean KI scores for these explanations in the tablet session to be significantly higher than those from the paper sessions. The collaborative explanations written in the tablet session were also more comprehensive than those written in the paper sessions (i.e., higher word count). Students primarily interacted with
other students, followed by interactions with devices and their teacher. The teacher’s main focus was her students, followed by the collective visualizations.

In the biodiversity activity, 6 of 16 groups were able to accurately match their climatic scenario to the rainforest station, which is the same level of accuracy achieved as in Year 1. However, the CER scores for explanations improved in Year 2. Moreover, while the CER scores in Year 1 had corresponded with the accuracy of the students’ final choice, this was not observed in the Year 2 sample, perhaps as a result of the higher CER scores. Students were seen to engage with their device the most, followed by interactions with other students, and then by intermittent interactions with their teacher. The teacher interacted most often with students (individually, in small groups, and in plenary discussions), followed by interactions with the collective visualization. One feature that distinguished the Year 2 from Year 1 enactments was the higher incidence of teacher-class interaction. The teacher facilitated the data review and discussion phases of the activity, which represented a third of the time spent during the biodiversity activity.

I evaluated whether the curriculum supported students in understanding evolution and biodiversity concepts. 24 students completed both the pre- and post-test, which consisted of four questions, with two questions on evolution and two on biodiversity. Each response was scored using a KI rubric, and a paired-samples t test was conducted on the total score of the pre- and post-test. The results indicated that the mean percentage of the post-test ($M = 67.29\%$, $SD = 13.67\%$) was significantly greater than the scores of the pre-test ($M = 53.33\%$, $SD = 11.29\%$), with $t(23) = 3.58$, $p < 0.005$.

The next section discusses the individual level of interactions within the EvoRoom activities, with a particular focus on the collective inquiry activities with immersive simulations.

6.5.2 Individual level

Finding: Significantly higher post-test scores compared to pre-test scores

The curriculum was evaluated to examine whether it supported students in understanding evolution and biodiversity concepts. 24 students completed both the pre- and post-test, which consisted of four questions, with two questions on evolution and two on biodiversity. Each response was scored using a KI rubric, and a paired-samples t test was conducted on the total score of the pre- and post-test. The results indicated that the mean percentage of the post-test ($M$
= 67.29%, SD = 13.67%) was significantly greater than the scores of the pre-test (M = 53.33%, SD = 11.29%), with t(23) = 3.58, p < 0.005.

Finding: Student attitudes were positive, rating their immersive experience highly

In both Year 1 and Year 2 iterations, student engagement with the immersive media was strong, as evidenced by their post-activity responses. Students were asked to complete post-activity questionnaires after both biodiversity and evolution activities. 37 students responded to the post-evolution activity questionnaire. The responses from those who participated in the paper version of the activity were not significantly different from those who participated in the tablet version, and all responses are included together in the following table (Table 15). The immersivity of EvoRoom was rated highly, at an average of 8 out of 10 (SD = 1.97).

Table 15. Student attitudes on EvoRoom, Year 2 evolution activity version

<table>
<thead>
<tr>
<th>Items</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall activity</td>
<td>6.89</td>
<td>1.65</td>
</tr>
<tr>
<td>Visualizing rainforest scenarios</td>
<td>7.16</td>
<td>1.99</td>
</tr>
<tr>
<td>Role of discussions</td>
<td>5.61</td>
<td>1.73</td>
</tr>
<tr>
<td>Flow of information</td>
<td>6.76</td>
<td>1.40</td>
</tr>
<tr>
<td>Use of tablets of accessing additional information (e.g., field guide)</td>
<td>7.38</td>
<td>1.63</td>
</tr>
<tr>
<td>Use of the &quot;smart classroom&quot; (e.g., large screen projectors, immersive environment, etc.)</td>
<td>8.11</td>
<td>1.97</td>
</tr>
</tbody>
</table>

38 students responded to the post-biodiversity activity questionnaire (Table 16). Students rated the use of Zydeco with an average of 6 of 10 (SD = 2.60). The immersivity of EvoRoom was rated the highest, at an average of 8 out of 10 (SD = 1.97).

Table 16. Student attitudes on EvoRoom biodiversity activity, Year 2 version

<table>
<thead>
<tr>
<th>Items</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall activity</td>
<td>7.29</td>
<td>1.39</td>
</tr>
<tr>
<td>Visualizing rainforest scenarios</td>
<td>7.58</td>
<td>2.10</td>
</tr>
<tr>
<td>Role of discussions</td>
<td>6.89</td>
<td>2.19</td>
</tr>
<tr>
<td>Use of Zydeco</td>
<td>6.38</td>
<td>2.60</td>
</tr>
<tr>
<td>Use of additional information (e.g., field guide)</td>
<td>5.55</td>
<td>2.29</td>
</tr>
<tr>
<td>Use of the &quot;smart classroom&quot; (e.g., large screen projectors, immersive environment, etc.)</td>
<td>8.00</td>
<td>1.97</td>
</tr>
</tbody>
</table>
Across all iterations, student attitudes towards EvoRoom was high (Figure 44), achieving mean scores of 7 to 8 (out of 10) for overall activity and visualizing content, with the use of the immersive space consistently receiving the highest scores, between mean scores of 8 to 9 points.

**Finding:** Students moved around the room during activities

In the Year 1 EvoRoom activities, content was indexed to at least four different areas of the room, and students were directed around the room using a QR sign in functionality (i.e., to register their presence at each location). Although movement was detected throughout (i.e., demonstrating progress on the design goal), the co-design team had felt that the tasks were perhaps “too scripted.” In general, we loosened the rigidity in certain aspects of the script to allow for natural movements around the room. In Year 2, we removed the stringent QR scanning functionality, while maintaining the indexicality of the content to different areas of the room. Students were either directed by instructions on their tablets or verbally by their teacher to move around the room (Table 17 and Figure 44. Student attitudes toward EvoRoom through design iterations)
Table 18). An analysis of student movement (similar to that in Year 1) was conducted for the Year 2 evolution activities using videos collected from a session with paper handouts (31 video clips) and a session using tablet computers (29 video clips), as well as a session of the biodiversity activity (30 video clips). Each student’s position(s) in the room during each clip were coded according to his or her placement in designated areas of the room (Figure 45). Movement was coded as change in the student’s position(s) within or between clips.

**Table 17.** Levels of interaction and movement prompts during phases of the EvoRoom evolution activity in Year 2.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Level of interaction</th>
<th>Movement prompts</th>
<th>Paper Session Duration (h:mm:ss)</th>
<th>Tablet Session Duration (h:mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Plenary</td>
<td>Once students entered the room, no movement expected during teacher-led introduction</td>
<td>0:02:59</td>
<td>0:07:43</td>
</tr>
<tr>
<td>Observation I</td>
<td>Guided individual</td>
<td>Specific time period locations (i.e., 200, 150, 100, 50 MYA) assigned through instructions on tablet. Student guides were to remain at their assigned location</td>
<td>n/a</td>
<td>0:21:24</td>
</tr>
<tr>
<td>Group reflection I</td>
<td>Collaborative</td>
<td>In paper sessions, teacher instructed students to complete questions on all four locations but did not give further instruction with respect to location (i.e., which location to visit first). In the tablet session, the teacher and the tablet instructed students to go to a specific location in the room</td>
<td>0:13:35</td>
<td>0:12:36</td>
</tr>
<tr>
<td>Observation II</td>
<td>Guided individual</td>
<td>Specific time period locations (i.e., 25, 10, 5, 2 MYA) assigned through instructions on tablet. Student guides were to remain at their assigned location</td>
<td>n/a</td>
<td>0:11:47</td>
</tr>
<tr>
<td>Group reflection II</td>
<td>Collaborative</td>
<td>Same as Group reflection I</td>
<td>0:10:15</td>
<td>0:05:34</td>
</tr>
<tr>
<td>Explanation</td>
<td>Individual, Collective</td>
<td>No specific locations assigned</td>
<td>0:24:33</td>
<td>n/a</td>
</tr>
<tr>
<td>Discussion</td>
<td>Plenary</td>
<td>No movement expected</td>
<td>0:11:14</td>
<td>n/a</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1:02:36</td>
<td>0:59:04</td>
</tr>
</tbody>
</table>
Table 18. Levels of interaction and movement prompts during phases of the EvoRoom biodiversity activity in Year 2.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Level of interaction</th>
<th>Movement prompts</th>
<th>Average Duration (h:mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Plenary</td>
<td>Once students entered the room, no movement expected during teacher-led introduction</td>
<td>0:10:19</td>
</tr>
<tr>
<td>Observation</td>
<td>Collaborative</td>
<td>No movement prompts. Students chose the rainforest stations to (individually and) collaboratively make observations</td>
<td>0:24:22</td>
</tr>
<tr>
<td>Data Review</td>
<td>Plenary</td>
<td>No movement expected during teacher-led discussion</td>
<td>0:04:11</td>
</tr>
<tr>
<td>Explanation</td>
<td>Collaborative, Collective</td>
<td>No movement prompts as students collaboratively ranked rainforest stations and explained their choices</td>
<td>0:09:23</td>
</tr>
<tr>
<td>Discussion</td>
<td>Plenary</td>
<td>Few movement expected as students presented their explanations at the front displays and the teacher led a summative discussion</td>
<td>0:13:40</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1:01:41</td>
</tr>
</tbody>
</table>

Figure 45. EvoRoom room set up, indicating video camera positions (A-E) during the biodiversity activity and evolution activity in Year 2. Students’ positions in the room were assigned to one of six locations: 1) Rainforest A, 2) Rainforest B, 3) Rainforest C, 4) Rainforest D, 5) Front boards, 6) Table, according to the designated areas indicated inside dotted lines.
Figure 46. Average student movement (between video clips, across six locations) in each phase of the EvoRoom evolution activity, paper version, in Year 2. Note, group reflection I and II were combined as one phase in the paper version.

Figure 47. Average student movement (between video clips, across six locations) in each phase of the EvoRoom evolution activity, tablet version, in Year 2.
Figure 48. Average student movement (between video clips, across six locations) in each phase of the EvoRoom biodiversity activity in Year 2.

Movement was detected in all phases of the activities with the exception of the introduction in the paper version of the evolution activity (Figure 46), and group reflection II phase of the tablet version of the same activity (Figure 47). The y-axis on these graphs shows the number of student “movement events” (i.e., where a student crossed from one region of the room to another) observed in any phase of the activity. Movement was detected in all phases of the biodiversity activity (Figure 48). In the case of the introduction, students had already entered the room when the activity began, and in the group reflection II phase, most students were sitting down in specific locations as directed by the tablet and their teacher to complete their questions. This phenomenon will be discussed in greater detail below, under the “collaborative level” subsection.

In general, the movement analysis shows that students were moving around the room as intended, without the need for a specific QR sign in functionality. Instructions provided by their tablet and teacher, together with improved design of the needs and affordances of the rooms, were sufficient to ensure movement to different areas of the room.
Finding: More attention was directed to other students

In Year 1, one issue noted was the concurrence of student-student interactions with student-device gazes (i.e., when they were interacting with peers, they were also looking at their tablets). In response, how students engaged with each other was one area of focus for Year 2 design improvements. The patterns of interaction analysis presented below shows that this overall design goal was achieved. For the evolution activity, the analysis was performed on a session with paper handouts and a session using tablet computers. A total of 31 and 29 10-second long video clips were analyzed at 2-minute intervals in each session, respectively. In the biodiversity activity, 30 video clips were analyzed.

In the evolution activity, students interacted with other students frequently in both paper and tablet sessions of the activity with slightly more student-to-student interactions observed in the tablet session (90% of video clips) compared to the paper session (84% of video clips; Figure 49 and Figure 50). In the tablet session, this was followed closely by student-device interaction (76% of video clips). There were fewer occurrences of student-device interaction in the paper session (i.e. the equivalent of student-device interaction translated to writing on paper handouts in paper sessions), but it was still the second most frequent type of student interaction (55% of video clips). Student-teacher interactions were also observed in 55% of video clips in the tablet session and 48% of video clips from the tablet session.
In the biodiversity activity, individual students interacted with a device in 93% of the segments analyzed (Figure 51) – slightly more frequently than with one another (87% of the
A similar pattern was observed in terms of students’ gaze targets. Students looked at their device the most and at least one student was observed looking at their device in all segments. Students also gazed at other students in most of the time segments as well, more frequently than gazes toward the immersive walls (70% of the time). Gazes towards the collective visualization (on the front interactive whiteboards) were observed in 37% of the clips, concentrated in the discussion portion of the activity. Students looked at their teachers in 53% of the video clips. In 30% of the video segments, student-student or student-teacher interactions were supported by deictic gestures (e.g., pointing) toward the immersive wall or the collective visualization (Figure 52).

Figure 51. Student interaction patterns of the EvoRoom biodiversity activity in Year 2.

Figure 52. Deictic gestures (e.g., pointing) observed over duration of EvoRoom biodiversity activity in Year 2.
Compared to the Year 1 biodiversity activity, there were more gazes directed at other students in the Year 2 biodiversity activity, but also more interactions with student devices (Figure 53). Using gaze as an indicator of user attention, this suggests that students were indeed paying more attention to their peers during the activity compared to Year 1, as intended in the design. Student-device gaze and interaction numbers, however, indicate that students’ devices held students’ concentration to a greater degree in Year 2’s biodiversity activity.

In Year 2 of the evolution activity, there were more incidences of student gazes and student interactions in both paper and tablet sessions of the activity (Figure 54). There were also lower incidences of device interactions in the paper version, which was expected, since fewer students had access to a “device” (i.e., there were only two sets of paper handouts per group, a set of questions and a set of paper resources with additional information, paralleling what was available on the tablets).

Overall, Year 2 activities encouraged more attention to be paid to other students. At the same time, student tablets continued to hold many students’ attention throughout much of the activities. Many students engaged in more than one interaction at a time, which often involved their tablets.
**Figure 53.** Student and device interaction patterns observed in the EvoRoom biodiversity activity, Year 1 compared to Year 2.

**Figure 54.** Student and device interaction patterns observed in the EvoRoom evolution activity, Year 1 compared to Year 2.
Finding: Addition of “guides” observed with improved observational accuracy and increased student-student interactions

In Year 2, we also responded to the following design recommendation: *Offer more opportunities for student-student interactions, particularly those leading to deeper interactions.* One change made in the evolution activity to improve student-student interactions was to offer more opportunities for exchanges in the observation phase (another change will be discussed under the collaborative level section). Certain students acted as “guides” to support individual observations of different time periods in the rainforest environment (note that this was only implemented in the tablet session). Similar to a docent’s role in a museum, students could receive guidance from a peer at each of the time periods, in the task of selecting whether their assigned organism was present in that period, and otherwise noting the organism’s predecessor.

Three times as many student-student interactions were found in the observation phase of the Year 2 evolution activity compared to Year 1 (Figure 55). Student-device interactions across both versions remained at a consistent level.
Figure 55. Average number of student-student and student-device interactions in the observation phase of the EvoRoom evolution activity in Years 1 and 2.

Students also achieved higher observational accuracy scores than in the previous year. How well students performed with the help of a guide was examined. 335 answers to the question: Which of the following is most likely your organism's ancestor? were collected by the tablets, of which 83.88% were accurate across all time periods. As in Year 1, there was an upward trend of accuracy compared to time period (presumably because the organisms shared more similarities with their present-day counterparts in more recent times). In Year 2, over 90% accuracy was reached by “100 million years ago” whereas in Year 1, over 90% accuracy was only reached at two time periods (25 and 2 million years ago; Figure 56).
Figure 56. Observation accuracy by time period in EvoRoom evolution activity in Years 1 and 2. Accuracy in Year 1 was averaged over four sessions.

The student interactions between guide-participant pairs tended to be brief and consisted of question and answer type of exchanges. Still, the addition of guides allowed students to quickly move through a straightforward task, and set the stage for student interactions involving a specialized “expert” peer throughout the rest of the activity.

Finding: Significantly improved explanations compared to pilot study and Year 1 evolution activity

A design recommendation for Year 2 activities was focused on supporting student reflection by improving data collection and explanation writing scaffolds. In the evolution activity, the explanation work was supported by the cladogram, a visualization that represented the evolutionary lineages of the organisms in the room, which was designed as a collectively created artifact by aggregating individual student observations. While the quality of explanations in Year 1 improved over those from the pilot study, the co-design team wanted to see further improvements. To this end, students were asked to explicitly review the cladogram and to pick
one organism for which they would write a final focused explanation (i.e., of its evolutionary trajectory through 200 million years).

At the end of the activity in all three versions of the evolution activity (i.e., pilot, Year 1, Year 2), students reflected on the evolutionary forces that were at play in the environment through 200 million years, allowing the culminating explanation to be compared. Due to time and technological constraints, students in the tablet group were unable to complete the final step of discussing and posting ideas about evolutionary processes. This was remedied by asking students to answer an analogous question as a post-activity assignment and doing the class discussion at the following period: *Choose an organism from the Borneo ecosystem and discuss the evolutionary forces you think are at play through 200 million years.* Although worded differently, the question posed for the students’ post-activity assignment was analogous to the explanation question designed for the end of the evolution activity. Students reflected on what evolutionary forces they believed were at play in this environment, with the difference being that in the current iteration, students focused their attention on a particular species of their choice.

38 explanations were written and the answers were coded using the KI scale, revealing that students who participated in the Year 2’s iteration achieved a mean KI score of 3.7 ($M = 3.71$, $SD = 1.14$), showing a pattern of successively improvement over the pilot and Year 1 iteration. Knowledge integration scores for students' explanation of evolutionary processes in Year 2 were significantly higher than those in Year 1 and the pilot study, $F(2, 92) = 12.64$, $p<0.001$ (Figure 57). Correspondingly, there were also more explanations that were coded as “complex,” as over 50% of the notes were coded either as Basic or Complex (Figure 58).

The improvement in Year 2 explanation scores is partly a result of improvement to the activity design, but may also have benefited from allowing students to complete the question after the activity. It could also be due to improved phrasing of the question, which included more scaffolding in asking students to review the cladogram and choose a specific species to reflect upon.
Figure 57. Mean KI scores of evolution explanations in pilot and Years 1 and 2 iterations of the EvoRoom evolution activity.

Figure 58. Distribution of evolution explanations' KI scores in the pilot and Years 1 and 2 iterations of EvoRoom evolution activity.
6.5.3 Collaborative level

**Finding: A majority of students relied on photographs as evidence in their observations**

In the Year 1 biodiversity activity, the observation phase was designed in two parts, an individual portion where students noted the presence of their assigned species, and a group observation step, where members made preliminary conjectures about whether the rainforest stations (depicting various scenarios) could be associated with their group variable (e.g., high temperature). In the Year 2 biodiversity activity, the two steps were combined into one observation phase, creating more opportunities for peer interactions. Students were instructed to move around the space and make observations about the rainforest scenarios as a group. Additionally, multimodal options for recording observations (such as taking photos, videos) were introduced via the Zydeco application to improve the ease of collecting observations (e.g., reducing duration of head-down typing behaviour), thereby allowing more time for interaction with others. A “control” version of Borneo (i.e., with no abnormal environmental influence) was included in Year 2 (on the front interactive whiteboards) as a reference to promote more thoughtful comparisons of the four rainforest stations.

193 student observations were collected, with an average of 12 observations contributed by each group ($SD = 5.6$). The vast majority of these observations (89%) contained an image, with less than half of all data collected containing any text notes (43%). It was interesting that, in one of the sessions, three groups made fewer than five text-supported observations, tending to only take photographs of areas and verbally discuss their observations (i.e., and not record them). To confirm that observations were “on task” and relevant, we again coded all observations that had accompanying descriptive text (in either text note or title) or audio (either in the audio note or video entry) in terms of their “potential usefulness” (i.e., where each discrete unit of within the observation was coded). 190 observations were coded, with each group contributing an average of 12 observations ($SD=8.3$). 98% of the observations were categorized as potentially useful. IRR was performed on 20% of data, where 87% agreement was achieved (Kappa=0.83, $p<0.001$). Hence, students were able to use Zydeco to collect potentially useful supportive evidence for their collaborative inquiry tasks.

Further, a majority of student explanations in Year 2 (94%) relied on data objects that contain images as evidence (a form of observational data not used in Year 1). This points to the
effectiveness of using photographic capture for observations within immersive environments. This was somewhat surprising, as we had anticipated some dependence on written observations to serve as evidence, indicating that while written observations were useful to some, other students found images to be more informative or accessible. This may be because the annotations accompanying the images supplied students with sufficient information about the observed. It could also be that the highly visual immersive simulation environment lent itself to image-based observations. By enabling access of information through different modalities, we hoped to increase the awareness of students within the immersive space, providing a richer basis for reflection.

While there was an increase in the average number of student-to-student interactions per video clip (Figure 59), not all students worked in their groups, despite being given specific collaborative tasks via their personal devices. Each group member was provided with a device, most of which had the Zydeco application loaded for recording observations. One member from each group was provided with a reference tool (i.e., a tablet loaded with the field guide, their predictions, and collaborative food web). It was expected that the groups would walk around together noting observations, receiving aid from their reference “guide” when needed. However, tracking of student locations revealed that none of the four groups that were analyzed remained together in the same location (i.e., station A, B, C, D, front boards, or table) throughout the observation phase. Some students walked autonomously or in pairs to the various rainforest stations, collecting evidence – but rarely as an entire group. Two of the four groups worked together (i.e., with all members at the same location) some of the time (i.e., in 83% and 58% of video clips analyzed) while other groups worked in pairs or in threes, with the rest of their group members observing another area of the room the majority of the time (i.e., in 82% of video clips). Some students broke off from their own group to discuss with other groups’ members, asking them what their variables were and their initial thoughts on which rainforest stations matched their variables. This was an unexpected but productive strategy.
Figure 59. Average number of student-to-student and student-device interactions in each 10-second video clip analyzed for the observation phase of the EvoRoom biodiversity activity in Years 1 and 2.

While taking photos was widely used as a method of data collection and appeared to support an increased level of student-to-student interactions, the design change seemed to have more of an impact on student-device interaction rates (which may be indirectly why student-student interactions increased). Because of Zydeco’s ease of capturing and titling photographic evidence to serve as observations, there was less need for head-down typing into the tablet. Still, even though efforts were made to reduce “head down” behaviour, it was still up to the individual student to engage with peers.

Design recommendation: Students can use photography as an effective means for recording observation in immersive simulations, structuring their observations with tags or other annotations to support the review of collected information.
Finding: Improved explanations in biodiversity activity, but accurate identification of rainforest scenario remains low

In the Year 1 biodiversity activity, both the accuracy of rainforest identification and quality of explanations were seen to be wanting for improvement. To scaffold students’ explanation writing with their observational data in Year 2’s biodiversity activity, students needed to add observational data to their explanations as evidence of their claims.

Similar to the results in the first iteration, 6 out of the 16 total groups correctly identified the rainforest stations, and in one of the sessions all four groups correctly identified their environmental factor. In spite of these failings to identify the correct rainforest (i.e., that reflected their targeted factor), students’ final explanations were more complex and scientifically accurate than in Year 1, scoring an average of 7.6 of 8 ($SD = 0.6$), with no significant relationship between identification accuracy and CER scores (as seen in Year 1; Figure 60). IRR was performed on 20% of data, where substantial agreement was achieved (Kappa=0.71, $p<0.01$). It should be noted though that in the session where all four groups correctly identified their factors, all groups achieved perfect scores for their final explanations. This suggests that there may indeed be some relationship between accuracy on this task and sophistication of explanation, but the data collected in Year 2 did not come out as significant.

![Figure 60. Mean explanation scores (CER scores) by identification accuracy in EvoRoom biodiversity activity, Year 1 compared to Year 2.](image)
Of all the data objects that were contributed by students, 40.4% were later used as evidence to support the explanations. Amongst the evidence used to support claims, most included a photo (93.6%), with less than half including a text note attached to the data object included as evidence (46.2%; Figure 61). One group mentioned that they only took photos because they had previously conducted a lot of research on the different environments and were looking for characteristics in the photos they knew would be in each environment. Another group fixated on certain traits they knew their scenario should have, and went looking for any observational evidence that exhibited those traits. For example, high rainfall would result in an environment with more water and greater biodiversity, and so they took photos of any elements of the displays with plentiful water.

![Figure 61. Composition of data objects used as evidence](image)

As noted above, the explanation scores from Year 2 improved in sophistication from those of Year 1, indicating that more students were able to produce well-reasoned claims with appropriate supportive evidence. Incorrectly identified rainforest stations were sometimes accompanied by strong explanations with appropriate evidence. This was the case if students’ incoming ideas about the impact of their environment factor differed from what was presented as the correct answer. As such, the students’ inability to identify rainforest scenarios only served to highlight false assumptions and possible rigid thinking, unrelated to their observational data collection.
Design recommendation: Scaffold students in connecting their explanation to their observational data.

Finding: Lower levels of student movement during group reflection correlated higher explanation scores

A second design goal for Year 2, prompted by our notice of an interaction pattern in Year 1 where students often talked with peers while typing on his or her tablet, was to improve the quality of student-student interactions. We had also noticed that students did not discuss with all members of their group, as instructed during the group reflection phase of the evolution activity, and mainly worked individually. In the Year 2 iteration, a more reflective group task was added, where students were asked to compare the rainforest at different time periods. This was a more active and reflective task, requiring the expertise of various group members with different specialties and included the following explicit 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 paper session of the evolution activity, the individual observation phase was eliminated since it was not feasible without the underlying technology of the tablet application. We opted instead to lengthen the group reflection phase by asking students to make comparisons across all successive time periods in their groups (e.g., 200 compared to 150 MYA, 150 compared to 100 MYA, 100 compared to 50 MYA…etc. up to 2 MYA). There were four to five students in each group, with one person writing out answers and another holding on to the resource package that contained information about organisms shown on immersive walls.

In the tablet session, students did the same comparison task as in the paper session but they only had one comparison (e.g., of 200 to 150 million years ago) to perform at each phase instead of four. They were also assigned a location to work from and the collaborative process was further supported through task-based roles. Not only were groups members assigned jigsawed organism specialties, they were also asked to designate a specific person to act as the scribe of the group (for a particular question), as well as other members to be time period
specialists (i.e., responsible for looking up resources about the rainforest at each specific time period).

In the two sessions with paper handouts, only 67% of the comparisons were complete, while all of the assigned comparisons were made in the one session utilizing tablets. Student responses were again scored using a KI scale, which found the mean KI score in the tablet sessions ($M=3.33$, $SD=0.60$) to be significantly higher than that from the paper sessions ($M=1.9$, $SD=0.69$), $t(7) = 3.04, p < 0.05$.

**Figure 62.** Average number of student-to-student interactions in each 10-second video clip analyzed for the group reflection phase of the EvoRoom Evolution activity in Years 1 and 2.

Compared to the group reflection phase in the Year 1 evolution activity, more student-student interactions were observed in both paper and tablet sessions (Figure 62). In the paper sessions, students were encouraged to move around, and demonstrated a surprising number of student-student interactions, compared to the tablet session – nearly double the number. The only person with a clear task in the paper session was the scribe, even the person holding the paper resources weren’t seen to be using them as often as the corresponding resource members of tablet groups. Other group members contributed to the discussion at their discretion. While some were active in discussions, others walked around with group members but did not say very much.
In the tablet session, students were encouraged to remain in one area, and hence were stationary, either sitting on the floor or standing around the table working in a circular formation. No one seemed to be left out of the discussion, despite having the same number of members in a group as the paper session.

Further examination of students’ collaboration is revealed through multimodal interaction analysis, which again showed quite distinct forms of collaboration between paper and tablet sessions. In the paper session, a group of four was seen examining walls C and D to make comparisons between the two (Figure 63). The group remained together, but two of the four group members were the main participants (Dan and Jody) of the discussion. One member (Dan) was particularly active, moving between walls C and D and frequently pointing or making pointing gestures towards the walls. Two of other members were less active (Lucy and Jeremy), remaining largely on the periphery of the discussion, but clearly observing the walls and paying attention to the discussion. Lucy offered one piece of information about the tapir, but otherwise kept observing with her arms crossed. The fourth member, Jeremy, did not contribute but remained close to the group, except when walking between walls C and D to observe the content more carefully.

The somewhat uneven patterns of participation in this group interaction reflect challenges that are common to many classrooms, where some students participate more actively than others. In the case of this particular group, the two less active members seemed to be thoughtful about the content of the simulations, either making well-timed comments (indicating that they were listening to the exchange while observing the walls) or moving between rainforest stations (immersive walls) to make comparisons. It appears that this group of students could have benefited from collaboration scaffolds (i.e., as provided to the tablet sessions) that assigned roles to each student and directed members’ attention to specific information.
Figure 63. Multimodal interaction analysis of a small group interaction, in the paper session of Year 2’s evolution activity.

In the group reflection phase of the tablet session, two of the three groups sat down in their designated corners of the room (as directed by their tablets and their teacher) to answer their
assigned questions while a third group stood in front of the walls during part of their discussion. A multimodal interaction analysis of the third group revealed how they worked together in the presence of collaborations scaffolds (i.e., functional tasks assigned, screens limited to functions needed to support their assigned tasks). The group of four worked in pairs as well as a whole group (Figure 64). In the beginning, Phebe and Sharon were observing together, while Cory and Ray worked as a pair. All four members considered the differences between walls A and B together, after Phebe asked the group (line 14). Sharon shared information about a mass extinction that occurred prior to one of the time periods from her tablet, and when Phebe had a question, Sharon pointed out information on Cory’s tablet. All members looked at his tablet as a common referent, but Ray was more interested in answering the question for which he was the scribe for, asking Cory for assistance. The teacher, in an attempt to help, inadvertently broke up the interaction by offering additional paper copies of resources (i.e., information about specific time periods).

While other groups worked collaboratively to address the three assigned questions, one at a time, the members in this group chose to answer all three questions at the same time. Cory, Phebe, and Ray were each responsible for answering a question relating to the comparison of the rainforests at 200 MYA and 150 MYA. Sharon was responsible for the information lookup for 200 MYA, and once Cory submitted an answer to his question, was able to take on the information resource role for 150 MYA. Both resource roles supported scribe members during this interaction, but Ray and Phebe had opposing goals: one sought to answer the question, and the other wanted to start a discussion. This interaction showed that limiting information resources to a specific group member allowed them to support their scribe peers and that freeing up the tablet screens of scribes supported their individual work. In fact, when the teacher showed Ray additional paper-based resources, he no longer needed to work with Cory and moved away from the group.
Figure 64. Multimodal interaction analysis of a small group interaction, in the tablet session of Year 2’s evolution activity.
Group interactions such as those delineated above indicated that explanations were better constructed (based on their KI scores) in the tablet session compared to the paper session, suggesting that limiting movement, assigning functional roles, and limiting resources that are relevant to those with specific functional roles would result in an environment that is more conducive to collaborative reflection. Another example of functional roles being assigned to students in the evolution activity was the use of guides in the observation phase. Task based roles were implicitly assigned to students in the biodiversity activity by way of the type of device they received. As discussed above, the Zydeco application did not have any collaboration scaffolds built in; rather the type of device students received determined the task they were given. This was not sufficient to foster collaborations amongst all group members throughout the activity. Overall, groups in the tablet session of the evolution activity were most effective, likely because students’ tablet screens showed only what their roles called for, productively constraining their collaboration.

**Design recommendation:** Reduce movement and incorporate collaboration scaffolds allow students to focus on collaborative reflective work

**Finding: Unrestrained natural movements were more conducive to observational work rather than to reflective tasks**

A multimodal examination of a group interaction during the observation phase of the Year 2 biodiversity activity highlights some differences between the biodiversity activity in Years 1 and 2 (Figure 65). During the observation phase, students were tasked with moving around the room and observing the four available rainforest stations. Students were scaffolded in how the observations were recorded using Zydeco (e.g., after capturing a photo, students were prompted to annotate the observation with the station ID assigned to the display, including a title and tags relating to possible climatic scenarios). They were also scaffolded by the very nature of the device they received (i.e., with Zydeco, or a field guide). The group analysis below reveals brief, “broken up” interactions, in which members walked away from their group during discussions to examine various wall content more carefully, have discussions with group members separately (i.e., Lynn with Lara and Lynn with Max), and have conversations interrupted by other groups’ members. There were moments in which students were focused on the same set of wall content (e.g., “Rainforest C”), much like the interaction examined in Year 1, but the discussion did not become deeper or more animated (e.g., more gestures) as it had in the
previous year. The interaction also did not include all of the group members.

Figure 65. Multimodal interaction analysis of a small group interaction, in which students discuss whether the rainforest ecosystem shown on the wall in front of them represented one that is affected by the group’s climatic variable (low rainfall).

At the outset, two of the three students in this group had already narrowed their choices to “Rainforest B” or “Rainforest C.” One student (Max) was seated in a chair by the table, when Lynn walked up to the other side of the table, leaned in and asked Max to confirm her suspicions.
Max, who was looking down at this tablet at the time, looked up and answered. He looked down at his tablet again to consult their and other groups’ earlier prediction assignments, in order to gather more information. At this point, Lynn walked around the table and looked at the interactive whiteboards at the front of the room. Max swiveled his chair to look at Lynn as she moved and told her that the front boards showed the original state of the rainforest prior to climatic effects. Lara, a third group member who was standing at the front edge of the table and had not contributed to the interaction, turned to the front boards along with Lynn, and the two of them had a brief exchange before another group’s member (Lily) pointed out something in “Rainforest C” (unintelligible). Max also looked at the wall with his group members. Max and Lara looked at one another at 16:42, while Lynn moved to Rainforest B to examine it. The three alternated their gaze toward Rainforest B and C at the end of the discussion. A fourth group member was not part of this interaction.

In the biodiversity activities in Years 1 and 2, students were tasked with making observations and initial conjectures about whether the rainforest stations could have resulted from their assigned environmental variable’s effect. In Year 1, students were led from station to station as a group, with all members of the group required to sign into the location before receiving further instructions. Students were also assigned functional roles of writing down answers to their group question (i.e., could this be your rainforest?) or looking up additional resources using their field guide or prior group predictions. In Year 2, the script was adjusted such that students were told to work “as a group” to identify the rainforest station that best matched the results of their environmental variable, but were free to move about the room as they wanted to. Roles were implicitly assigned by way of the device students received (i.e., iPads for looking up resources, iPods and iPad minis for making observations). Although the goals of the tasks in Year 1 and 2 were quite similar, the patterns of interactions seen in the enactments were distinct.

In Year 1, students within a group were constrained in their location, roles, and material resources as a group, resulting in more sustained interactions amongst members as they discussed the same rainforest station throughout their exchange. Also their discourse typically progressed to consensus. Year 2’s exchanges between group members were characterized by more brief interactions, frequently broken off for observations or interactions with other groups and then resumed to discuss choices. While these interactions would not necessarily be described
as higher quality or deeper than the interactions amongst students in the Year 1 biodiversity activity, they highlight how certain constraints within the learning environment and script can influence the ways in which students interact with one another. While the Year 1 scripts and constraints created a space for deeper collaborative reflection, the freedom for movement and interactions in Year 2’s design allowed students to engage in different lines of reasoning within a short period of time, which was seen to be productive early on in the brainstorming process.

**Design recommendation:** For collaboration, encourage movement and natural social interactions to allow students to explore the environment and explore initial ideas, but provide well-defined tasks with group scaffolding to support more sustained, reflective discussions.

### 6.5.4 Collective level

**Finding:** Students successfully constructed a collective knowledge base, building their field guide and other resources.

In Year 2 activity designs, meaningful collaborations were supported with a combination of jigsawed teams and collaboration scaffolds. One important design feature of the collective inquiry activity was 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 the specialist would have detailed information about species from his or her assigned group). This feature was carefully designed into collaborative steps of the activities, allowing students to work towards a shared artifact for further exploration. But it was also instrumental in one of the important collective aspects of the design: students’ construction of a single field guide that included all relevant species from the ecosystem. In order to help students feel like "experts" in their specialization upon arrival in the EvoRoom environment, we needed to first engage them in pre-activities that would exercise their nascent knowledge, allowing them to feel more competent and solid in their expertise. Engagement was not enforced in such activities, nor was effort graded; yet the student contributions were impressive.

In order for all class sections to work together on completing a field guide, each student was assigned not only a specialist category and species within that category, but to several of the following headings for their species: Brief Summary, Distribution, Taxonomy, Morphology, Size, Habitat, Behaviour, Reproduction, Life Cycle, Evolution, Systematics or Phylogenetics,
Physiology, Conservation Status, Threats, and Benefits. There were 14 headings in total and the number of headings assigned depended on the volume of the expected contribution. With 35 organisms in the field guide, there were 490 subheadings in total. Prior to their participation in the evolution activity, 84.49% of the subheadings were complete.

A timeline assignment was broken down into five subheadings: Birds, Other mammals, Plants & Insects, Primates, and Environment, with eight time periods that needed to be researched (i.e., 200, 150, 100, 50, 25, 10, 5, and 2 MYA). Multiple students were assigned to each of the subtopics. Prior to their participation in the evolution activity, the wiki page documenting the rainforest at various time periods was only slightly less complete (57.50%) than the main sections for species, but still contained substantial information.

Thus, our complex collective distribution of specializations and assignments led to the successful creation of a substantive resource to be used by all students during the collective inquiry activities with immersive simulations. Over 50 students collectively completed a field guide as part of their curricular activities, and students worked together to create a map of the evolutionary lineages of the species in the simulated rainforest ecosystem in the evolution activity. In both cases, individual students had their own piece of the larger puzzle for which they were responsible.

The field guide was later used during collective inquiry activities with immersive simulations, as well as during the collaborative food web homework activity. Because of EOL Ecosystem Explorer’s technological limitations, each class was provided the same set of login information; as such individual contributions were not tracked. There was a total of 33 organisms present in the food web, and for both class sections not every organism was associated with another (i.e. food web only partially complete). In the first class section, 31 unique interactions were identified (e.g., white fronted langur competes for habitat with black crested leaf-monkey; Figure 66). In the second, there were 41 interactions created. Comparing the two collaborative food webs, only 8 interactions were shared between the two, making a case for both classes completing the one shared food web.
Figure 66. Completed collaborative food web in EOL’s ecosystem explorer tool. The Laurel Fig was selected (in red), which highlights all of its connections at the bottom of the page.
Finding: Collective patterns of early ideas influenced student decisions

To give collective work a larger presence and improve its “visibility” and to encourage more students to review everyone’s ideas, the Year 2 evolution activity was adapted so that all students would need to review the collective artifact (i.e., cladogram) in choosing a species for which they would explain its evolutionary trajectory. Due to technological issues that occurred during the enactment, students reviewed the cladogram at home and thus the manner in which they reviewed this collective artifact was lost to any analysis. For the biodiversity activity, however, student observations were pooled into a collective knowledge base, which was the focus of attention during the data review step.

During the biodiversity data discussion, the teacher used the collective visualization’s filtering functionality to review the groups’ work. For example, toggling the visibility of “earthquake” observations and hiding all others revealed only those associated with earthquakes. In the collective visualization, the observations were organized according to the rainforest stations the observations were about. In this way, the teacher was able to notice preliminary trends (e.g., “station B and C could be low rainfall”). The teacher also expanded the data objects to reveal detailed information (e.g., text note, annotations), reading out examples or examining larger images. After the data discussion, students accessed the collective set of data objects from their own tablets.

The data review discussion revealed students’ patterns of early ideas, however many students had false assumptions that permeated through to their observations. To understand how students used their session’s collective information, we examined the students’ final choice with the pattern of collected observational data tagged with their particular climate scenario. 13 of 16 groups (81.3%) chose a station associated with the highest number of data objects tagged with their environmental factor. In the students' final explanations, two of the three remaining groups indicated that they considered the collective data, but had reasons to believe that the more popular choice was incorrect. However, in these three cases, their final choices as well as the stations associated with the highest number of data objects tagged with their scenario were incorrect. The data objects were associated with the correct environmental factor in 8 of 16 instances (50% collective accuracy).
Showing these early patterns thus potentially affected students’ final choice and overall accuracy. There was one session where all the groups selected the correct rainforest station for their assigned factor. In the other sessions, the accuracy ranged between 0% and 50%. In the session with the highest accuracy rate in Year 2, the collective pattern shown during the data review step was essentially correct (i.e., the highest number of data objects was annotated with the correct environmental factor for each of the four rainforest stations), which likely contributed to the high accuracy rate. While showing a correct collective pattern translated to a higher accuracy rate, showing incorrect collective patterns were associated with lower accuracy. Thus, while technology can help the teacher by exposing students’ assumptions for possible remediation, this information should be presented in a manner that encourages students and teacher to advance the discussion. For example, collective knowledge could be positioned to students as a body of work to be revised and built upon, rather than a “completed” state of knowledge.

**Design recommendation:** Support and guidance is needed to help students build upon collective knowledge

### 6.5.5 Design Implications

This work revealed a number of opportunities for refinement of the EvoRoom activities and technology supports, particularly concerning how to design collective knowledge building experiences in digitally augmented physical spaces. 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 likely impacted their group or session’s collective success. In both activities, we found that students paid careful attention to the immersive media as well as other media components (tablet software, visualizations) in the immersive simulation. Many of the artifacts that captured student reflection about evolutionary biology resulted from interactions with immersive walls as well as discussion amongst students and their group members. However, this was as much a feature of our pedagogical design as the influence of any specific media. During the collective inquiry activity, visualizations that aggregated students’ collective observations served as an important
tool and shared artifact to encourage deeper discussions and drive further reflection. Successful design features of our immersive simulation include: visualizations of the rainforest; displays of the collective knowledge (i.e., in the form of a cladogram); supporting collaboration in the activity script (Table 19). However, there remains a need for further work on fostering collective knowledge construction.

**Table 19.** Summary of findings and design recommendations from Year 2

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Year 2 findings</th>
<th>Year 2 design recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>1. Significantly higher post-test scores compared to pre-test scores</td>
<td>• Students can use photography as an effective means for recording observation in immersive simulations, structuring their observations with tags or other annotations to support the review of collected information <em>(from finding 7)</em></td>
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<tr>
<td></td>
<td>2. Student attitudes were positive, rating their immersive experience highly</td>
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<td></td>
<td>3. Students moved around the room during activities</td>
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<td></td>
<td>4. More attention was directed to other students</td>
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<td></td>
<td>5. Addition of “guides” observed with improved observational accuracy and increased student-student interactions</td>
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<td></td>
<td>6. Significantly improved explanations compared to pilot study and Year 1 evolution activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. A majority of students relied on photographs as evidence in their observations</td>
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<tr>
<td>Collaborative</td>
<td>8. Improved explanations in biodiversity activity, but accurate identification of rainforest scenario remains low</td>
<td>• Scaffold students in connecting their explanation to their observational data <em>(from finding 8)</em></td>
</tr>
<tr>
<td></td>
<td>9. Lower levels of student movement during group reflection correlated higher explanation scores</td>
<td>• Reduce movement and incorporate collaboration scaffolds allow students to focus on collaborative reflective work <em>(from finding 9)</em></td>
</tr>
<tr>
<td></td>
<td>10. Unrestrained natural movements were more conducive to observational work rather than to reflective tasks</td>
<td>• For collaboration, encourage movement and natural social interactions to allow students to explore the environment and explore initial ideas, but provide well defined tasks with group scaffolding to support more sustained, reflective discussions</td>
</tr>
<tr>
<td>Collective</td>
<td>Students successfully constructed a collective knowledge base, building their field guide and other resources</td>
<td>Support and guidance is needed to help students build upon collective knowledge <em>(from finding 11)</em></td>
</tr>
<tr>
<td>Collective</td>
<td>Collective patterns of early ideas influenced student decisions</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 7

7 Discussion and Conclusions

This thesis reported on a pilot study and two design iterations of a biodiversity and evolution unit that incorporated the use of immersive simulations and collective inquiry activities as important and interwoven elements in the curriculum design. The unit included a variety of activities including carefully designed homework to support student experience, conventional in-class activities (i.e., lecture, labs and readings), and a field trip to a local zoo. My research questions, framed around the design of the immersive simulations and concomitant activities, are concerned with how the design of activities and the environment (including technology supports) can successfully engage students in collective inquiry. The preceding chapters have presented the designs as they were enacted sequentially (in pilot, Year 1 and Year 2), and discussed the findings in terms of the individual, collaborative, and collective dimensions of collective inquiry. This chapter synthesizes those findings to address the research questions, as presented in Chapter 1. I then discuss the findings with regard to the KCI model and design principles related to the model. Finally I discuss some of the broader implications of this work, for future research in the domain of mixed reality learning environments for collective inquiry.

7.1 Addressing the Research Questions

This section directly addresses the research questions that guided the study, synthesizing findings from enactments in three design iterations.

7.1.1 RQ1: How can immersive simulations be designed to support collective inquiry?

To answer the first research question on how we can design immersive simulations to support collective inquiry, I focused on three levels of interaction that are present within any collective inquiry script: (1) the individual level (2) the collaborative level, and (3) the collective levels of activity and knowledge construction. Dillenbourg and Jermann (2010) outlined these three social planes as ones from which we can examine cognitive activity: level 1, intrapsychological plane (individual cognition); level 2, interpsychological plane (small group interactions); and level 3, the social plane (collective interactions). These three planes map onto
the three dimensions from my research question, and can be used as a lens to discuss how students engage with various components of collective inquiry. For instance, student engagement and reflection were treated as occurring on an “individual” level, even though most collaborative exchanges would also entail some aspects of individual engagement and reflection. Students’ experience of working with and interacting with others in the immersive simulation environment, as well as their reflections and personal experience are seen as aspects of individual interaction. When considering the design of a collective inquiry space, one of the dimensions must therefore consider the individual engagement and reflection. How do students move around the room? How do they interact with various components of the room? What are their individual learning artifacts or outcomes?

For the dimension of collaborative interactions, much of our designs were quite relevant as they cast students into small groups from three to or six students, with individual members holding specific specializations and roles to play. The interaction amongst members of these groups was an important locus for design, as we asked how students could collaborate with one another in an immersive learning environment. Indeed, one of the interesting affordances of such an environment is that students may enter it in groups and work together, as they would in a real-world rainforest or other setting for inquiry (e.g., local stream, woodland, etc.). Thus, I set out to address the question of how we can promote meaningful discourse and effective knowledge co-construction for small groups working in such an environment.

Finally, an overarching goal for design within the research tradition of knowledge communities (e.g., Scardamalia & Bereiter, 2000; Slotta, Tissenbaum & Lui, 2013) is to enable students to work collectively as a knowledge community. I asked the question of how collective progress can be supported, represented, and evaluated in an immersive environment. I have even employed the terminology “collective immersive simulation environment” (e.g., Lui et al, 2014) to refer to room-size environments designed intentionally to support a large group as it works coherently to advance its knowledge and experience of the environment. This challenge is closely linked to students’ epistemic ideas about “how and why” they are learning, the role of their peers (i.e., collaboration? Divide and conquer? Competition?) and the culture of knowledge sharing within the classroom. A third dimension of designing for collective inquiry is thus managing collective knowledge and furthering collective progress on the social plane. I discuss
each of the three dimensions below, with respect to the broader question of: How can immersive simulations be designed to support collective inquiry?

7.1.1.1 Individual level

Design recommendations on individual aspects of collective inquiry emerged from the series of design iterations. On the whole, these recommendations fall under one of two broader themes: locational affordances of a mixed reality environment, and scaffolding students’ knowledge work. I begin by examining the locational aspects, then move on to the knowledge work.

In a mixed reality environment like EvoRoom, much of the appeal and impact is related to the physical space within which the simulation is set, the “immersivity” of the room itself, and the opportunities it affords for naturalistic physical and social interactions. A key aspect of the design effort was placed in the locational affordances of the room. Through several design iterations and enactments, I saw first-hand that we cannot take for granted that students will automatically move around the room simply because there is room to move. Similarly, we also cannot assume that student talk to one another as they work simply because they are allowed to do so. The following set of recommendations resulted from our successive efforts to encourage students to actively move around the room to make observations about wall content and engage in deep discussions with other students:

- Encourage student movement around the physical space of the immersive simulation by designing activities and prompts that required student localization (pilot)
- Offer more opportunities for student-student interactions, including more reflective group tasks, prompting engagement with other students where the media content serves as a source of discussion or cognitive support (Year 1)

Early on in the thesis study, we saw that indexing the topical content of the simulations and activities to the physical locations of room, such that students are required to move around to review all content, could support natural interactions amongst peers as they worked in parallel on their various individual and collaborative tasks. We leveraged the physical space of the room, mapping different rainforest “time periods” or “biodiversity scenarios” to different locations, which helped students remain on task and achieve moderately high accuracy rates of observation. When guides were introduced in the Year 2 evolution activity to provide further opportunities for student-student interactions, the accuracy rate increased further. Although the level of discourse
was not as substantive as we had idealized (i.e., typically short interactions where participants asked guides for information), it occurred in the first phase of the activity, in which students were building their collective knowledge base (i.e., cladogram). So high-level discourse was not necessary. Similar to encouraging students to move around the room, offering opportunities for low-level interactions amongst students early in the activity set the tone of the activity for later collaborations. It also served to minimize the amount of time and effort required for this portion of the activity, both of which were scarce resources and important considerations.

Year 2 efforts to improve the quality of student interactions revealed more nuanced findings around locational affordances of the room. From the somewhat fortuitous “paper sessions” of the Year 2 evolution activity, we saw that unrestricted movement around the room likely hindered students in producing quality explanations of comparisons between the rainforest at various time periods. Students were frequently encouraged to move around the room to compare all versions of the rainforest, which resulted in more student-student interactions but lower KI scores on their explanations (the outcome of their interaction). In the tablet session, students were encouraged to remain in the same location with their group members for this more reflective task, resulting in comparatively higher KI scores. Collaboration scaffolds were also employed in the tablet session, giving each member a specific task in their discussions. Both design features were seen to be important to the outcome, the latter of which will be discussed in detail in a later section on collaboration.

A comparison between Year 1 and Year 2’s biodiversity activities also highlighted the difference between structured movement and unrestricted movement. In the Year 1 observation step, students were led around the room as a group by instructions on their tablet screen, and required to sign into each location with QR scans. They reviewed the rainforests one at a time. In Year 2, the technology did not limit student movement around the room and the resultant pattern was quite different. Students reviewed all four rainforest stations, not one at a time, but often two at a time, comparing one to the next, frequently moving between stations. Students also made observations as individuals, pairs or triads (as opposed to the entire group of four) – subgroups that changed throughout the phase as students dynamically moved in and out of partnerships.

While unrestricted movement did allow students more freedom in terms of their unofficial group structure, the content in which they engaged in, and the time they spent in each
interaction, it did not necessarily improve the quality of their interactions with each other. From the literature on patterns of interaction of computer-supported learning environments, a high quality interaction between students may be characterized by sustained interactions and on-topic discourse (Lipponen et al., 2003). From the literature on multimodal interactions and learning (e.g., Price & Jewitt, 2013; Sakr et al., 2014), a high quality interaction may be marked by the presence of gestures (indicating engagement in discourse), attention towards one another (e.g., gaze), and posture (consider a pair of students looking at other components with their shoulders directed away from one another, with a pair looking at each other, their shoulders directed at each other, using gestures to denote external information into their discourse). In phases of the Year 2 biodiversity activity that employed unrestricted movement, the frequency of student-student interactions and incidences of gestures were high, but the interactions were not sustained. As with other interactions of limited length, discourse was not given sufficient opportunity to progress.

Perhaps the best examples of reflective student interactions was seen in the Year 1 biodiversity activity where students were led from location to location making observations at each of the four rainforest stations, and in the tablet sessions of the Year 2 evolution activity, where students made comparisons between two time periods. In both cases, students were given room to think and discuss when the option of moving around and talking to other groups was taken away from them. Certainly, there are times when freedom to do as the student wishes is valued in the activity design, and there will be phases of activity when numerous short student interactions are productive. This thesis research only served to highlight some of the tensions around creating affordances for different patterns of interaction through movement and student interactions (Table 20).

Table 20. Affordances of movement and patterns of interaction for tasks in collective inquiry

<table>
<thead>
<tr>
<th>Task</th>
<th>Pattern of Movement</th>
<th>Preferred Interaction Pattern</th>
<th>EvoRoom Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build collective knowledge base as</td>
<td>Structured</td>
<td>Many gazes toward wall content Many student-student interactions</td>
<td>Evolution activity observation phase, Year 1 and 2</td>
</tr>
<tr>
<td>individuals</td>
<td></td>
<td>(natural social interactions, guided interactions) Low level knowledge exchange</td>
<td></td>
</tr>
<tr>
<td>Observe as individuals</td>
<td>Unrestricted</td>
<td>Many (natural social interactions, guided interactions)</td>
<td>Biodiversity activity, observation phase, Year 2</td>
</tr>
</tbody>
</table>
With respect to scaffolding students’ cognitive engagement and reflection, the following design recommendations emerged from our three successive trials:

- Support higher-level thinking about evolutionary mechanisms by including more structured and scaffolded tasks that help students make connections to the relevant features of the simulations (pilot)
- Scaffold students’ data collection and explanation writing (Year 1)
- Students can use photography as an effective means for recording observation in immersive simulations, structuring their observations with tags or other annotations to support the review of collected information (Year 2)

The results of this research are consistent with previous KCI studies, in that scaffolds played a particularly important role (e.g., Fong, 2014; Najafi, 2011; Peters, 2010, Tissenbaum, 2014). On a cognitive level, structured observation questions scaffolded students in early phases of the activities to survey the immersive environment. In more open inquiry tasks, such as in Year 2’s biodiversity activity, photography was an important means for recording observations, particularly when structured with tags or other annotations for supporting the review of collected information. When photographs were offered as an option for making observations (in addition to others forms of recording), they quickly became the primary mode utilized by students. From the same activity, scaffolding students’ explanations of their observational data (i.e., photographs) was seen to support higher quality explanations, as compared with the previous iteration of the biodiversity activity. This is in line with other studies examining how students collected observational data in other contexts, such as museums and field trips (Cahill et al., 2011; Kuhn et al., 2011; Lo et al., 2013).

In terms of the activity structure, the design of EvoRoom began with a fairly open structure, allowing researchers to see how students innately behaved and worked in an immersive mixed reality environment. In the pilot study, students were scaffolded in making observations through the structure of the note itself, by having to identify the organism and the environment
(e.g., Borneo, Sumatra) the note was about, but otherwise had free rein on what to write about. Students had difficulties following productive lines of inquiry, and often wrote about behaviours of organisms that did not have significant consequence, particularly since they did not know how the activity was to progress and what would be asked of them later in the activity. Much more structure was added in Year 1 activities, scaffolding observations by asking structured questions (i.e., is the organism present here?), also scaffolding which location (e.g., 200 MYA) they were to be observing. While the added structures were associated with improvements in observation rates and high quality explanations, a rigid activity script also meant that students had to be doing the same task at all times, even though students finished at different rates. Those who finished earlier had to wait for their peers before the activity could move to the next phase, whereas in a more open activity structure, students could continue adding more observations until the teacher announced the next phase.

In Year 2, we experimented with a more flexible design, questioning whether it was necessary for students to scan into locations while others waited for everyone in order to move on. As discussed above, the results were somewhat surprising. The presence of locational scaffolds were linked to interactions patterns that allowed students mental and physical space and time to work on reflective questions as a group. Furthermore, locational technology may sometimes be needed to ensure that all members within a designed interaction are within close proximity of one other. Although locational affordances of a mixed reality environment and scaffolding knowledge work began as different design themes, the two dovetailed in later iterations, demonstrating the complexity of scaffolding in mixed reality environments, which extends to movement and the student interaction space—not typically considered in traditional CSCL environments. With recent advances in indoor positional technology (e.g., http://estimate.com/indoor, Vanhemert, 2014), researchers are well positioned to investigate new designs, incorporating more fluid interactions, such as contextual displays on student tablets based on their location in the room, and represent a rich area for future work.

7.1.1.2 Collaborative level

When considering collaborative group processes in immersive simulations, the following design recommendations emerged:
• Add a level of scripting to support student small groups, giving them more explicit opportunities to share and exchange in the advancement of their inquiry tasks (*pilot*)
• Scaffold collaborations by providing functional roles to ensure participation, including prompts to use media as cognitive supports (*Year 1*)
• Scaffold students in connecting their explanation to their observational data (*Year 2*)
• Reduce movement and incorporate collaboration scaffolds allow students to focus on collaborative reflective work (*Year 2*)
• For collaboration, encourage movement and natural social interactions to allow students to explore the environment and explore initial ideas, but provide well defined tasks with group scaffolding to support more sustained, reflective discussions (*Year 2*)

Both recommendations are variations along the same theme—scaffolding collaborations, which was achieved in EvoRoom through one of two ways: students were assigned a content specialty and jigsawed into groups, and students were assigned task-based roles (e.g., scribe, information look-up, guides).

A key design feature throughout the curriculum design in both Years 1 and 2 was the use of specializations (e.g., birds, primates) maintained by the students throughout the curriculum. This 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 Year 2, which allowed students to gain further expertise in their assigned species specialty. 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 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. Despite this, students saw content specialization as an important aspect of collective inquiry as evidenced by one student’s comment on her post-activity questionnaire:

*I really enjoyed how the activity allowed me to work together with my classmates and to assign each person with different roles in order to complete the assignment in time. Together, we were able to decide on the best way to approach the task at hand, and we had discussions over the information we were*
given in order to determine our answers. I think this really helped me get closer to some of my classmates and it made the assignment more interesting and comfortable; altogether, it enabled me to get a lot more out of the task than I think I would have if it were an individual activity. (Year 2 student, post evolution activity reflection)

Another means of designing interdependency among peers was through task-based roles within the activity (as opposed to content expertise). First employed in the Year 1 biodiversity activity during the collaborative observation phase, students were designated to write down their group’s answer, look up information about their prediction, or locate information in the field guide. Along with locational scaffolding, students were observed to have sustained discourse about the question posed to the group (i.e., could this be your rainforest?). In the tablet sessions of Year 2’s evolution activity, students were provided with similar collaboration scaffolds. 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).

Students were observed to collaborate around each other’s devices. For instance, in the group interaction analysed in the Year 2 evolution activity, all students referred to one student’s tablet, which contained detailed information about one of the time periods they were reviewing. This demonstrated how separating information amongst students encouraged them to rely on peers during collaborations. In the same group interaction, however, sustained interactions were lacking, which was due in part to the three questions that had to be answered by the students being displayed on three students’ tablets at the same time. The students were thus focused on their own question, whereas in the Year 1 biodiversity activity, only one question had been displayed at a time.

In activity designs where collaboration was structured though verbal or textual instruction or by way of assigning students a particular type of device, interesting points of failure were observed. For example, in Year 1’s evolution activity, students were asked to discuss with group members certain questions during the group reflection phase, but none of the groups consulted together as a cohesive whole. This may be due in part to the fact that the questions posed to them did not explicitly require the expertise of all group members to help frame an answer. Or perhaps there was a lack of consequence for the group not collaborating as a whole, or an absence of
activity structures to encourage them to do so. In the Year 2 biodiversity activity, the device students received determined their tasks in the group (e.g., observation recorder, information look up), but since the task was more open ended (e.g., capture observations about each of the rainforest stations), without locational scaffolds and other activity structure, students also did not perform the task as a cohesive group. Again, the nature of the task certainly impacted on the results and interaction patterns observed, as did the supports around collaboration processes.

A more meaningful, but difficult source of interdependency was 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 to 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 the evolution activity, 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 Year 1 and 2 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.

7.1.1.3 Collective level

With respect to working with collective levels of knowledge, the following design recommendations were suggested:
• Make students’ collective inquiry products visible and accessible during the activity, and allow students as well as the teacher to interact with the display (pilot)
• Give collective work a larger role within the activity design, and improve its “visibility” to encourage more students to review the collective products (Year 1)
• Support and guidance is needed to help students build upon collective knowledge (Year 2)

In collective inquiry, an important aspect is the building of collective knowledge through individual and small group actions. A second aspect is, naturally, the review of collective knowledge and using it in a consequential task. The two previous sections addressed this challenge by discussing means to achieve individual engagement and collaborative processes. This section emphasizes the design of collective tasks, mechanisms for aggregation, and pathways to the review of collective knowledge. In EvoRoom, the review of each party’s contributions is achieved through a number of ways: the class website (e.g., where students completed the field guide, predictions…etc.), and large displays of aggregated observations and notes—as ambient displays or to mediate teacher-led discussion.

Information from the class website was employed during collective inquiry activities through student tablets and was an important source of information as students collaborated to answer assigned review and reflective questions. Ambient displays of aggregated information were featured in Year 1’s activities, in which the teacher was found to be the primary user and facilitated ad hoc discussions between students and the teacher alike. While not everyone reviewed the collective visualizations in the biodiversity activity, students were instructed to do so in the evolution activity that followed, and achieved a 100% review rate in the latter activity. In both the pilot and Year 1’s evolution activity, a final discussion led by the teacher at a visualization of aggregated explanations closed the activity. Students reported the final discussion to be revelatory for them, particularly on the topic of natural selection. Still, in Year 2, the co-design team wanted to experiment with other ways of engaging students with collective information, and incorporated a data review step in the biodiversity activity where the teacher led a discussion with an aggregated visualization to help students consider the state of the collective knowledge base.

Results showed that while the data review discussion in the Year 2 biodiversity activity revealed patterns of early ideas that students had, many students adopted false assumptions,
which permeated through to the data they collected. Showing these early patterns (that had an average accuracy rate of 50%) potentially affected students’ final choice and overall accuracy.

It was interesting that in both the Year 1 and 2 biodiversity activity, there was one session where all the groups selected the correct rainforest station for their assigned factor. In the other sessions, the accuracy ranged between 0% and 50%. In the session with the highest accuracy rate in Year 2, the collective pattern shown during the data review step was already correct (i.e., the highest number of data objects were annotated with the correct environmental factor for each of the four rainforest stations), which likely contributed to the high accuracy rate. While showing a correct collective pattern translated to a higher accuracy rate, showing incorrect collective patterns was associated with lower accuracy. It is true that technology can help the teacher and students reveal their assumptions and have this information corrected, but it should be presented in a manner that encourages students and teacher to advance the discussion. For example, collective knowledge could be positioned to students as a body of work to be revised and built upon, rather than a “completed” state of knowledge. Future designs could benefit from providing more support and guidance in encouraging students to think about what the collective set of observational data means for their own question in the investigation, and how this may be built upon and used in their explanation.

Large shared displays, such as the collective visualizations on the interactive whiteboards, have been used as status displays to promote group awareness, while those that replicate content from personal devices have been shown to improve efficiency of collaboration by facilitating conversational grounding (Wallace et al., 2011). Our work contributes to this body of research by advancing the design of large shared displays that serve to display both status information as well aggregated content from numerous participants’ devices (i.e., collective visualizations).

As ambient displays, the collective visualizations supported teachers in monitoring student progress both in terms of tasks completed, as well as depth of thinking. For students, they grounded conversations, and served as the physical foci for ad hoc discussions with group members and with the teacher. They served as real-time representations of the collective knowledge, demonstrating emergent patterns, and served as presentation displays for plenary discussions.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Pilot findings</th>
<th>Year 1 findings</th>
<th>Year 2 findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>1. Limited interactions amongst stationary students characterized the enactment 2. Only some student observations were focused on the intended pedagogical target 3. Quality of explanations was lower than desired</td>
<td>1. Significantly pre-post gains on a test of conceptual understanding 2. Student attitudes were positive, with high ratings of their immersive experience 3. Students moved around the room throughout activities 4. High incidences of student-device, student-student, and student-teacher interactions were observed 5. Structured observations resulted in accurate outcomes 6. Improved evolution explanations compared to pilot study 7. Explanations in biodiversity activity were limited in their accuracy and reasoning</td>
<td>1. Significantly higher post-test scores compared to pre-test scores 2. Student attitudes were positive, rating their immersive experience highly 3. Students moved around the room during activities 4. More attention was directed to other students 5. Addition of “guides” observed with improved observational accuracy and increased student-student interactions 6. Significantly improved explanations compared to pilot study and Year 1 evolution activity 7. A majority of students relied on photographs as evidence in their observations</td>
</tr>
<tr>
<td>Collaborative</td>
<td>4. Students believe that discussions allowed them to share ideas and highlighted items they did not individually notice, but are in favor of more challenging collaborative tasks</td>
<td>8. Specially assigned and jigsaw collaboration groups allowed students to transfer curricular expertise to their work in collective inquiry activities with immersive simulations 9. Students did not engage in discussion with all of their team members during evolution group reflection 10. Rotation of functional roles supported collaboration in biodiversity activity</td>
<td>8. Improved explanations in biodiversity activity, but accurate identification of rainforest scenario remains low 9. Lower levels of student movement during group reflection correlated higher explanation scores 10. Unrestrained natural movements were more conducive to observational work rather than to reflective tasks</td>
</tr>
<tr>
<td>Collective</td>
<td>5. Students had limited access to collective levels of knowledge</td>
<td>11. Ambient displays of collective knowledge encouraged ad-hoc discussions between students and with their teacher</td>
<td>11. Students successfully constructed a collective knowledge base, building their field guide and other resources 12. Collective patterns of early ideas influenced student decisions</td>
</tr>
</tbody>
</table>

**Cross-cutting themes**

**Figure 67. Summary of findings and identified themes**
Three cross-cutting themes can be identified amongst the findings from all EvoRoom designs within this thesis: 1) the physicality of the room, 2) the pedagogical script for student observation and reflection and collaboration, and 3) ways of including collective visualizations in the activity (Figure 67). These themes align with the various designed components, including the EvoRoom environment itself as well as the wider curriculum, and offer a framework for discussing the research questions. Findings about the physicality of the room (e.g., students’ movement, localization of content) relate to the affordances of the physical space for collective inquiry. Findings about the pedagogical script apply to the discussion of student scaffolds (i.e., tablet materials and interface) for supporting observation, reflection and collaboration. Findings related to different ways of including collective visualizations in the activity relate to the affordances of the collective visualizations for supporting shared knowledge work. Because activities were iteratively designed and can be broken down into analogous key steps, it is possible to attribute the differences in student interactions and inquiry outcomes, at least in part, to the design changes in each of the activity components as they occurred (e.g., to the room, tablet, visualization). A discussion of specific findings can demonstrate how these three themes can mediate students’ interactions with one another, with materials, or with their teacher, and how those interactions impact the outcomes of their inquiry.

For example, consider the design of the physical environment of the EvoRoom. In the observation phase of the pilot, the students were seated in stools and as a result had few interactions with each other. This may seem trivial at first glance, particularly since we offered students the stools to sit on during the introduction, but the motivation for exploring immersive simulations in science classroom was to provide a “collective immersion” experience, where they look around the room and talk to each other, as they’re moving around the room together. It was interesting to see that when the content was to indexed to certain locations, and students movement was structured by their tablets in Year 1 enactment, these design changes encouraged student movement around the physical space of the immersive simulation. By designing activities and prompts that required student localization, the pilot and Year 1 findings showed how the changes in room layout mediated student movement, and more importantly, their interactions with one another. By using the tablet to direct students to various locations in the room, it also offloaded the teacher’s orchestration load.
In answering the question of how immersive simulations can be designed to support collective inquiry, researchers and instructional designers need to pay careful attention to a number of dynamic and interconnected themes, on several interaction levels. Design recommendations from this study address individual student engagement with various components, their peers and teacher and the collaboration process thorough cognitive, locational, collaboration scaffolds and structured tasks. More open activity structures were more productive for ideation rather than for reflective collaboration. The patterns of collective ideas presented influenced student performance, either positively or negatively, depending on the accuracy of the pattern shown, suggesting the need for careful design, including real-time monitoring and input from the teacher. Other high-level design considerations include the patterns of interactions between students (e.g., many but superficial vs. few but intentional) and the nature of knowledge to be constructed at different time points during the activity (e.g., low level observations surveying environment vs. sustained progressive discourse; individual, small group, vs. collective knowledge) were also important design considerations.

### 7.1.2 Question 2: What roles do the teacher, peers, and materials play in student learning in immersive simulations?

The teacher was a central figure in all of the EvoRoom collective inquiry activities. In each, she introduced the activity, formed groups, managed the activity (moving students along when needed), engaged with individuals and small groups, and in most cases, facilitated class discussions. The extent to which she performed all of these tasks varied between iterations. In the observation phase of the evolution activity for instance, the teacher primarily communicated with students through teacher-class interactions, while in Years 1 and 2 (tablet session only, since the observation phase was eliminated in paper sessions), interactions with individual students and small groups occurred more often. This is perhaps due to the students’ tablets taking over some of the orchestration load (e.g., by directing students what to do, where to go…etc.), freeing up the teacher to discuss strategies for task completion or pedagogical content.

The affordances for natural and social interactions in the EvoRoom immersive environment were evident in the way students engaged with their peers. In individual activities, interactions with their peers allowed them to confirm the task at hand, making comments, and
other sociocultural behaviors that allowed them to identify themselves as joint participants of a collective experience. In collaborative phases of the activity, their peers served as sources of information, which was explicitly supported through jigsawed content expertise and collaborative scaffolds. Sustained interactions were also seen in activity designs with locational scaffolding.

Material elements, such as the immersive walls, student tablets, and large aggregated visualizations of collective knowledge, supported students’ individual knowledge work and served as mediating objects during discussions. The immersive simulation content effectively engaged students in the context of their inquiry. Across all iterations, student attitudes towards EvoRoom scored high, particularly for overall activity and visualizing content, with the use of the immersive space consistently receiving the highest scores. From student interviews and their comments from post-activity questionnaires, student felt that

“the [large displays that served as “walls” of the room] really helped to immerse the group in the activity and prompted us to get more involved.”

-- Student comment from the pilot evolution activity

Another student wrote:

*I liked how engaging and fun the activity was. It was an amazing way to learn in a group setting. I really liked the challenge of finding which rainforest was our own, it made us apply our previous research to the activity. Instead of just asking us questions about our predictions you put us in an interesting setting, which was a unique way to make sure we absorbed the techniques and information we learned.*

-- Student comment from the Year 1 biodiversity activity

Both students described the setting to be an important aspect of their experience, demonstrating positive outcomes for the immersive simulation environment in supporting their engagement.

In all of the EvoRoom collective inquiry activities, each student was to receive a tablet computer to support their knowledge work, providing instructions, collecting responses, and
sending the data to be stored in the collective knowledge base. This was realized in all enactments except in the paper sessions of the Year 2 evolution activity. Without the tablet application’s support, the collective knowledge base could not be built. In the comparison phase, task-based roles were not distributed evenly, which led to some group members not participating fully. Although those students were observing the immersive walls alongside their more active group members (who tended to hold the set of paper resources), they did not make many verbal contributions to the group discussion. This also placed the burden of responsibility in completing the work on the one person who held the pen. With the tablet scaffolding collaboration, the role of scribe could be transferred from person to person in the group. For example, in the Year 1 biodiversity activity, the role of the scribe changed as the students moved from rainforest station to station. As there were four stations (thus four questions to complete), each group member had a turn to act as scribe. Despite students’ natural personality tendencies for engaging in group discussions, this enactment was associated with a more equitable pattern of participation. In collaboration tasks where group members’ tablets showed different information (e.g., person tasked with looking up information at 200 MYA vs. 150 MYA) as in Year 2 evolution activity, the tablet was observed to be a mediating object among group members, referring to it as a source of information within an interaction.

The collective visualizations provided the teacher with a means for reviewing student work and monitoring progress. When they were made available throughout the activity as ambient displays, the teacher was seen to frequently interact with the interactive white boards, moving nodes and reviewing content, as well as engaging students in extemporaneous discussions. The visualizations also provided a source of evidence about whether students were on-task. In one instance, the teacher saw that a student wrote a meaningless emoticon as a note, and responded accordingly. In another instance, she noticed incorrect annotations being assigned to certain observation objects and asked the students to change this.

Many discussions were observed around the collective visualizations, both spontaneous and planned. Spontaneous discussions occurred when the teacher was monitoring class progress at the interactive white boards, whereby students would approach and engage in discussion. Some students walked up to the displays independently, with their group members joining them later. In most such cases, the teacher then joined the group discussion. The collective visualizations also served as an important artifact for teacher-led class discussions. They were
designed as summative discussions in most activity designs, where the teacher directed student attention towards elements of the collective knowledge base and discussed trends in student thinking and how it translated to the goals of the activity.

7.2 Broader Implications

7.2.1 The KCI model

Throughout our curriculum design, we referred to the principles of the Knowledge Community and Inquiry (KCI) model as a theoretical reference. Four principles guided the design of this KCI curriculum (Slotta, Tissenbaum & Lui, 2013):

1. Students work collectively as a knowledge community to produce a knowledge base that serves as a resource for ongoing inquiry within a specific science domain;

2. The knowledge base is accessible for use as a resource for student inquiry, as well as for editing and improvement by all members;

3. Collaborative inquiry activities are designed that ensure the coverage of targeted science learning goals, including assessable outcomes;

4. The teacher plays a specific role defined within the inquiry script, but also a general orchestration role, scaffolded by the technology environment.

A broad goal of this research, which reached beyond simply developing an immersive rainforest environment, was to investigate how a group of students could interact productively within such an environment as an inquiry community, and what forms of activity and materials would foster such interactions. I also sought to explore the role of such learning experiences within a broader theoretical perspective about learning and instruction. These goals shaped the designs of student observations and aggregated displays (i.e., to encourage further discussion and guide inquiry progress). While strict adherence to KCI was not the explicit goal of this research, the model served as a theoretical foundation for our collective inquiry design. Hence, we prioritized the basic elements of the model: a community knowledge base that was indexed to the domain content (e.g., the various species and their relationships, represented as food webs and cladograms); and collective inquiry activities where students made use of the knowledge base as a resource.
This research also identified a direction for further research in KCI curricula. As exemplified by the Year 2 biodiversity activity, more support and guidance may be needed for students to consider the meaning and implications of “collective knowledge,” including how to critically look at patterns of their collective observations, and perhaps more importantly, how to build upon that collective knowledge base. A gap in how students examined collective knowledge was only identified when there was a means of comparing the state of collective knowledge with how students incorporated knowledge objects from the collective database within their final explanations. This study thus demonstrates a need for more research to examine how students work with collective knowledge, which is a consideration for future activity designs.

7.2.2 Mixed reality environments

This work contributes to the body of research on mixed reality learning environments by presenting examples of how students collected data from immersive simulations, how tablets supported their inquiry, and how large visualization displays supported teachers and students in reviewing the collective work to inform next steps. It presents one of the first studies on collective inquiry through the use of immersive simulations to engage students in a traditionally challenging scientific domain (evolutionary biology) through several levels of interaction (i.e., individual, small group, and whole class). It also serves as an example of a digitally augmented physical space that incorporates the use of personal devices, mixing one-to-one screen experiences with collective immersion via several large-screen displays of dynamic content and shared displays of emergent visualizations of collective knowledge work.

Additionally, my research identified two challenges (and opportunities) in scaffolding students in collective and collaborative inquiry not present in traditional CSCL learning environments, namely: (1) how to strike a balance between locational and collaborative (task-based roles) scaffolds, and (2) how to make use of time and task based constraints within student devices to enhance the productivity of collaborations and knowledge work. Like most mixed reality learning environments, the EvoRoom immersive simulation environment has a number of complex components. The depth of student interactions within such an environment can vary greatly depending on how the activity is structured, what materials are provided to students, at
what time, and what roles they play during each phase of activity. The patterns of interactions examined in this thesis may serve as examples on how to take full advantage of the affordances of an immersive environment through activity design, helping students and teachers to achieve certain kinds of knowledge work.

### 7.3 Conclusions

Overall, we found that EvoRoom enabled students to think deeply about evolutionary biology mechanisms and supported their reasoning about climatic impacts on biodiversity. With respect to the broader curriculum, assigning students to expertise groups (i.e., the species socializations) was an important aspect of the design, but we recognize that not all students “bought-in” to their assigned roles. This resulted in different levels of effort put into their work within the broader curriculum and 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 session’s collective success. In both iterations, we found that students paid careful attention to the immersive media as well as other interactive components (tablet software, collective visualizations) in the EvoRoom immersive simulation environment. Much of the within-activity artifacts that demonstrated student reflection about evolutionary biology and biodiversity 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.

During the collective inquiry activity, visualizations that aggregated students’ collective observations served as an important shared artifact to encourage deeper discussions – often led by the teacher – which in turn guided further reflection. Successful design features of our immersive simulation include the visualizations of the rainforest, the mechanisms for collecting discrete observations and generating collective visualizations; the scaffolding software for student tablets; and the structured (i.e., scripted) design of individual and collaborative activities. Perhaps most importantly, the specific activity sequences within the EvoRoom itself were conceptualized as being deeply situated within a larger curriculum design. We did not want students to “just walk in cold” to the immersive environment, with all activities being experienced as distinct from or supplemental to the core curriculum. Rather, we wanted the
experience in the room to be challenging and engaging, deeply designed into the core curriculum, such that students had gained necessary expertise before entering the room, found new and important relationships during their experience, and benefited in subsequent classroom or field activities as a consequence. The design of such learning environments is still in its relative infancy, and this study has hopefully revealed some of the important dimensions, dynamics and guidelines that will help inform future efforts.
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Appendices
8.1.1 Appendix A

Student Information Letter

* to be printed on OISE/UT letterhead

To: Students of [Teacher’s name] grade [#] science class
From: Dr. James D. Slotta
Subject: UTS teachers’ participation in a curriculum planning study at University of Toronto.

I am interested in conducting a research project in your school entitled: New Ways of Teaching and Learning in Technology Enhanced Classrooms. This project will investigate how students can help each other in creating and solving a variety of science problems. Your science teacher will design activities that allow you to collaborate with your classmates in small groups or take part in whole class cooperative learning. Different technologies will be used depending on the topic and type of activity. My research team, including myself and two doctoral students (Mike Tissenbaum, Michelle Lui), will help your teacher use the technology by providing design assistance and technical support. Example technologies are wikis, online discussion forums, Web-based learning environments, and simulations. The information provided from this study will be valuable to our research community to understand how teachers develop inquiry curriculum, and how students learn from this curriculum. It will also be of value to your school administration, in terms of promoting innovative teaching practices for your teachers.

It is important that you know that both your teacher and the school principal have approved of this study. Most research activities will involve only normal teaching practices. We will examine the teachers’ curriculum designs, observe their teaching, and ask them about their assessments of student work. Occasionally we will ask students for an interview to gain a deeper understanding of their experience of the curriculum, as well as their understanding of the topic. If you are asked to participate in an interview, we will give you and your parents a separate Interview Consent Form. We may also want to videotape certain class periods, in which event we would give a separate Video Permission Letter to all students in the class and their parents.

Because any activities associated with this project will occur as part of your regularly scheduled class, they will not require any additional effort on your part. Efforts will be made to make sure this research does not interfere with your regular learning and only improves your learning experience and your teachers’ experiences as well. Some possible activities you may participate in include: learning about and using new technologies, having discussions about math or science problems with your classmates; and participating in brief interviews with myself or my doctoral students. You may also be asked to complete a short questionnaire about certain math or science concepts at the beginning of the term so that we can assess your developing understanding. Only myself and my doctoral students will have access to any of the information collected for the study. At no time will your names, your teacher’s names, or the name of your school be identified in published documents. All information that is collected will be kept in locked files and will be destroyed upon completion of the research.
There are no risks associated with participation in this study and you are free to withdraw from the research at any time. Your participation in this study in no way affects your grade for the course. If you decide not to participate in the study, or if you withdraw from the study at any time, your grade will not be influenced in any way.

Every effort will be taken to make sure your identity is kept confidential. Most of the information used in this research project will be in the form of computer-based materials used during your curriculum activities. Your identity will be visible to your classmates and your teacher, but will not be available to anyone from outside the school. Our research team will work with your materials, but will never include your name or any identifying information in any of our analyses, reports, or materials. For our own internal reference to your information, we will replace your name with a random ID number (not your student number). Any information will only be accessed from a secure database within my research laboratory. If you are asked for an interview, we will do so either before or after class, or when your teacher is not in the room. All interviews will be conducted in a private room during your lunch hour or after school.

If either you or your parents/guardians have any questions about the study please feel free to contact me by phone: 416-978-0121 or through email: jslotta@oise.utoronto.ca. Any questions about your rights as a participant can be directed to the University of Toronto Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273.

Sincerely,

James D. Slotta
Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT
Canada Research Chair in Education and Technology

Published study results will be made available for students and/or parents who are interested. Please feel free to contact the principal investigator with any questions or concerns: James D. Slotta, Associate Processor. OISE/UT, 252 Bloor Street West, Toronto, ON M5S 1V6. Phone: (416) 978-0121, Email: jslotta@oise.utoronto.ca
To: Parents and/or Guardians of [Teacher’s name] grade [#] science class
From: Dr. James D. Slotta
Subject: Letter of Consent to be videotaped/photographed as part of a University of Toronto Study

This letter is requesting your permission for your child to appear in a video and/or photographs as part of an ongoing collaboration between our research group at The University of Toronto and the UTS science department. This project has been approved by Rosemary Evans, Principal of UTS, and by the University of Toronto Research Ethics committee.

Earlier this year, you received an information letter about the project, which we are also providing again for your reference. Essentially, it is concerned with the design of inquiry science curriculum activities for UTS students. All curriculum is designed by the teachers, in collaboration with our group.

This letter requests your permission for your child to appear in a video and/or photographs as part of a regular classroom observation. The video/photos will not focus on your child specifically, but rather the classroom as a whole. The cameras will be set-up in an area of the classroom to capture the normal, everyday interactions that occur between students and the teacher. The cameras will be directed only at students who have agreed to appear in a video and/or photographs. If a non-consenting student is interacting with a consenting student(s), the video/photos will not take place to respect the wishes of the non-consenting student. The teacher is aware of the recording, but will not know whether a student has agreed to appear in a video/photos or not (in order to avoid any sense of favoritism). The willingness to appear in a video and/or photos is strictly voluntary, and will provide an important source of information to our research team, including myself and two doctoral students (Mike Tissenbaum and Michelle Lui). You or your child may withdraw your consent to be videotaped at any time, if uncomfortable or inconvenienced for any reason. Video/photos will only take place during regularly scheduled class time. You are receiving this letter because your child indicated a willingness to appear in a video/photos, however, your permission is required before any recording can take place.

There are several options for you to consider if you grant permission for your child to take part in this research. You can choose all, some or none of them. Please put a check mark on the corresponding line(s) that grants me your permission to be videotaped and/or photographed:

I grant permission to be videotaped: Yes: ___ No: ___
I grant permission to be photographed: Yes: ___ No: ___
Please put a check mark on the corresponding line(s) that grants me your permission to use the video and/or photography footage for the following purposes:

I grant permission to use the videos/photos as raw data for coding and analysis (video will not be shown publically)  
Yes: ___ No: ___

I grant permission to use the videos/photos in presentations in classrooms or conferences  
Yes: ___ No: ___

I grant permission to use the video in other types of promotional video, such as posting on our project Web site  
Yes: ___ No: ___

If you consent to your child appearing in a video and/or photographs for this study, please return the attached permission form. You will be given a copy of this form for your reference.

If you have any questions or concerns about the study, please feel free to contact me by phone: 416-978-0121 or through email: jslotta@oise.utoronto.ca. Questions about your child’s rights as participants can be directed to the Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273.

Sincerely,

James D. Slotta
Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT
Canada Research Chair in Education and Technology

Please complete and return the consent form below by [date] to your child’s science teacher at UTS.

I have carefully read and understood the details of the study outlined in this letter.

__________________________________________  
Name of Student (please print)  
__________________________________________  
Name of Parent/Guardian (please print)

__________________________________________  
Student’s Signature  
__________________________________________  
Parent/Guardian’s Signature

__________________________________________  
Date

Published study results will be made available for students and/or parents who are interested. Please contact the principal investigator by phone at: (416) 978-0121 Email: jslotta@oise.utoronto.ca. Any questions about teachers’ or students’ rights as participants can be directed to the University of Toronto Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273. Research results will be made available upon request.
8.1.3 Appendix C
UTS Parent and/or Guardian Interview Consent Letter

* to be printed on OISE/UT letterhead

To: Parents and/or Guardians of [Teacher’s name] grade [#] science class
From: Dr. James D. Slotta
Subject: Letter of Consent to be interviewed as part of a University of Toronto Study

This letter is requesting your permission for your child to be interviewed as part of an ongoing collaboration between our research group at The University of Toronto and the UTS science department. This project has been approved by Rosemary Evans, Principal of UTS, and by the University of Toronto Research Ethics committee.

Earlier this year, you received an information letter about the project, which we are also providing again for your reference. Essentially, it is concerned with the design of inquiry science curriculum activities for UTS students. All curriculum is designed by the teachers, in collaboration with our group.

This letter requests your permission to interview your child about his or her experience with those activities: Were they enjoyable? Were they an effective way to learn? Did they help classmates collaborate with one another? The interview itself will have no impact on your child's grade. The teacher is aware that interviews are happening, but will not know the identities of student being interviewed (in order to avoid any sense of favoritism).

This interview is strictly voluntary, and will provide an important source of information to our research team, including myself and two doctoral students (Mike Tissenbaum and Michelle Lui). Your child is free to withdraw from the interview at any time, if uncomfortable or inconvenienced for any reason. Interviews will last approximately 10-15 minutes, and will be conducted between classes or immediately after school. You are receiving this letter because your child volunteered to be interviewed, although your permission is required before the interview can take place.

If you consent to your child participating in an interview for this study, please return the attached permission form. You will be given a copy of this form for your reference.

If you have any questions or concerns about the study, please feel free to contact me by phone: 416-978-0121 or through email: jslotta@oise.utoronto.ca. Questions about your child’s rights as participants can be directed to the Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273.

Sincerely,
James D. Slotta  
Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT  
Canada Research Chair in Education and Technology  

Please complete and return the consent form below by [date] to your child’s science teacher at UTS.  

I have carefully read and understood the details of the study outlined in this letter.  

________________________________  __________________________________  
Name of Student (please print)   Name of Parent/Guardian (please print)  
________________________________  __________________________________  
Student’s Signature              Parent/Guardian’s Signature  

Date  

Published study results will be made available for students and/or parents who are interested.  
Please contact the principal investigator by phone at: (416) 978-0121 Email:  
jslotta@oise.utoronto.ca. Any questions about teachers’ or students’ rights as participants can be  
directed to the University of Toronto Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273. Research results will be made available upon request.
8.1.4 Appendix D

School Principal Consent Letter

* to be printed on OISE/UT letterhead

To: Principal, University of Toronto Schools
From: Dr. James D. Slotta, Associate Professor, OISE/University of Toronto
Subject: Letter of Consent to Participate in University of Toronto Study

I am interested in conducting a research project in your school entitled: *New Ways of Teaching and Learning in Technology Enhanced Classrooms*. This project will investigate how teachers can employ collaborative technologies in their classrooms or in special purpose technology laboratories to enhance students’ understanding of science concepts and inquiry problems. Specifically, science teachers from your school will collaborate with myself and my doctoral students to design curriculum activities that enable students to collaborate and add to the class’s collective knowledge base in various ways such as small groups or whole class cooperative learning. A variety of technologies will be used in such designs, depending on teacher’s comfort level, and the requirements of their pedagogical designs. My research team, including myself and two doctoral students (Mike Tissenbaum and Michelle Lui) will enable teachers to succeed with the technology, providing design assistance and technical support.

Technologies will likely include wikis, online discussion forums, Web-based learning environments, touch surfaces, handheld computers, and specially designed web portals. The information that this study generates will be valuable to our research community, in terms of our understanding of how teachers develop inquiry curriculum, and how students learn from such curriculum. It will also be of value to your school administration, in terms of promoting innovative teaching practices and deep reflections on the part of teachers.

Most research activities will involve only normal teaching practices, such as curriculum design and the assigning of regular homework. We will analyze the teachers’ curriculum designs, observe the enactment during class, and consult with teachers about their assessments of student work. Occasionally we will seek interviews with students to provide a deeper understanding of their experience of the curriculum, as well as their understanding of the relevant curriculum topics. In these cases, we will request permission from selected students’ parents, using the Interview Permission Letter attached below. In addition, we may also wish to videotape some selected class periods, in which event we would also secure video permission from every student’s parent, using the Video Permission Letter, also attached below.

Because these sessions will be conducted as part of the normally occurring instructional practices within your school, we do not expect any additional effort or negative impact on your students. Every attempt will be made to ensure that this research in no way impedes the regular course of instruction and only serves to enhance the students’ and teachers’ experiences. Some possible student activities will include: learning about and using new technologies, having discussions about science topics with their classmates; and participating in brief interviews with myself or my doctoral students. Students may also be asked to complete a short questionnaire about their ideas concerning science topics at the beginning of the term, to help us assess their developing understanding. Only myself, the teachers, and my doctoral students, who will be identified well
in advance, will have access to any of the data collected for the study. At no time will students’
names, teachers’ names, or the name of your school be identified in published documents. All
information that is collected will be kept in locked files and will be destroyed upon completion
of the research. There are no risks associated with participation in this study and teachers will be
free to withdraw from the research at any time.

Procedures will be taken to ensure the identities of participating and non-participating students
remain confidential during all phases of the study. Most of the information used in this study will
be from the computer-based data logs. This information will only be accessed only from a secure
database within my research laboratory. If a student is asked for an interview, they will be asked
either before or after class, or when their teacher is not in the room. Interviews will take place
either during lunch hour or after school. At no time will teachers know whether or not a student
has elected to participate in an interview.

A copy of this consent form will be given to you for your reference. If you have any the study
please feel free to contact me by phone: 416-978-0121 or through email:
jslotta@oise.utoronto.ca. Any questions about teachers’ or students’ rights as participants can be
directed to the University of Toronto Ethics Review Office at: ethics.review@utoronto.ca or
416-946-3273. Research results will be made available upon request.

Sincerely,

James D. Slotta
Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT
Canada Research Chair in Education and Technology

I give my permission for Dr. James D. Slotta to conduct the research project outlined above.

________________________________________  __________
Signature                        Date

Published study results will be made available for students and/or parents who are interested.
Please feel free to contact the principal investigator with any questions or concerns: James D.
Slotta, Associate Processor. OISE/UT, 252 Bloor Street West, Toronto, ON M5S 1V6. Phone:
(416) 978-0121, Email: jslotta@oise.utoronto.ca
8.1.5 Appendix E
Teacher Consent Letter

* to be printed on OISE/UT letterhead

To: [Teacher’s name]
From: Dr. James D. Slotta, Associate Professor, OISE/University of Toronto
Subject: Letter of Consent to Participate in University of Toronto Study

I am interested in conducting a research project in your class this year entitled *New Ways of Teaching and Learning in Technology Enhanced Classrooms*. As part of a research project, I am interested in how teachers can use technology in their classrooms to help students’ understanding of science. Specifically, my research team would collaborate with you and your colleagues to design a collaborative curriculum where students interact deeply with peers in rich inquiry activities. The information that this study generates will aid in finding new and perhaps better ways for teachers to help students develop deep understandings about science.

This study provides a unique opportunity for students in your class to experience an innovative approach to science learning that utilizes technology and aligns with new curriculum standards. Consenting students in your grade [#] science class will be participating in the study. The students would be participating in the study during regularly scheduled class time. Every attempt will be made to ensure that the study does not impede any of the regular course instruction and will enrich the students’ learning experiences. Occasionally, myself or two of my doctoral students (Mike Tissenbaum and Michelle Lui) might need to interview students after school or during their regular lunch hour. As a participating teacher, you may also be asked to participate in an interview before, during, or after the study. It is important that you know that participation in this activity is strictly voluntary and you and/or your students may withdraw from the study at any time, for any reason, and without penalty.

Some of the things the students would do during the study are: learning about and using new technologies, having discussions about science with their classmates; and participating in brief interviews with one of my doctoral students or myself. Students may also be asked to complete a short questionnaire about science at the beginning and end of the study so that any changes in their level of understanding can be measured. All information collected during the study will be used for the purposes of data analysis. Only my doctoral students and myself will have access to any of the data that is collected for the study. At no time will students’ names, your name, or the name of your school be identified in published documents. All information that is collected will be kept in locked files and will be destroyed after the research is completed. There are no risks associated with participation in this study and students’ grades will not be affected by choosing to participate.

Procedures will be taken to ensure the identities of participating and non-participating students remain confidential during all phases of the study. Most of the information used in this study will be from the computer-based data logs. This information will only be accessed from my or my doctoral students’ own private computer. You will not know which students have decided to participate in the study. Information will be reviewed only from those students who are participating in the study. Any written data (e.g. quizzes) will be collected from the entire class.
In private, a photocopy will be made only of the work completed by participating students. If a student is asked for an interview, they will be asked either before or after class, or when their teacher is not in the room. Interviews will take place either during lunch hour or after school. At no time will you know whether or not a student has decided to participate in the study.

A copy of this consent form will be given to you for your reference. If you have any questions about the study please feel free to contact me by phone: 416-978-0121 or through email: jslotta@oise.utoronto.ca. Questions about students’ rights as participants can be directed to the University of Toronto Ethics Review Office at: ethics.review@utoronto.ca or 416-946-3273. Research results will be made available upon request.

Sincerely,

James D. Slotta
Associate Professor, Department of Curriculum, Teaching and Learning, OISE/UT
Canada Research Chair in Education and Technology

I give my permission for Dr. James D. Slotta to conduct the research project outlined above.

__________________________________  __________________
Signature                               Date

Published study results will be made available for students and/or parents who are interested. Please feel free to contact the principal investigator with any questions or concerns: James D. Slotta, Associate Processor. OISE/UT, 252 Bloor Street West, Toronto, ON M5S 1V6. Phone: (416) 923-6641 Ext. 2446, Email: jslotta@oise.utoronto.ca
8.1.6 Appendix F
Activity Questionnaire Questions

1. On a scale of 1 to 10 (1 – very bad; 10 – extremely good), how would you rate the activity overall?

2. Below is a list of descriptors, select all the options that apply to your perception of the activity.
   - Entertaining
   - Intriguing
   - Engaging
   - Easy to follow
   - Challenging
   - Helpful
   - Useful
   - Confusing
   - Too slow
   - Too fast
   - Well rounded
   - Logical
   - Conducive to learning
   - Good graphics
   - Bad graphics
   - Welcoming
   - Comfortable
   - Uncomfortable
   - Choppyp
   - Fluid
   - Too busy
   - Simple
   - Complicated

3. On a scale of 1 to 10 (1 – not useful; 10 – very useful), how do you rate the activity in terms of:
   a) Visualizing the rainforest scenarios
   b) Role of discussions amongst your group members
   c) Role of discussions with other students (i.e., not your group members)
   d) Role of discussions with your teacher
   e) Use of additional information (e.g., field guide, predictions, food web)
   f) Use of the “Smart classroom” (e.g. large screen projectors, immersive environment, etc.)
   g) Use of tablet application

4. What was the most successful / useful portion of the activity?

5. Give one suggestion for improving this activity.
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.

3. What is biodiversity? Give the most complete definition you can think of.

4. Why is it important to preserve biodiversity? Include at least two well-supported reasons.